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QUARTERMASTER RESEARCH & ENGINEERING COMMAND
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TEXTILE SERIES REPORT
NO. 110

MEASURING AND PREDICTING THE GENERATION OF STATIC ELECTRICITY IN MILITARY CLOTHING

QUARTERMASTER RESEARCH & ENGINEERING CENTER
TEXTILE, CLOTHING AND FOOTWEAR DIVISION

SEPTEMBER 1959 NATICK, MASSACHUSETTS

HEADQUARTERS
QUARTERMASTER RESEARCH & ENGINEERING COMMAND, US ARMY
Quartermaster Research & Engineering Center
Natick, Massachusetts

TEXTILE, CLOTHING & FOOTWEAR DIVISION

Textile Series

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MEASURING AND PREDICTING THE GENERATION OF STATIC ELECTRICITY IN MILITARY CLOTHING

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FOREWORD

The generation of static electricity in clothing systems has been known for many years. At no time previously has the problem been considered serious from a military standpoint because with fabrics such as wool and cotton, which have usually constituted the combat ensembles, the generation of static charges of sufficient magnitude to create a problem would be very unlikely. The high regain properties of wool and cotton under reasonable temperature and humidity conditions of the atmosphere tend to preclude the generation of dangerously high voltages.

With the use in military clothing of manmade fibers which are highly hydrophobic in nature, and consequently excellent insulators, the likelihood of static generation, even under normal ambient conditions has greatly increased. In dry climate areas, such as the Arctic and desert, the hazard from static generation has accordingly become a problem to the individual and to the development of equipment to protect him.

The study reported in the following pages represents a review of the problem presented by static generation in clothing, and an exploration of the methods by which the problem can be minimized and the generation of a charge be evaluated on a clothing system.

This study was initiated because of a letter from the Chief, Office of Research and Development, Office of The Quartermaster General, dated 17 May 1954 (file QMRRV 400.112) Subject: Anti-Static Finish. It was requested that consideration be given to the causes for the reports originating in the field, alleging difficulty due to static generation.

The work reported was accomplished by Mr. Crugnola and Corporal Robinson while members of the Textile, Clothing & Footwear Division. Supervision was provided consecutively by Dr. George R. Thomas and Mr. Alvin O. Ramsley, and the whole program was under the general direction of Mr. Frank J. Rizzo, Chief, Textile Dyeing Laboratory Branch.

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PART III THE QUARTERMASTER DEVICE TO MEASURE STATIC ELECTRICITY

ABSTRACT

An analysis has been made of the method and circumstances by which static electrical charges are generated on garment assemblies and on individuals wearing them.

Data obtained under a contract with the National Bureau of Standards indicate that any clothing system which produces on a man a potential exceeding 3000 volts is hazardous because it can cause the ignition of gasoline-air mixtures; lower voltages are sufficient to detonate certain primers. It was also shown that such voltages are readily obtainable with garment combinations involving wool and nylon at 75°F and 35% R.H. and even with cotton (normally not troublesome) at 75°F and humidities less than 25%. Additional observations, made in the Climatic Chamber of the Quartermaster Research & Engineering Center at -40°F, have demonstrated that potentials as high as 8000 volts were often recorded when test subjects removed various components of the cold-dry uniform. The manmade hydrophobic fibers (as a class) produce voltages above those required to produce hazardous conditions.

All contacting layers of a clothing assembly system will require antistatic treatment in order to avoid problems due to static. It is felt, however, that the underwear need not be so treated due to the fact that such layers will carry sufficient moisture to be conductive. No treatment on the clothing system, per se, will be satisfactory without simultaneous attention being given to the footwear. This also must be conducting if adequate dissipation of static charges is to be achieved.

An investigation is reported on the effectiveness and durability of 12 antistatic finishes on various fabrics, and one finish is pinpointed which possesses the best combination of effectiveness and durability.

From a review of published instrumental methods by which the electrostatic behavior of a fabric may be assessed, it was concluded that none of these is capable of giving an adequate, quantitative forecast of the hazard inherent in a particular multi-layer system. For this purpose, an instrument has been developed and is described herein. Results obtained with this instrument agree with those obtained from "on-the-individual" type test.

MEASURING AND PREDICTING THE GENERATION OF STATIC ELECTRICITY IN MILITARY CLOTHING

Introduction

1. Reports from the Field

Static electricity has long been recognized as a fire and explosion hazard in industrial processes. Hospital operating room explosions traceable to the accumulation of static electricity on non-conducting surfaces, such as rubber or fabric sheetings, have become increasingly conspicuous in recent years, both in this country and abroad.[27]

Similarly, in the past several years, military reports have associated the electrification of clothing with the creation of certain field hazards. One such account dealt with the experience of an Army Ordnance disposal squad. The unit commander, in reporting the incident, stated that the static electricity generated in the frieze liner of the Field Jacket, had been of such an amount as to detonate various fuses. Other accounts have mentioned that the body armor vest has created similar situations.

The U. S. Air Force is very much concerned over reports, received from various air fields, of sparks and shocks experienced by personnel during refueling operations.[41] It is even reported that explosions of fuel have occurred under such circumstances. At first these phenomena were attributed to the presence of thunderstorms in the vicinity of the field. A more comprehensive analysis has disclosed a contradictory situation: (1) no such reports came from areas where there is very frequent thunderstorm activity, and (2) such reports came from areas virtually devoid of thunderstorm activity. As a result, attention has been drawn to the refueling operator and, in particular, to his clothing, as the source of the difficulty.[41]

2. Purpose and Scope

This report summarizes an investigation of the problem of static electricity in clothing assemblies from the standpoint of the hazard which may be incurred due to the specific characteristics of the component clothing items. Also, it contains an analysis of the manner of generation of static electricity and of the specific atmospheric and other conditions under which the problem becomes acute. Data are given from on-the-individual tests of static electricity on men wearing the cold-dry uniform. Also included are data derived from an evaluation of antistatic finishes for effectiveness and durability. Instrumental methods for predicting the electrostatic propensity of a fabric or fabric assembly are reviewed and a new Quartermaster device is described and discussed.

3. Definition of Terms

In discussing static electricity, it is important that there be a clear definition of the terminology and basic mathematical relationships which will be used:

a. Static electricity[31]

Static electricity connotes the phenomena of attraction and repulsion observed between electrically-charged bodies from the effects of "dynamic electricity" which is utilized in the generation of power or energy when it passed through a system.

b. Static charge (Q)

If an object exerts an electrical force on another object, it is said to be charged. The force exerted is dependent on the amount of the charge; that is, a static charge is considered an amount or quantity of electricity. If a body is electrically neutral, the resultant charge is zero. The unit of static charge, "coulomb", corresponds to a charge of 6.25×10^{18} electrons.[7]

c. Potential (V)

When an electrical force is applied to a body, the body tends to move in the direction of the force. If the body is free and moves in the direction of the force, it loses potential energy. If, instead, the body moves against the force, work must be done to overcome it, and the body gains potential energy. An electrostatic unit of potential difference exists between two points A and B, when one "erg" of work must be expended to move one stat-coulomb of positive charge from B to A against the electric field created by a positively-charged body A. The potential is therefore a measure of the electrical forces which are present in a given situation.

d. Distinction between charge and potential

It is important to avoid confusing the two distinct quantities: "charge", which measures the excess or deficiency of electrons, and "potential", which measures the possibility of work being done if a charge is available to do it. In approximate analogy between electricity and water, electric charge corresponds to the quantity of water, while potential corresponds to the pressure which forces the water to flow.

e. Capacitance (or capacity) (C)

When a charge on a conductor is increased, the strength of the force field surrounding it increases in direct proportion to the charge. It follows from the previous definitions that the potential

(V) of the conductor is proportional to the charge on it (Q):

$$\frac{Q}{V} = C$$

where C (by difinition, the capacitance) is the constant for any given conductor. If a given charge is accumulated on a body of small capacitance, the potential of this small capacitance could be considerably higher than that observed when the identical charge is placed on a body of larger capacitance.

f. Conductor and Non-Conductor

In general, a conductor is a medium through or on which electricity can pass. A non-conductor, or insulator, is a medium which prevents or reduces the flow of electricity. However, there is no sharp distinction between conductors and insulators; it is only a matter of degree. Under ordinary conditions, there is no perfect conductor and no perfect insulator; instead, materials can be rated from good conductors to very poor conductors or from poor insulators to very good insulators.

g. Energy of a Charged Conductor (W)

The energy which is releasible from a charged conductor through the formation of a spark can be calculated from the equation:

$$W \text{ (energy)} = 1/2\ CV^2$$

Where C is the capacitance and V is the potential.

h. Static Propensity

This is a qualitative measure of the tendency of a material to accumulate an electrostatic charge.

4. Basic Theory on How Electrical Charges are Generated on Materials

When two materials are placed in contact with one another, electrons pass from one material to the other without the addition of energy. The direction of transfer of the electrons depends upon the relative positions of the energy levels of the surface electrons. There are vacant or unoccupied energy levels on both surfaces; these are referred to as "holes". Electrons seek the lowest available energy level. Certain electrons of one surface have or occupy energy levels higher than unoccupied levels on the second surface; and so, seeking the lowest available level, the electrons leave one surface for the other. As a result, one surface collects a surplus of electrons and will be negatively charged; the second will be deficient in electrons and will become positive. As long as the surfaces remain in contact with each other or in close proximity, the opposite charges bind each other, and the external system remains neutral.

When the surfaces are separated, the work which is done against the binding forces establishes a potential gradient between the surfaces. This potential difference acts to reestablish electrical equilibrium. How effectively this is accomplished depends on the conductivity of surfaces involved. If both surfaces are good conductors (or rather, poor insulators), the transferred electrons and resultant holes have mobility. Thus the potential gradient is effective in discharging the surfaces at points where the surfaces separate. If, on the other hand, both surfaces are good insulators, then the mobility of electrons and holes is restricted and the potential difference is not effective in discharging the surfaces. If one surface is a good insulator and the other a poor insulator, the charges on the poor insulator do have mobility. However, a complete discharge still does not take place because those charges on the good insulator cannot flow freely and hence the recombination of electrons and holes is not possible.

When a charge exists on a material, the extent of possible hazard depends upon the specific situation and a spark must occur.[1] If gasoline fumes or other flammable substances are at hand, the amount of energy released by the formation of the spark must be at least equal to the ignition or excitation energy required to detonate the hazardous substance. A spark is a release of the energy from the charged system, and this is calculated as shown previously from the equation, $W = 1/2\ CV^2$.

5. Clothed Man as an Example

Considering a practical application of the theory, it is asserted that a man may be considered a charged conductor. His capacitance has been estimated at 200 micro-micro farads.[30]

Let us consider for the first situation an individual insulated from ground, wearing a wool shirt and a nylon armor vest over it. These materials in contact result in a transfer of charges such that the wool becomes positively charged and the nylon negatively charged. With the fabric layers in contact or in close proximity, the system (man, shirt, and vest) is neutral; that is, there is an electrical balance so that no charge is apparent on the man. Negative charges on the nylon are offset or bound by the positive charges on the wool. If the outer garment, the nylon armor vest, is removed, the l... of conductivity of these materials prevents the flow of the charges which would restore electrical neutrality. The result:- the individual is left with a high positive charge.

In this case, the positive charges on the wool are no longer bound by the negative charges on the nylon. Since electrical neutrality must be maintained, the charges on the wool now attract negative charges to the skin immediately beneath the shirt. Because (by intentional experimental design) the man is insulated from ground, the redistribution of body charges alters the individual's potential with respect to ground, leaving him with a high positive charge which, in turn, will produce a spark if any part of his body should approach a conductor.

The release of the spark brings the man and his shirt into electrical balance. Nevertheless, if the man subsequently removes the wool shirt, the body is left with uncompensated charges and a second spark can be released on contact with a grounded conductor. The first spark enabled the body to take up electrons to neutralize the positive charge in the shirt; subsequent removal of the shirt leaves the body with an excess of negative charges. The electrons which moved to the body in the first spark now leave it in a second. Figure 1 illustrates the sequence of events in the situations described.

The <u>second</u> experimental situation uses the same ensemble, but the man is grounded. The same distribution of charges is produced on the wool and nylon but now when the nylon vest is removed, the unbalance of charges on the body is neutralized by electrons immediately taken up from ground, and the man's potential is unaltered. Under such conditions, no spark can take place. When the shirt is removed, the flow of electrons is immediately to ground. Thus again no spark can be realized.

In practice, we are concerned most often with something between the two extreme situations discussed above. The degree of insulation between the man and ground is usually neither infinite nor zero. Much depends on his footwear and on the nature of the surface upon which he stands or on whatever separates his body from ground.

6. Nearby Flammable Substances, the Other Factor in Hazardous Situations

As previously stated, the consequences of the release of a spark depend upon the specific situation in which the individual finds himself. If no hazardous substance is present, the only result of a spark is discomfort to the individual. If a hazardous substance is present, the extent of the hazard depends, as previously noted, upon the amount and rate of release of energy which is contained by the charged system and the amount of energy required to initiate the hazardous reaction.

7. The Hazardous Electrical "Ceiling" For Clothed Man

In order to explore the problem of static in clothing systems from the standpoint of the possible hazard incurred, the Quartermaster Corps contracted for a study at the National Bureau of Standards.[34] As part of this study, an investigation was made of the energy required to initiate various explosive reactions. These are listed in Table I. Also listed is the potential to which an individual ($C = 200 \times 10^{-12}$ farads) would have to be charged in order to contain this specific energy.

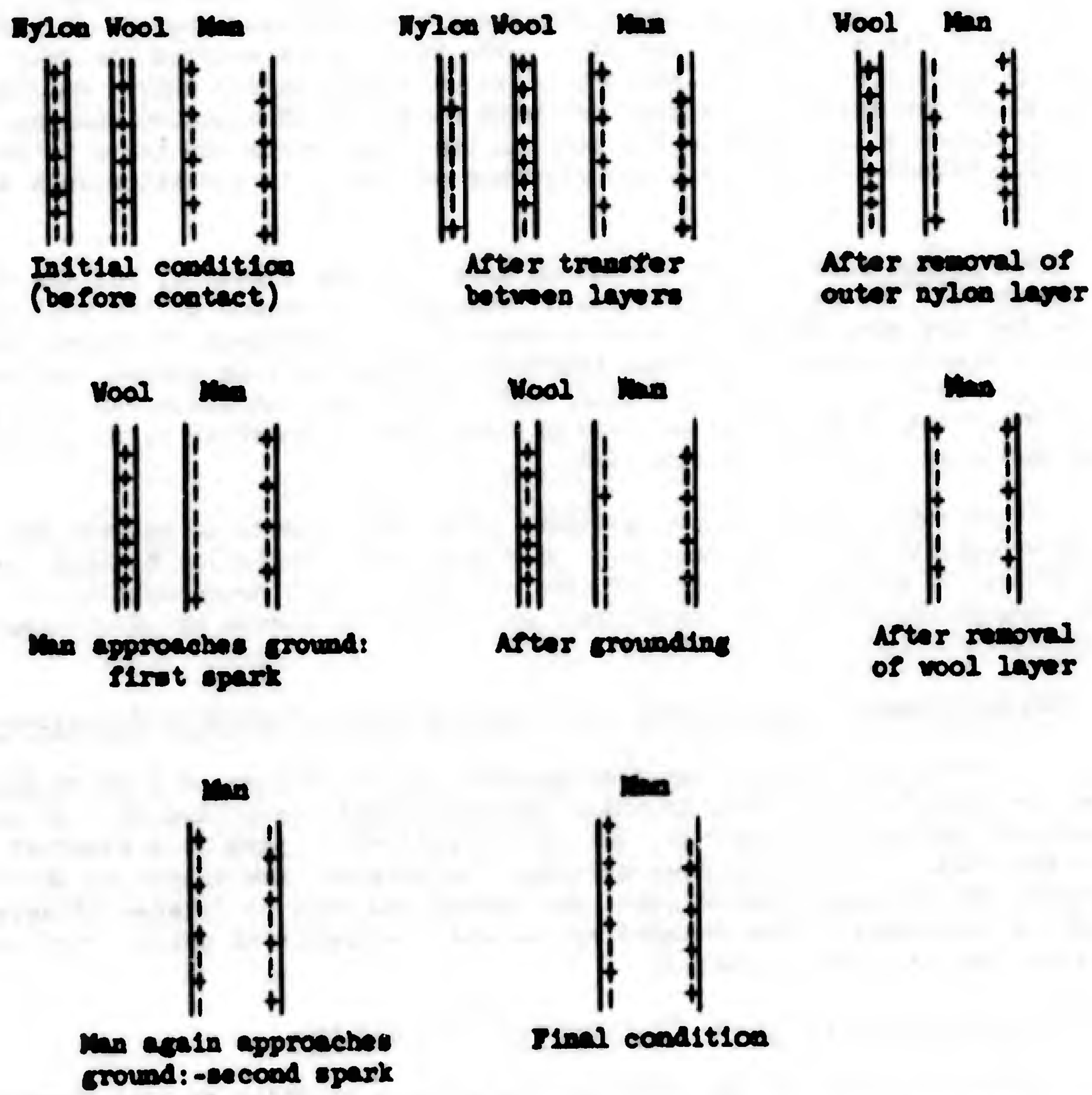


Figure 1 Sequence of sparks produced by a man insulated from ground, wearing wool shirt and a nylon armor vest over it.

TABLE I: ENERGIES AND CORRESPONDING POTENTIALS IN AN INDIVIDUAL NECESSARY FOR IGNITION

	Ignition energy (in milli-joules)	Corresponding potential necessary for ignition (in volts)
Methane	0.5	2150
Gasoline	0.8	2650
Ether (diethyl)	0.2	1350
Cyclopropane	0.2	1350
Benzene	0.5	2150
Acetone	0.6	2350
Copper Acetylide	0.002	150
Lead Azide	0.04	650

It is seen that any clothing system which produces a potential on the man exceeding 2650 volts is capable of igniting gasoline-air mixtures as well as all the other compositions listed. A potential of 650 volts is theoretically capable of igniting certain militarily important primer materials, such as lead azide.[30,31,32]

PART I: EXTENT OF ELECTROSTATIC HAZARD
Data From On-the-Individual Tests of Static Charges

1. National Bureau of Standards Studies, at 75°F

The data on ignition energies appearing in Table I supply a basis of reference by which the nature and extent of the problem may be assessed. The above-mentioned program at the National Bureau of Standards was logically extended to the measurement of the voltages generated on the individual by manipulating components of the ensemble which he was wearing. This study included fabrics of nylon, wool, cotton, saponified acetate, and a wool/nylon blend. The measurements were made at 75°F and at relative humidities of 65%, 35%, and 20%. The experimental design was similar to the first condition utilized in the application of one of the theoretical situations previously discussed, that is, the man insulated from ground. The conclusions of this study may be summarized as follows:

a. Effect of Removing Garments. No significant voltages were obtained unless one of the garment layers was removed.

b. Effect of Humidity. The following tabulation summarizes the results at various humidities: (The temperature was 75°F in each situation)

65%RH: None of the garment combinations produced potentials required for the detonation of the most active of the materials studied by the National Bureau of Standards.

35%RH: Garment combinations containing nylon and wool, nylon and cotton, and nylon and wool-nylon, produced potentials in excess of 2650 volts (this represents the potential required for the more active materials).

20%RH: The garment combinations listed above (for 35%RH test) caused higher potentials; also, high potentials were obtained with a wool and cotton combination.

Below 20%RH: High voltages were produced on the man, even with cotton (normally not a troublesome fiber). The voltages so produced are of a degree considered dangerous for the group of primers and other materials studied by the National Bureau of Standards.

2. Quartermaster Cold Chamber Studies

The results outlined above were all obtained at ambient laboratory temperatures (75°F). It is generally believed that static phenomena are more prevalent at lower temperatures and lower humidities. This has been confirmed by experience in cold-dry areas. In view of this, it was deemed necessary that a study be made at very low temperatures and low humidities. The National Bureau of Standards was not able to carry on low temperature studies and thus the required evaluation was accomplished by the authors in the Climatic Chambers at the QM R&E Center. A temperature of -40°F was used (principally because at that time the Chamber was being operated at this temperature for other studies).

a. Test Conditions

Previous work had established that significant voltages were obtained only when a layer of the clothing assembly was removed. To simulate a typical situation occurring in the field, it was felt that one probable design characteristic for the experiments in the Chambers would be to have a man enter a slightly heated shelter before removing his outer garments. In practice an individual would be most likely to remove this clothing on entering a shelter. Accordingly, a tent was pitched inside the Chamber and heated with two electric radiators to a temperature of +20°F. Measurements were made both in the heated tent and also in the unsheltered (-40°F) part of the Cold Chamber. Thus, the temperature in the Cold Chamber was -40°F, and the temperature inside the tent was +20°F. Plywood was used as a platform in the tent and a rubberized fabric treadmill-belt was used in the open Chamber.

b. Test Subjects and Clothing

Two subjects (A and B) were used in the tests.

The cold-dry ensemble was worn by each subject (see Appendix for complete list of items). The three items of principal concern for these tests were: 1) the wool-nylon shirt 2) the cotton field jacket with liner and 3) the nylon body armor vest.

c. Measuring instrument

All of the reported data were obtained with a Kiethley Model 200 Electrometer utilizing a 1000-1 voltage divider. This combination permits the measurement of electrostatic potentials over a range of -10,000 to + 10,000 volts with respect to ground.

In addition, a Rawson Electrostatic Voltmeter, Type 518, was used to check the reliability of the Kiethley instrument. The Voltmeter had been calibrated to -10°F and since it does not contain any electronic components, it was thought to be more dependable at the extreme temperature (-40°F) used in the test. This instrument was not used for obtaining data because it does not differentiate potentials as to sign (+ or -).

d. Test Plan

The items of the cold-dry ensemble directly involved in the tests (the field jacket with its frieze/fortisan liner, the nylon body armor vest, and the wool/nylon shirt) were conditioned overnight in the test Chamber at -40°F. The rest of the clothing was kept in the laboratory and put on and taken off there.

The field jacket, vest, and shirt were brought into the anteroom of the Climatic Chamber and donned just prior to starting the tests. The two subjects then entered the chamber and remained 15 to 20 minutes, walking slowly about. At the end of this period the subjects, one at a time, mounted the particular platform selected (either the rubberized fabric at -40°F in the open Chamber or the plywood at +20°F in the heated tent). As each subject, in turn, removed the various garment layers, the other subject recorded the voltages developed.

In the National Bureau of Standard studies, the outer garment was rubbed vigorously against the inner garment and then removed. This procedure was thought somewhat unrealistic and exaggerated and, therefore, not used in this investigation. Instead, the test subjects simply put on the garments, walked around for a short time and then removed them. The potentials observed and herein recorded were developed in this manner.

e. Results at -40°F, Rubberized Platform

The voltages shown below were recorded when the test subjects A and B removed the garments while standing on a rubberized fabric platform in the -40°F temperature:

		Average A	Average B	Maximum (A or B)
After removing:	mittens & inserts	433	767	2000
	jacket and liner	5333	7833	8000
	vest	2333	6100	6500

The results in the above tabulation are the average of three measurements for each subject.

f. Results at +20°F, Plywood Platform

The potentials (in volts) listed below were developed when the two test subjects removed the garments while standing on a 1/2 inch plywood platform in the heated tent (+20°F), which had been pitched in the Chamber:

		Average A	Average B	Maximum (A or B)
After removing:	mittens and inserts	300	333	900
	jacket and liner	2700	4833	6000
	vest	1200	4100	5500

3. Quartermaster Laboratory Study, at 84°F.

As was shown above, the magnitude of the resulting voltage is dependent on whatever separates the individual from ground. In order to obtain a quantitative example of this, measurements were made with the test subjects standing alternately on 1/2 inch plywood (a relatively poor insulating material) and 1/2 inch lucite (a good insulating material). The purpose was to illustrate the manner in which the voltages obtained are related to the degree of insulation afforded by test subject's footwear and the material on which he is standing. These observations were made in the Quartermaster laboratory at ambient conditions (84°F and 13% RH).

a. Voltages Related to Insulation (Platform)

The following data show the variation of potential (in volts) with degree of insulation (1/2 inch lucite or 1/2 inch plywood) for subjects A and B:

		Lucite		Plywood	
		A	B	A	B
	mittens and inserts	233	400	0	0
After removing:	jacket and liner	1833	2000	333	567
	vest	1600	4033	500	1133

It is obvious from the above that the voltages registered and consequently the hazard is markedly affected by the degree of insulation involved between the subject and ground.

b. Voltages Related to Particular Garments

It will be noticed in the previous tabulations that the higher voltages were generally obtained by test subject B. In order to determine if this was due to differences in clothing or differences between individuals (i.e., one being more susceptible to these phenomena than another), a series of observations were made where the test subjects exchanged the vests, jackets, and shirts. The following tabulation gives the variation of potential (in volts) according to particular garments:

		As worn in tests		Vest & Jacket Exchanged		Shirt only Exchanged	
		A	B	A	B	A	B
	mittens and inserts	733	400	700	600	500	200
After removing:	jacket and liner	1833	2000	1200	2000	1300	1000
	vest	1600	4033	1100	3100	3500	1300

The results obtained indicate that, at least in part, the differences were due to clothing, in particular to the wool/nylon shirt. However, tests subsequent to these have also shown that one individual may be more liable to these effects than another.

By rationalizing the significance of the data just presented, in terms of actual wear conditions, one must conclude that:

(1) Static charges in excess of those which could initiate certain hazardous reactions in militarily significant materials are generated in clothing systems.

(2) The hazard does not exist except as layers of clothing are separated upon removing clothing components. As long as the components remain on the individual, the system is neutral because positive and negative charges, although possibly separated, are in sufficient proximity to each other to be within the

normal field of neutral influence and, therefore, equalize each other.

(3) Only elements of the clothing ensemble in direct contact with each other need to be made conductive. Thus, in a system which involves an outer layer fabric, an insulating layer, and a lining in which the lining contacts a clothing element of dissimilar characteristics, only the lining needs to be treated.

(4) Underwear may not require treatment due to the high regain obtainable from body moisture.

(5) Footwear must be conductive.

(6) The outer layer of the ensemble would not normally require treatment to increase its conductivity; however, because of the danger of frictional contact between the clothed man and other surfaces (leather or plastic seats, vehicles, drums, etc.) the outer layer should be treated in those ensembles which are worn where hazards are likely to occur.

PART II: EVALUATION OF ANTISTATIC FINISHES

1. Finishes Tested

To minimize the hazard and discomfort caused by the electrification of fabric, the chemical industry has developed a series of compounds known as "antistats." The basic property imparted by these finishes to a fabric is an increase in fabric surface conductivity. This higher conductivity enables the transferred charges to move more freely across the fabric surface and to dissipate to the layers involved as has been described in Part I of this report. The present section reports the findings of a screening of commercially available compounds directed to the selection of those agents with the best combination of effectiveness and durability for military purposes. The products tested were limited to those which were represented by the supplier to have durability to laundering. This was necessitated by the fact that reapplication in the field was not considered feasible. The finishes have been evaluated on the basis of surface resistivity (see Part III for details of test method).

2. Effectiveness

The following table summarizes the findings of the National Bureau of Standards obtained on four fabrics of different fiber composition which had been treated with six different antistatic agents. These results have been expressed in terms of the log of resistivity per square unit of surface. The data are summarized in Table II.

As a basis of establishing the level of effectiveness, Industry's practices in this regard have been accepted. Industry considers any material having a surface resistivity, in log R units, not exceeding 11.0, to have good characteristics. A fair rating is given to any material which does not exceed 12.5 log units, and any material exceeding 13.1 log units is considered unsatisfactory. In reality, the establishment of a value of 11.0 represents the acceptance of cotton fabrics as a frame of reference for static propensity. Cotton fabrics have been known to present no serious problems with respect to static generation, although as will be shown later in this report, static development on cotton fabrics becomes possible under certain conditions.

The antistatic agents which are the subject of Table II are identified as follows:

1. Aqueous dispersion of a polymeric cationic material.
2. An organic ester.
3. A cationic polymeric material.
4. Polyvinyl pyrrolidone derivative.
5. Conductive carbon applied from alcohol dispersion - Concentration on fabric: (1%)
6. Conductive carbon applied from an aqueous dispersion - Concentration on fabric: (1%)

TABLE II: SURFACE RESISTIVITY (LOG R/UNIT^2) OF 4 FABRICS WITH 6 ANTISTATIC FINISHES AT VARIOUS TEMPERATURES AND RELATIVE HUMIDITIES

Antistatic Agent	2%R.H.-4°F	2%R.H.32°F	70%R.H.32°F	50%R.H.75°F	2%R.H.122°F
			a. COTTON, 6 OZ. OXFORD		
Untreated	17	15.5	10.0	10.3	14.5
1	"	15.3	9.7	9.8	13.8
2	"	14.0	9.3	9.5	11.8
3	"	15.3	10.0	10.3	14.5
4	"	15.5	9.0	10.0	14.3
5	"	15.5	10.0	10.0	14.3
6	"	15.5	10.0	10.0	14.3
			b. WOOL, 16 OZ. SERGE		
Untreated	17	15.7	12.5	12.3	16.0
1	"	15.7	11.0	11.0	14.3
2	10.8	12.9	10.3	10.0	10.6
3	17	15.8	11.3	11.6	15.0
4	"	15.7	12.6	12.3	15.8
5	"	15.8	12.3	11.8	15.9
6	"	15.8	12.3	12.0	17.0
			c. NYLON, 3 OZ. OXFORD		
Untreated	17	15.7	13.0	14.3	14.9
1	"	15.3	8.9	9.7	12.8
2	10.9	12.6	9.9	10.0	10.5
3	17	15.6	11.5	12.3	14.0
4	"	15.5	10.9	13.0	13.8
5	"	15.7	14.3	14.3	14.8
6	"	15.5	12.3	13.6	13.9
			d. NYLON, 14 OZ. DUCK		
Untreated	17	15.8	13.5	13.9	15.3
1	"	15.3	8.0	8.9	12.6
2	11.9	13.0	9.6	10.0	10.5
3	17	15.3	11.6	11.9	13.8
4	"	13.8	9.9	9.9	11.3
5	"	15.3	13.7	14.0	14.6
6	"	15.8	13.6	13.7	14.9

Three recently developed antistatic finishes which are identified further as Nos. 7, 8, and 9, were not available for the program at the National Bureau of Standards. These three products were applied to 3 oz. nylon oxford fabric and evaluated in the Quartermaster Laboratory. Two of the three products are chemically identified as (7) thermosetting resin and (8) an organic ester; the composition of Product #9 is unknown to the authors, probably an acrylate resin with hydrophilic groups.

Table III lists the resistivity observed with these materials at various temperatures and humidities.

TABLE III - SURFACE RESISTIVITY (LOG R/UNIT^2) FOR 3 OZ. NYLON OXFORD TREATED WITH THREE FINISHES

Agent	1%R.H.*32°F	1%R.H.80°F	17%R.H.80°F	27%R.H.80°F	45%R.H.80°F
7	12.5	11.2	10.2	10.0	9.4
8	12.7	11.1	10.4	10.3	9.7
9	15	13.5	9.6	9.8	7.6
Untreated Cotton	15	14.2			

*Less than 1%R.H. was obtained by enclosing the specimens mounted on electrodes in a chamber containing calcium sulfate; evacuating the chamber, readmitting air very slowly through a 48" drying tube; and conditioning 4 days before measuring.

Since the Quartermaster problem is severest at extremely dry and cold conditions, an examination of the above data of Tables II and III shows the following grouping in order of efficiency:

I Agent 2, 7, 8
II Agent 4, 9
III Agent 1, 3, 5, 6

It will be noted that the agents represented by Group III have practically no value since the surface resistivity of the treated fabric is essentially the same as the untreated fabric.

The above tables furnish evidence that temperature alone, independent of relative humidity, can alter the surface resistivity and that the lower the temperature, the higher the values for any given product. These data suggest that for any given agent, a cutoff point can be anticipated which can be determined by temperature or humidity or by both factors combined.

The tables given above do not specifically define the effect of relative humidity, per se, because absolute, rather than relative, humidity values are probably the more critical. In Table IV the specific effect of relative humidity can be seen. All determinations were made at 80°F on nylon fabric.

TABLE IV - CHANGE IN SURFACE RESISTIVITY OF NYLON FABRIC (ANTISTATICALLY TREATED) WITH VARYING HUMIDITY (80°F.)

Agent	48%R.H.	27%R.H.	18%R.H.	0%R.H.
1	10.4	11.9	12.4	13.9
4	9.7	10.3	10.4	11.1
6	7.6	9.8	9.6	13.5
7	9.4	10.0	10.2	11.2

The specific effect of temperature is shown in Table V where the same 4 agents have been tested at a relative humidity between 0 and 1% at a temperature of 80°F and again at 32°F.

TABLE V - CHANGE IN SURFACE RESISTIVITY OF NYLON FABRIC (ANTISTATICALLY TREATED) WITH VARYING TEMPERATURES - APPROXIMATELY ZERO HUMIDITY.

Agent	80°F	32°F
Cotton	14.0	>15.0
1	13.9	>15.0
4	11.1	12.7
6	13.5	>15.0
7	11.2	12.5

Further data are shown in Table VI for a polyester/rayon blend containing 65% polyester, 35% rayon, at a relative humidity approaching 0% at temperatures of 68°F, 32°F, and -11°F respectively.

TABLE VI - CHANGE IN SURFACE RESISTIVITY OF POLYESTER/RAYON BLEND FABRIC (ANTISTATICALLY TREATED) WITH TEMPERATURES - 0% R.H.

Treatment	Temperature		
	-11°F	32°F	68°F
No finish	>15	>14.6	>14.0
Crease resistant finish only	14.3	13.8	13.9
Agent 7 over crease resistance	14.3	13.7	13.0
Agent 8 over crease resistance	13.4	12.9	11.8

3. Durability to Laundering Tests

Although the above data furnish information which would eliminate from further consideration all but 3 of the agents studied, laundering tests were nevertheless conducted on 11 different agents applied to 5 separate fabrics. The fabrics selected were as follows:

Cloth, Nylon Oxford, 3 oz.
Cloth, Nylon for Armor, 14 oz.
Cloth, Wool/nylon Shirting, 16 oz., shrink resistant treated with chlorine emitting agent.
Cloth, Wool/nylon Shirting, 16 oz., shrink resistant treated with resin system.
Cloth, Dynel, Sateen, 9 oz.

The antistatic agents tested represented all of those previously enumerated; however, finishes 5 and 6, which were the conductive carbon-black dispersions applied to the fabric in 1% concentrations, were found to be inadequate and, accordingly, these were tested in 2½% and 5% dry add-on concentrations.

These two additional experiments were coded #10 and #10a. All agents were applied in accordance with manufacturer's recommendations. In order to assess the durability to laundering, the test was conducted in an Atlas Launderometer using the following cycle:

Container	-	Inconel tubes containing 50 steel balls, 1/4" in diameter and weighing a total of 51 grams.
Liquid	-	400 ml of a 0.2% solution of an anionic surfactant having the chemical composition represented by the formula $C_{17}H_{33}.CO.N(CH_3).C_2H_4.SO_3Na$
Time of Test	-	45 minutes
Temperature	-	105°F

All samples were rinsed under running cold water at tap temperature. Samples which were subjected to multiple launderings prior to measurement of surface resistivity were not dried between cycles. All samples were air dried at the end of the rated number of cycles at which resistivity determinations were scheduled. The durability of a specific agent was evaluated by surface resistivity measurements after 1,3,5 and 10 cycles of the above laundering procedure. The results are plotted as actual resistivity values rather than as changes in resistivity in order that the precise point at which the finish was no longer effective would be apparent. The data are plotted in Figures 2a to 2e inclusive.

The inspection of these figures results in the groupings shown below according to the durability exhibited by the agent in question. For this purpose, the absolute resistivity values have been disregarded. Also, each fabric is considered individually. The ratings are based on a value of I for most durable and a rating of IV for the least durable. The ratings are as follows:

Rating	Agent
Nylon, 3 oz. (Fig. 2a)	
I	1,7
II	3,10a
III	9,10
IV	2,4,8
Nylon, 14 oz. (Fig. 2b)	
I	7
II	1,3
III	9
IV	2,4,8

Rating	Agent
Dynel, 9 oz. (Fig. 2c)	
I	7
II	1,3,8,9
III	-------
IV	2,4
Wool/Nylon Shirting 16 oz. (Fig 2d) (Resin Treated)	
I	1,3,7,8
II	-------
III	-------
IV	2,4,9
Wool/Nylon Shirting 16 oz. (Fig 2e) (Chlorine Treated)	
I	1,3,7
II	8,9
III	-----
IV	2

4. Rating of Finishes For Both Effectiveness and Durability

An examination of the data relating to both effectiveness and durability leads to the following conclusions:

a. Agent #7, a thermosetting resin, exhibits the best combination of properties.

b. Agent #2, which is an organic ester, and the most effective with respect to resistivity, has been found to be non-durable.

c. Agent #1, an aqueous dispersion of a cationic polymeric material, and Agent #3, a material of the same general class, which are durable to laundering, are not effective in reducing surface resistivity.

d. Agent #8, an organic ester compound, shows fairly good durability on dynel and wool, but is non-durable on nylon; however, this product displays good effectiveness.

e. Agent #9, a modified acrylate resin, is only moderately satisfactory. Its properties with respect to both effectiveness and durability are average and considered insufficient for Quartermaster purposes.

One carbon black dispersion of high conductivity (that is, it has a resistivity of 5 log units) has been found which will withstand ten launderings in accordance with the above procedure. This material, however, would pose problems from the standpoint of color and was considered less desirable than any of the organic products which were tested and which impart little or no color to the fabric.

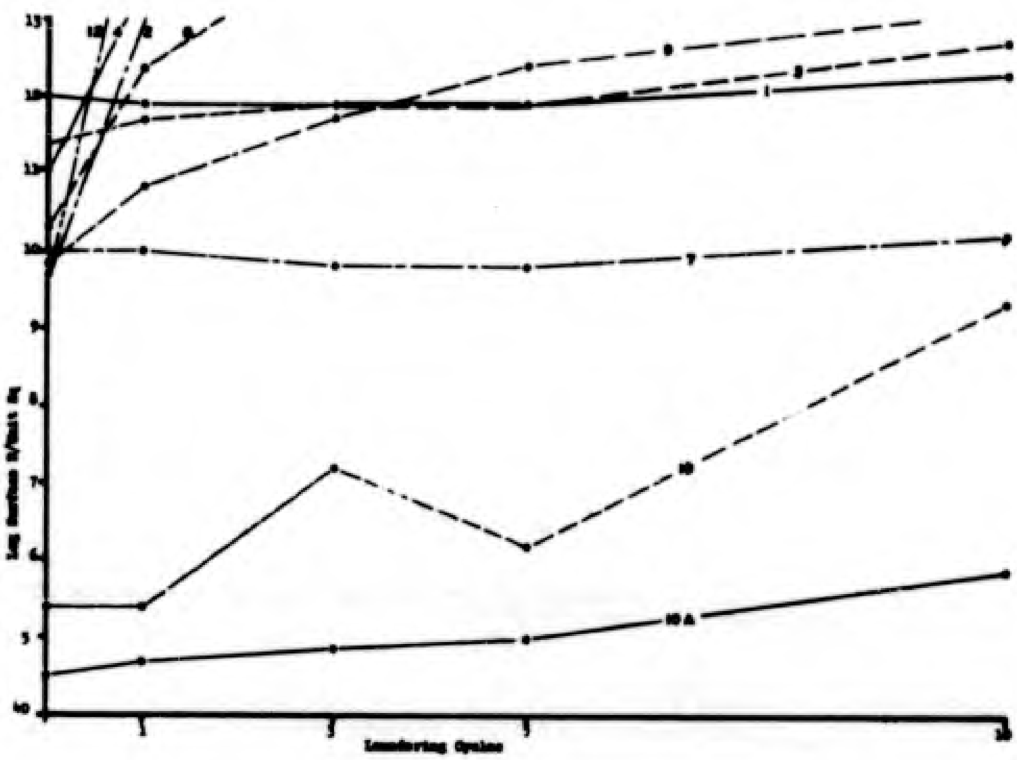


Figure 2a - 3 oz. Nylon; Variation of Surface Resistivity with Laundering 27% R.H.85°F

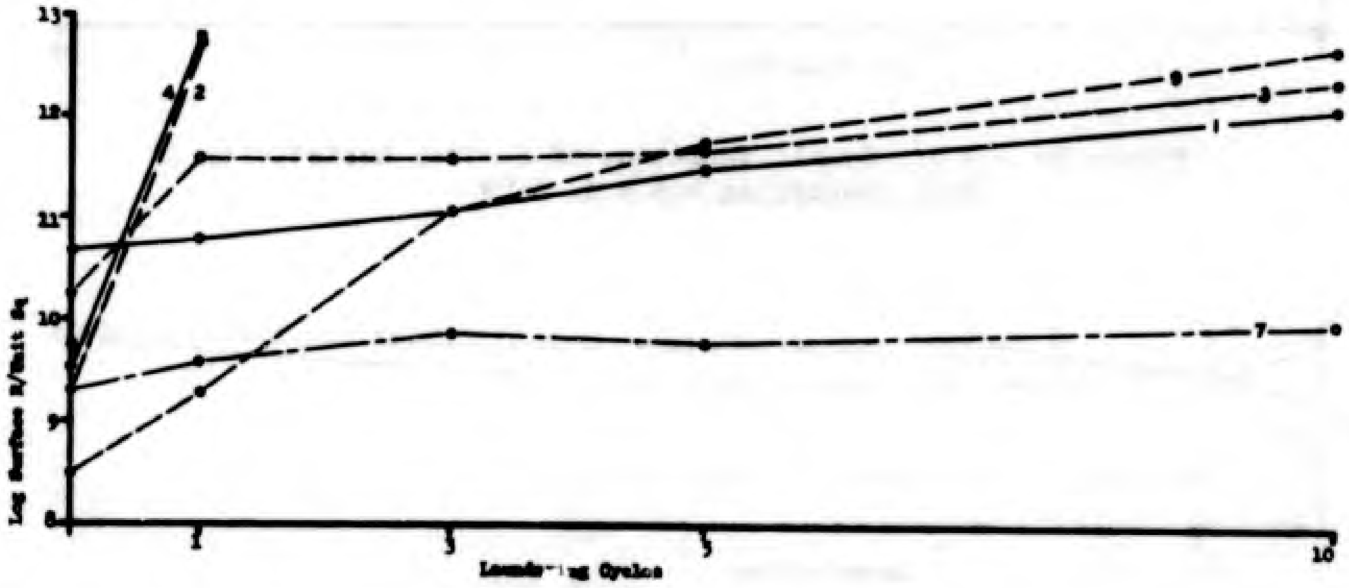


Figure 2b - 14 oz. Nylon; Variation of Surface Resistivity with Laundering 35% R.H. 78°F

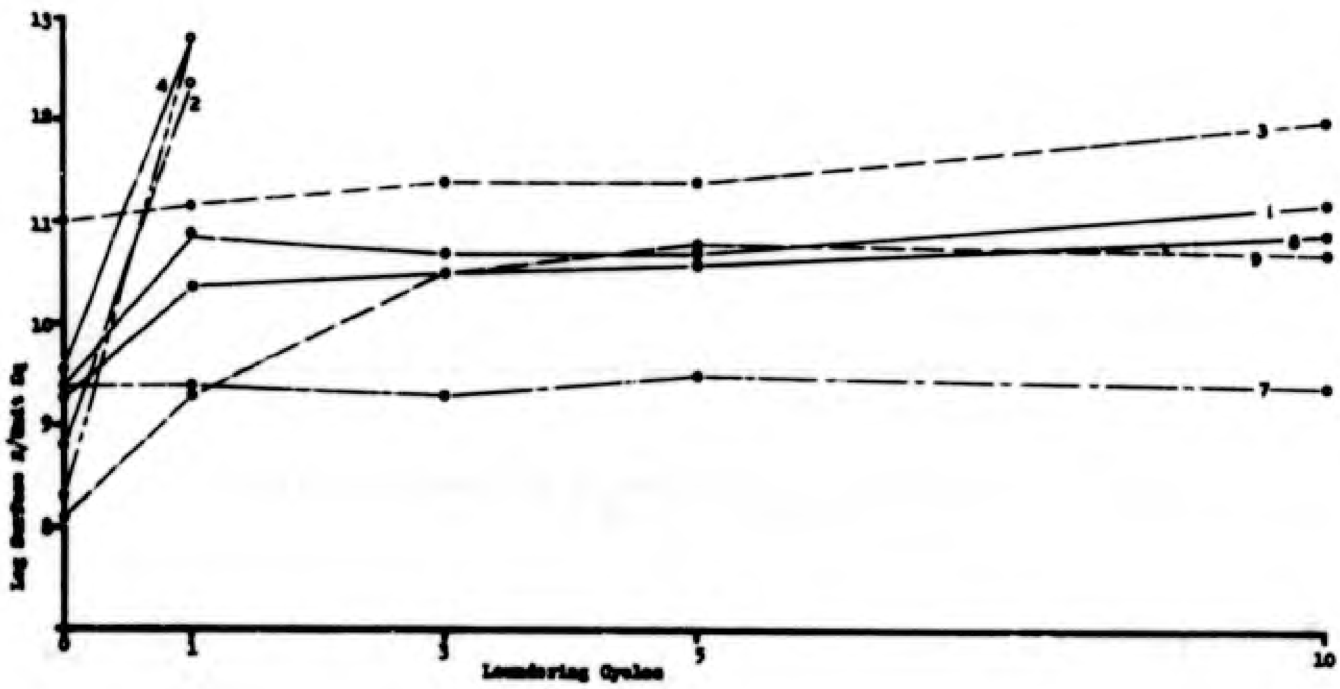


Figure 2c - 9 oz. Dynel; Variation of Surface Resistivity with Laundering. 40% R.H. 85°F

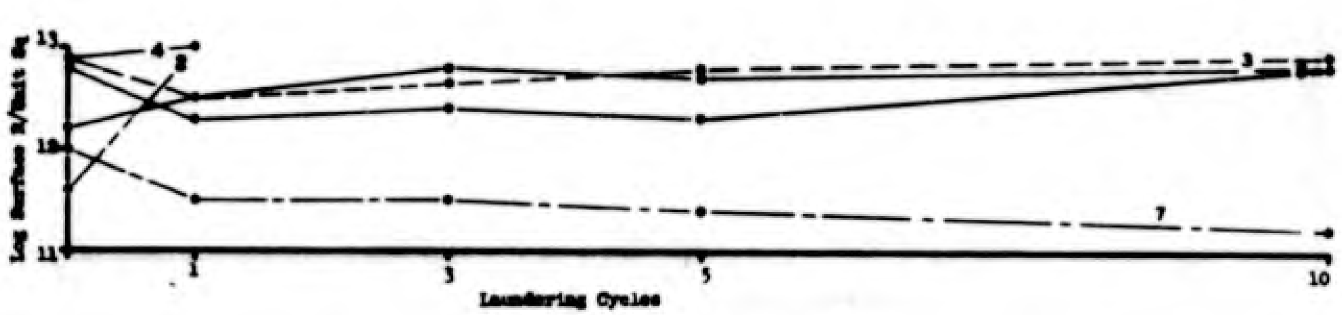


Figure 2d - 16 oz. Wool Nylon Shirting (Resin Treated) Variation of Surface Resistivity with Laundering. 18% R.H. 80°F.

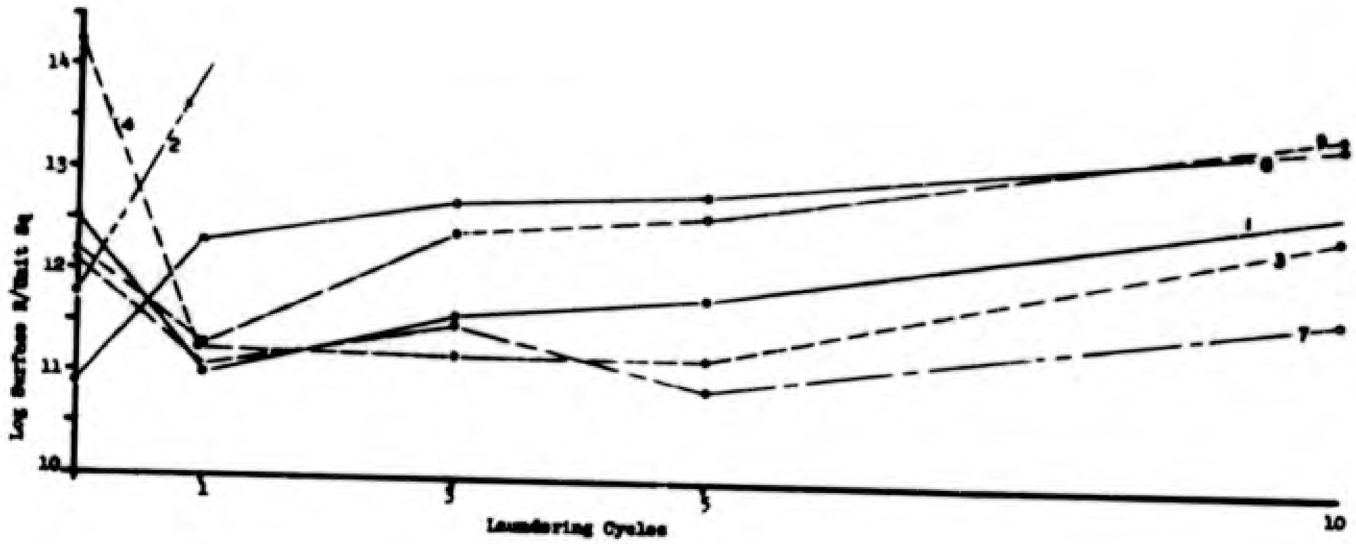


Figure 2e 16 OZ WOOL/NYLON SHIRTING (CHLORINE TREATED)
Variation of Surface Resistivity with Laundering.
22% R.H. 87°F

5. <u>Storage Characteristics</u>

The ageing properties of antistatic finishes, as with any functional finish, are of extreme importance for the usual long term storage which many Government materials undergo prior to use. It has been noted on occasion that some antistatic finishes lose effectiveness on standing. The reason for loss of effectiveness is not apparent and, in a sense, is not important for the purposes of the present study.

However, evidence exists that some products lose effectiveness by reaction with the fiber; others by loss of hygroscopic properties by penetrating deeply into the fiber substance rather than forming a surface coating of the fibers and yarns. However, it was felt that a technique should be available for forecasting, by accelerated ageing tests, losses in effectiveness which might occur in normal storage.

When the AATCC Committee on Antistatic Finishes, on which the Quartermaster Corps was represented, expressed an interest in the problem, it was decided to conduct the study under the auspices of the Committee and thus to involve a number of other laboratories. This was considered beneficial both to the Committee and to the Government. The procedure established included periodic investigation and recording of the effects of storage.

The main objective of the Committee was to devise methods by which the loss in effectiveness incurred during storage might be duplicated by accelerated techniques. Three fabrics, a triacetate, a polyester and a polyamide, were each treated in the facilities of the Quartermaster Research & Engineering Center, with 7 antistatic preparations. The 7 antistatic preparations are as follows:

1. 4A-GKB-91
2. Quarternary 3104
3. Ampitol VAC
4. LPR-5001-1E
5. Mollisan batch 660-93
6. Experimental Antistatic Agent #1
7. Experimental Antistatic Agent #2

These 3 fabrics were then distributed to all participating laboratories. The Quartermaster laboratories subjected the samples to 3 specific test situations designed to accelerate ageing. These were as follows:

(1) Simulated storage under moderate to normal conditions. For this purpose, the samples were mounted on a piece of copper screening located 30 inches in front of a fan. The period of exposure was 14 days during which the ambient temperature averaged 80°F to 85°F and the relative humidty, 60%. ("Fan")

(2) Simulated storage under hot-moist conditions. For this purpose, samples were placed in an oven at 160°F. The oven was fitted with a pan of water located beneath the samples. The test period was 7 days. ("Wet Oven")

(3) Simulated storage under hot-dry conditions. The samples were set in an oven at 160°F for 7 days. ("Dry Oven")

(See Table VII)

TABLE VII

SURFACE RESISTIVITIES* OF TREATED FABRICS AGED UNDER ACCELERATED CONDITIONS

Sample		Control	Fan	Oven Wet	Oven Dry
Triacetate	1	9.1	9.5	9.4	9.6
	2	10.7	12.6	11.8	11.1
	3	11.0	11.7	12.8	13.6
	4	9.5	9.2	10.3	10.5
	5	10.2	10.9	11.0	11.1
	6	10.0	10.5	10.9	10.6
	7	9.9	10.4	10.7	10.5
Polyester	1	9.3	9.4	10.0	9.8
	2	12.1	12.9	11.6	12.8
	3	11.4	12.6	13.6	13.6
	4	9.4	8.8	11.0	11.2
	5	11.4	11.8	13.6	13.6
	6	10.0	10.5	11.1	11.0
	7	10.4	10.6	11.3	11.4
Polyamide	1	9.6	9.8	10.2	10.5
	2	10.8	11.8	10.9	11.4
	3	10.9	11.8	13.0	13.6
	4	9.5	8.2	10.7	11.1
	5	11.1	12.4	13.0	12.8
	6	10.0	10.9	11.0	11.5
	7	10.2	10.7	11.3	11.1

*Log R units

The data given in Table VII show that the finishes were not uniformly affected.

This is further borne out by Table VIII which shows the distribution of resistivity values in log R units for each fabric for the three conditions of test.

TABLE VIII

DISTRIBUTION OF VARIOUS ANTISTATIC FINISHES WITH RESPECT TO RESISTIVITY VALUES UNDER THREE CONDITIONS OF TESTS

Fabrics	Test Conditions	Antistatic Finishes			
		(0.3 to 0.6)*	(0.7 to 1.1)*	(1.8 to 1.9)*	(2.6)*
	Fan	1,6,7	3,5	2	
Triacetate	Wet Oven	1	2,4,5,6,7	3	
	Dry Oven	1,2,6,7	4,5		3
		(0.1 to 0.5)*	(0.7 to 1.2)*	(1.6 to 1.8)*	(2.2)*
	Fan	1,5,6,7	2,3		
Polyester	Wet Oven		1,6,7	4	3,5
	Dry Oven	1	2,6,7	4	3,5
		(0.6 to 0.6)*	(0.9 to 1.3)*	(1.5 to 2.1)*	(2.7)*
	Fan	1,7	2,3,5,6		
Polyamide	Wet Oven	1,2	4,6,7	3,5	
	Dry Oven	2	1,7	4,5,6	3

*Range of Log R Units

A further comparison is shown in Table IX. In this, "a", "b", and "c" define a decreasing order of efficiency.

TABLE IX

LISTING* OF ANTISTATIC FINISHES ACCORDING TO COMPARATIVE LOSS IN EFFICIENCY CAUSED BY THREE AGEING PROCESSES

Antistatic Finish	Fabric	Fan	Wet Oven	Dry Oven
1	Triacetate	a	a	a
	Polyester	a	b	a
	Polyamide	a	a	b
2	Triacetate	c	b	a
	Polyester	b	a	a
	Polyamide	b	a	a
3	Triacetate	a	b	c
	Polyester	a	b	b
	Polyamide	a	b	c
4	Triacetate	a	b	c
	Polyester	a	b	b
	Polyamide	a	b	c
5	Triacetate	a	a	a
	Polyester	a	b	b
	Polyamide	a	b	b
6	Triacetate	a	b	a
	Polyester	a	b	b
	Polyamide	a	a	b
7	Triacetate	a	b	a
	Polyester	a	b	b
	Polyamide	a	b	b

*a = Highest efficiency; b = medium efficiency; c = lowest efficiency

The testing of the various fabrics took sufficient time so that certain samples placed in normal storage were exposed for 11 months before the testing was completed. In this time, the finishes had not deteriorated sufficiently under normal storage to permit a comparison. These data are given in Table X.

The AATCC Committee continued the studies for a period of 18 months and, at that time, concluded that the study should be terminated in view of the fact that the samples had changed insignificantly during the 18 months.

TABLE X

SURFACE RESISTIVITIES (LOG R UNITS) OF ANTISTATICALLY TREATED FABRICS AFTER ELEVEN MONTHS NORMAL STORAGE

Fabric	Antistatic Agent	Initial Value	After 11 Months
Triacetate	1	9.1	9.2
	2	10.7	10.7
	3	11.0	10.8
	4	9.5	9.6
	5	10.2	11.2
	6	10.0	10.4
	7	9.9	10.1
Polyester	1	9.3	9.5
	2	12.1	12.1
	3	11.4	11.4
	4	9.4	10.1
	5	11.4	11.9
	6	10.0	10.3
	7	10.4	10.6
Polyamide	1	9.6	9.5
	2	10.8	11.4
	3	10.9	11.9
	4	9.5	9.8
	5	11.1	11.9
	6	10.0	10.8
	7	10.2	10.7

It was observed that where a specific test condition showed an effect on a given sample, the effect did not necessarily carry through under a second condition. The data showed many reversals in results. On the basis of the above observations, it must be concluded that any predictions as to ageing conditions of an antistatic fabric will have to consider the specific type of storage anticipated for the material.

In summary, from the data presented in the previous paragraphs, it has been possible to demonstrate that antistatic agents are available which are durable to multiple launderings. The data further show that there is a specific cutoff point, due to temperature factors, for each antistatic agent.

Also, the data show that there is a cutoff point influenced by relative humidity factors. Accor gly, the combined effect of both temperature and humidity should lead a specific cutoff point in respect to intrinsic efficiency for each antistatic agent. This has been found to be the case.

For military requirements, it would appear, therefore, that antistats are available for the treatment of hydrophobic-fiber fabrics, but the data given above suggest that these agents do not have the minimum requirements which must be met for typical cold-dry conditions. The situation is less severe for hot-dry conditions and is exceedingly favorable for wet-cold conditions.

The storageability studies of antistatic agents, based on accelerated ageing methods, appear to be dependent upon the specific conditions of tests chosen. However, an 11-months storage of treated fabrics failed to show any cause for alarm for those agents which would otherwise come closest to meeting military characteristics.

PART III: THE QUARTERMASTER DEVICE TO MEASURE STATIC ELECTRICITY

1. Introduction: Theory and Deficiencies of Existing Methods

a. Theory: Resistivity of a fabric as a gauge of static propensity. In order to evaluate the static hazard inherent in a given clothing assembly system, one must determine the charge that is developed on the wearer when the specific layers of the assembly are separated. This measurement may be made directly on the wearer, as described in Part I of this report; indirectly by investigating the properties of a fabric itself. This Part constitutes a review of the instrumentation which has been reported for measuring the static propensity of textile materials.

The electrical resistivity of a fabric may be used as the criterion of its static propensity. Let us consider the charge developed on a clothing item under conditions as described in the Introduction to this report. For the sake of discussion, let it be assumed that instead of wool and nylon as the component elements, more conductive materials had been used. The transfer of charges which was observed in the assembly system would still take place with more conductive materials. But in this instance the higher conductivity of the material enables the electrons and the resultant "holes"* to move more freely over each of the surfaces. This increased mobility allows the charge to concentrate and to develop potential gradients at points of separation of the two surfaces. This brings about a discharge of the surface in the same manner as an isolated conductor can be discharged by touching a grounded wire to one edge.

If only one of the two surfaces is capable of conducting, the charges on that surface can move easily, but those on the non-conductive surface will remain unaffected. In this case, then, since the charges on the non-conducting fabric are not free to move about, at each point of separation only a small area of the conducting fabric will be neutralized. This might be considered as analogous to an attempt to discharge an electrified fabric or other non-conductor of large surface area with a grounded wire. The portion of the non-conductor which is neutralized depends on the mobility of the charges on it and the length of time the grounded wire is in contact with it. The necessity for having both surfaces conductive is further emphasized when it is considered that even a metal plate can be electrified by rubbing it with a non-conductive material, such as a fabric.

The above qualitative considerations suggest the use of resistivity of the fabric as a gauge of static propensity. Also, the use of this measurement agrees with the suggestion made by Keggin[21] that the amount of static charge is constant for a given process and is independent of the material upon which it is developed. However, the amount remaining depends upon the rate at which the charge can leak away. Hearle[16] has published a review of the work that had been done up to 1952 on the measurement of the resistivity of a fabric. Appendix B describes various ways to determine resistivity as well as other qualities.

*A hole is the term applied to the deficiency of one electron and therefore an amount of positive charge.

b. Principles of measuring resistivity

The electrical resistivity of the fabric is usually measured in either of two ways: by the use of a circuit employing an electrometer tube; or by the use of a condenser discharge.

(1) Use of circuit employing electrometer tube. The problem of measuring a high resistivity is the problem of measuring a small current. An electrometer tube is a "current amplifier." It is used for the amplification of extremely small direct currents of about 10^{-12} amps. and less. The direct current to be measured is passed through a resistor and the IR drop produced is impressed between the grid and cathode of the tube. This causes a change in the plate current. The ammeter is shunted to balance out normal plate current in order that the ammeter will indicate only the change in the plate current caused by current flowing in the input circuit. With a resistor of 10^{10} ohms the current amplification is about 250,000. Figure 3 illustrates a typical circuit for this type of measurement.

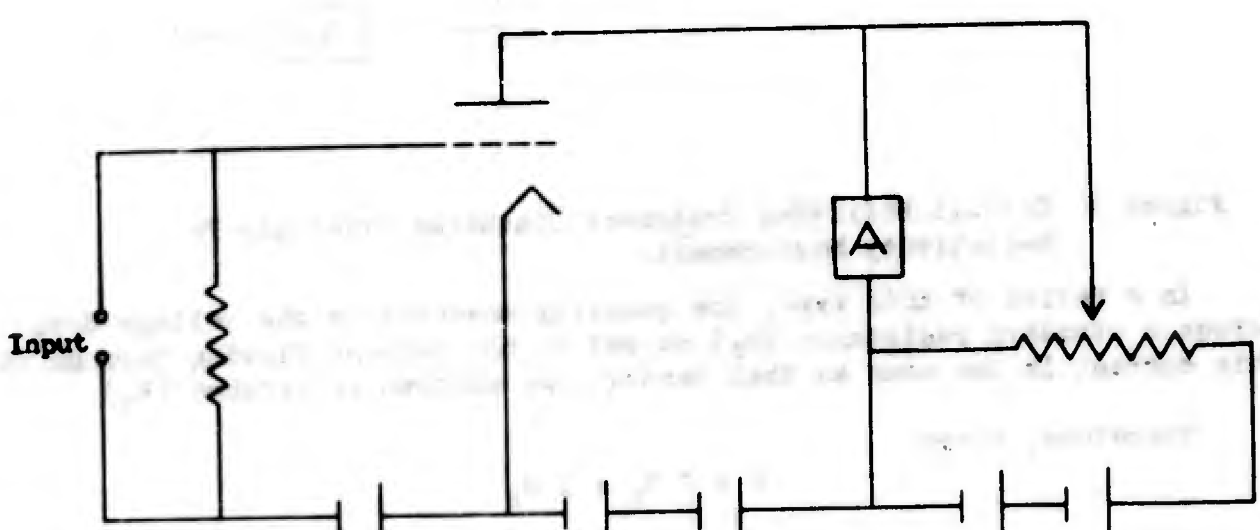


Figure 3 Electrometer Tube Circuit

Hayek & Chromey[14] have reported on a resistivity meter using an electrometer circuit of this type. (See Appendix for further details.) Commercially available electrometers consisting of a very sensitive d. c. vacuum voltmeter using an electrometer tube may be used, as illustrated in Figure 4.

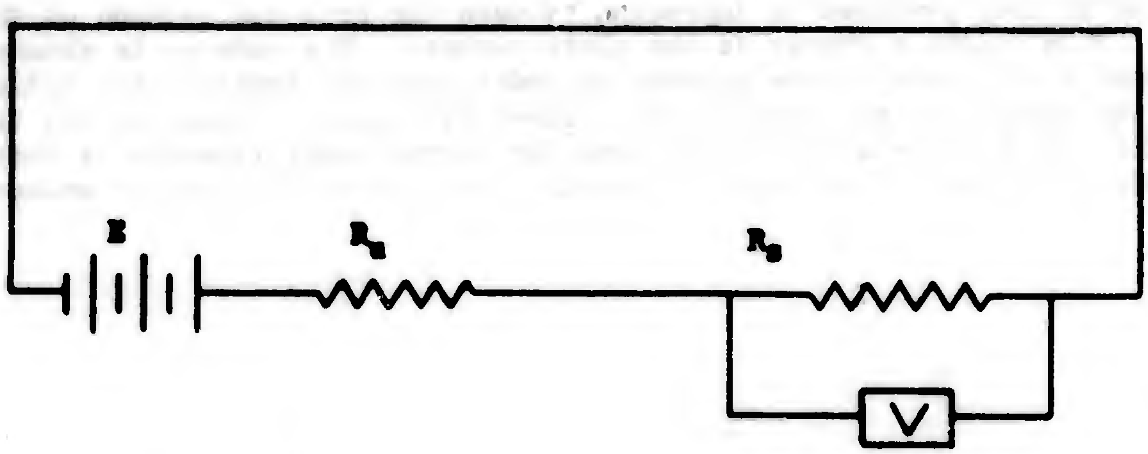


Figure 4 Circuit Utilizing Condenser Discharge Principle For Resistivity Measurement

In a device of this type, the quantity measured is the voltage drop across a standard resistance (R_s) caused by the current flowing through it. This current is the same as that through the unknown resistance (R_x).

Therefore, since

$$E = I R_x + I R_s$$

$$E = \frac{V}{R_s} R_x + \frac{V}{R_s} R_s$$

Solving for

$$R_x = R_s \frac{E-V}{V}$$

But, $$IR_s = V \text{ (on meter)}$$

So, $$I = \frac{V}{R_s}$$

(2) Use of condenser discharge. A second method for measuring high resistivity utilizes the discharge of a condenser. The charge q on a condenser of capacitance C initially of charge q_o at any time, t, during its discharge through a resistance, R, is:

$$q = q_o \exp. - \frac{t}{CR}$$

As $t \rightarrow \infty$, $q \longrightarrow 0$, i.e., condenser is discharged.

However:

$$q = CV$$

Hence

$$VC = V_o C \exp. - \frac{t}{CR}.$$

And cancelling out C, we get

$$V = V_o \exp. - \frac{t}{CR}$$

It can be seen that the potential to which a condenser is charged at any time, t, after it is allowed to discharge through a resistance, R, is equal to the initial potential times the exponential $- \frac{t}{CR}$. Thus, by measuring the length of time, t, required for a condenser of known capacitance, C, to drop in potential from V_o (initial) to a second potential V through an unknown resistance, and using the above equation, the unknown resistance can be calculated from the following equation:

$$R = \frac{t}{C \ln \left(\frac{V_o}{V}\right)}$$

This measurement may be made with the following circuit (Figure 5):

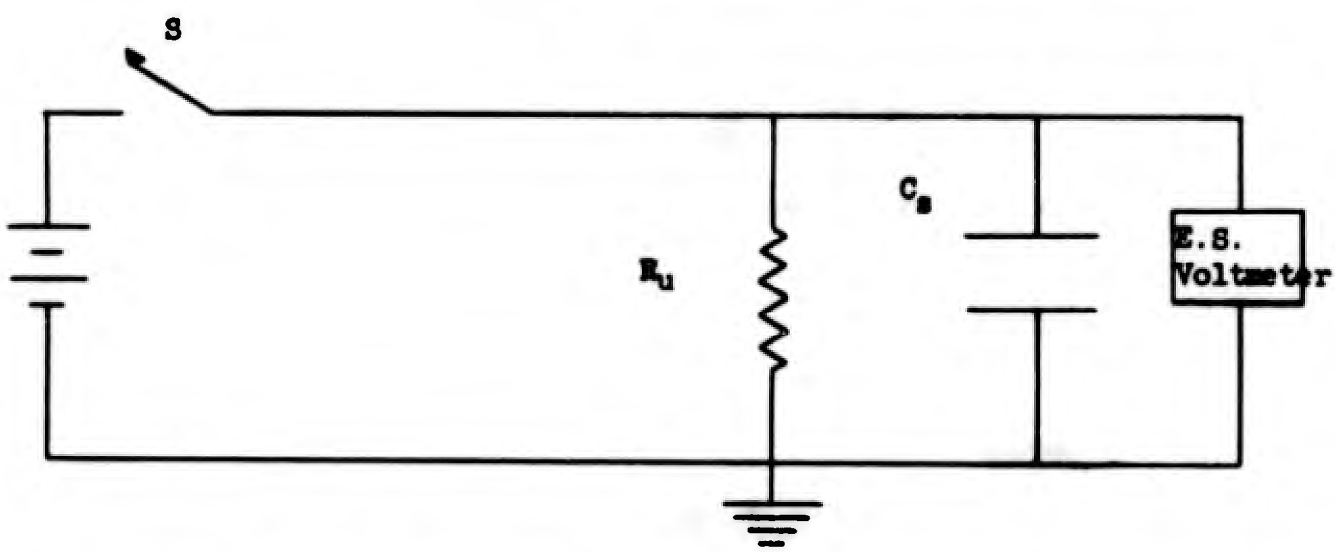


Figure 5 Circuit Utilizing Condenser Discharge Principle For Resistivity Measurement

The condenser in the preceding diagram is illustrated external to the voltmeter. However, in the measurement of high resistances, the inherent capacitance of the electrostatic voltmeter* (in more recent instruments: 8 mmf) is sufficient.** With lower resistances, of treated fabrics for example, it may be necessary to add an external capacitance in parallel with the meter. The capacitance C would then be the sum of the two.

*An electrostatic voltmeter consists of a fixed and a moving element. The potential to be measured is applied directly between these elements. The ch yes on the elements are of opposite polarity (one element being connected to ground) and attract each other according to electrostatic forces. The force of attraction is translated into a motion of the moving element (e.g., a light aluminum vane which rotates against the torque of a control spring) giving a means of measuring the potential difference. The usual voltmeter depends on a flow of current for its operation; the electrostatic voltmeter does not.

**By "sufficient" is meant that it will not discharge before a length of time required to make an accurate determination - about 1 minute.

c. <u>Limitations of instrument data in measuring static propensity of clothing ensemble</u>.

While the resistivity determination does yield information as to the electrostatic behaviour of a fabric, it cannot be indiscriminately used as a measure of the static problem as a whole. Some of the limitations are discussed below.

(1) <u>Inaccurate for a textile fabric</u>. The electrical resistivity of a textile varies with the voltage applied; that is, textiles do not follow Ohm's law, E/I = K. Confirmation of this fact is found in the literature.[16] These references consider untreated material but the writers have noted the same thing with treated fabrics. Figure 6 shows the variation in the electrical resistivity with voltage applied for a 3 oz. nylon oxford fabric treated with an antistatic finish.

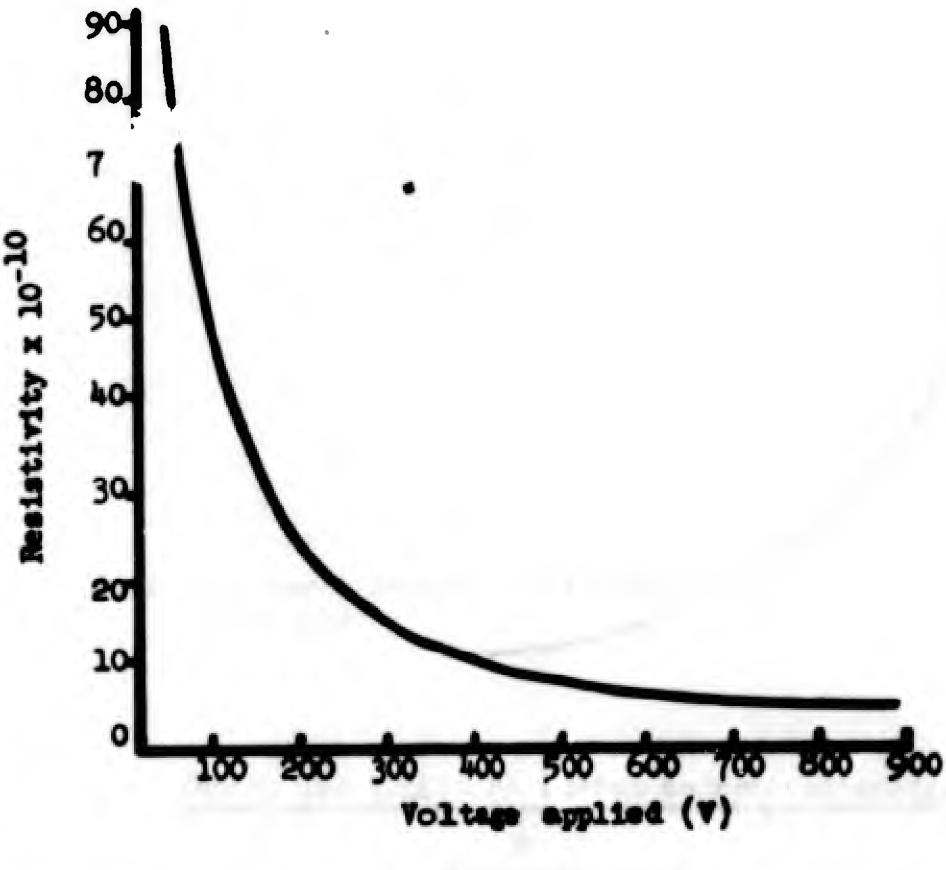


Figure 6 Variation of surface resistivity with voltage applied - treated 3 oz. nylon, 20% R.H., 82°F.

One makes a resistivity measurement to determine the rate at which a static charge on a fabric will leave it. This rate of charge dissipation has been investigated with the Hayek & Chromey Propensity Meter described in Appendix B. This instrument has been widely used. It measures, under controlled atmospheric conditions, the rate of decay of a charge on a fabric. The rate of decay of the charge can be taken as directly related to the resistivity. Figure 7 plots the rate of decay of two treated samples, a cotton fabric and a dynel fabric. These two samples contradict the reasoning behind the measurement, since the treated cotton which has a measured resistivity of 12.2 log units dissipates a static charge much more quickly than the treated dynel which has a resistivity of 11.6 log units per unit square of fabric surface. The resistivities were measured before and after the charge was generated and on that same portion of fabric upon which the static was developed (Figure 7).

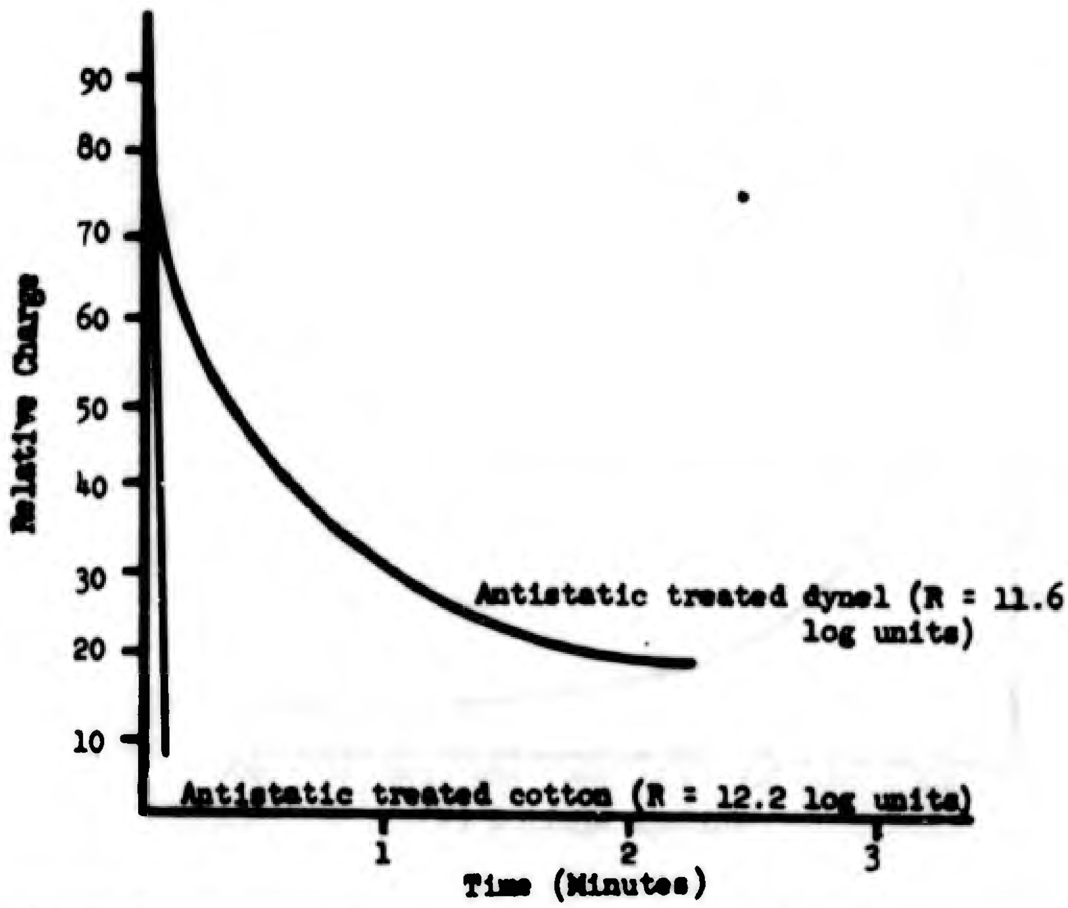


Figure 7 An Instance where the Resistivity Measurements are Inverse to the Rate of Charge Dissipation

(2) Ignores effect of second surface. Another objection to the use of resistivity as a measure of a fabric's static propensity is that it measures only the capacity of a single isolated fabric layer to dissipate a charge. Contrary-wise, the results obtained, both at the National Bureau of Standards and in the Quartermaster laboratories, suggest that the voltage, produced on a particular fabric worn as a component of a specific ensemble, is dependent upon interaction with a second fabric surface. Table XI shows the voltage which is developed on various fabric combinations.

TABLE XI: VARIATION OF VOLTAGE WITH SECOND SURFACE*

Inner fabric	Outer fabric	Voltage
Wool/nylon	Viscose/dacron	600
	Cotton	1400
	Nylon	4600
	Nylon w/antistatic	7500
Nylon	Viscose/dacron	2700
	Cotton	3600
	Wool/nylon	7500
	Nylon w/antistatic	2600
Nylon with antistatic finish	Viscose/dacron	2200
	Cotton	3400
	Wool/nylon	7800
	Nylon	1800

*Source: References 33 and 34

(3) Ignores the effect of blend. The situation with a blend involving both conductive and non-conductive fibers may also be considered. A resistivity measurement on such a fabric would be entirely dependent upon the fiber having the higher rate of conductance. Thus, resistivity measurements fail to provide a proper indication of the end use properties of a fiber blend fabric. Accordingly, results obtained with devices which measure, or are dependent upon resistivity, give an erroneous impression of the value of fiber blend fabrics. In Figure 8, data for three fabrics are plotted showing the rate of charge dissipation obtained with the Hayek and Chromey Propensity Meter: an all dynel, a 75%/25% blend of dynel and cotton, and an all cotton fabric.

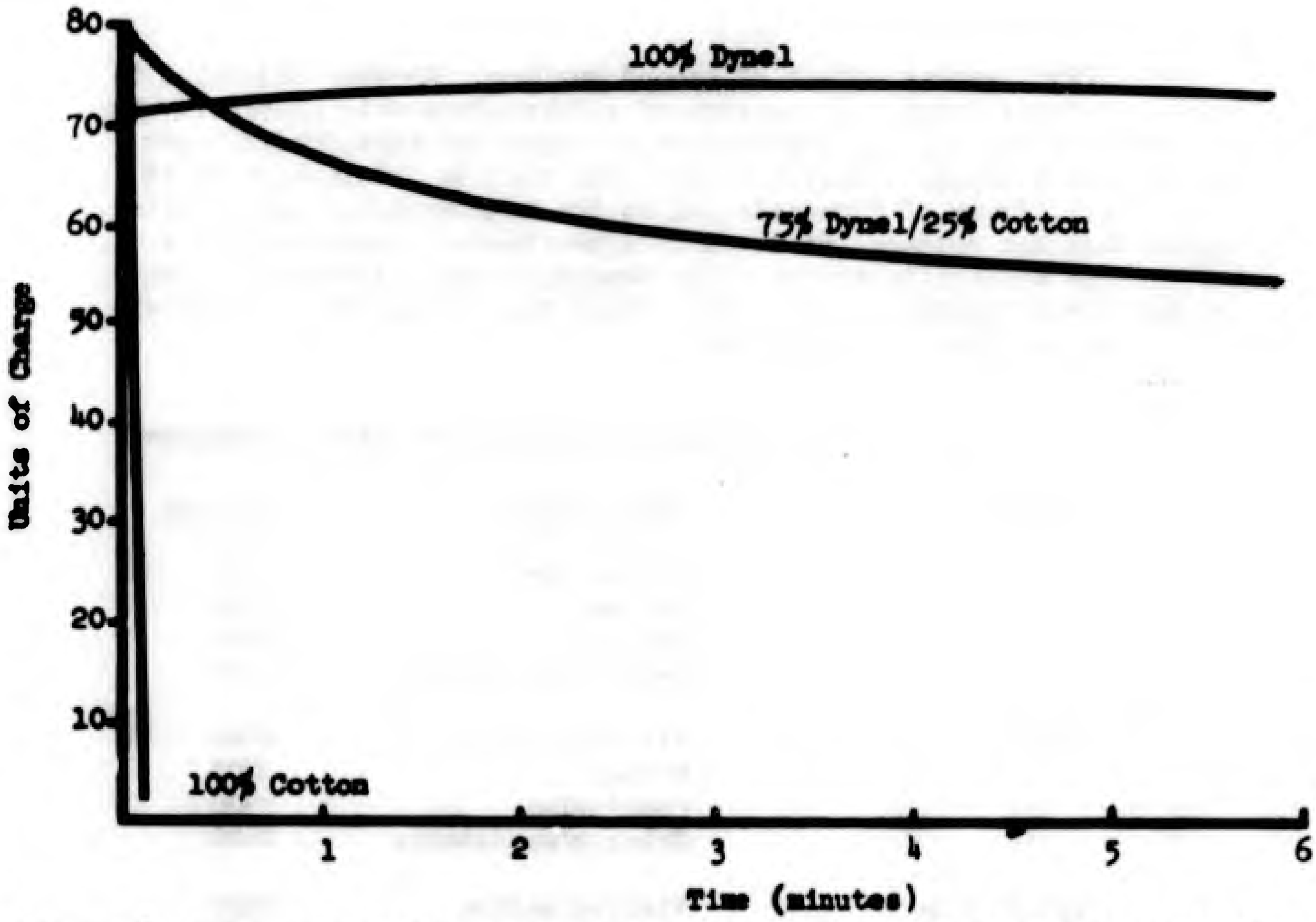


Figure 8 Failure of static propensity meter to forecast the static behavior of blends 60% R.H. 78°F

An inspection of the decay curves obtained with these 3 fabrics shows that, although a portion of the charge on the blend fabric does leave, the static propensity is not significantly different from that of the all-dynel fabric. It certainly does not compare favorably with the results obtained with the all-cotton fabric. When these same fabrics are measured by observing the voltages produced when the fabrics are worn in an ensemble by an individual, or by determining the total charge density (in micro-micro coulombs/in^2) as is possible with the new Quartermaster device to be described later in this report, we find that the static propensity of the 75% dynel/ 25% cotton blend is not different from that of the all-cotton fabric. Table XII gives these data.

TABLE XII: CHARGE DENSITY* OF DYNEL, COTTON AND A BLEND (in micro-micro coulombs/in^2)

Dynel(%)	Cotton(%)	
100	0	1760
0	100	70
75	25	70

*Measured by new Quartermaster device

To further investigate the anomolous results obtained with the Hayek and Chromey instrument as compared to the data from a clothed individual, a piece of polyester film, which is electrically extremely troublesome under normal conditions, was coated on one side with conductive carbon black. A charge was then generated on the uncoated side using the Hayek and Chromey instrument and observations were made on the rate of charge dissipation. No significant depreciation of the charge was apparent. The sample was then removed from the instrument and dropped into a steel beaker attached to an electrometer. The meter indicated that the film was neutral with no resulting charge. The sample was then replaced on the Hayek and Chromey instrument and, without further rubbing, was remeasured. The instrument indicated that the film still contained a charge and, in fact, had not dissipated any of its charge.

When the film was in the metal beaker, it was evident, from the fact that it stuck to the sides of the beaker, that there were localised charges on it, yet the summation of charges on the film was zero, as was indicated on the electrometer.

From the foregoing observations, it must be concluded that the improvement of the static propensity of a synthetic fabric by blending a non-conductive fiber with a fiber of higher conducting power, does not result from the more conductive fiber providing a path over which the charges on the non-conductive fiber can bleed away. Rather, it suggests that the more conductive fiber first dissipates any charge which has developed on it and then takes up a charge opposite to that on the non-conductive fiber so as to produce a neutral configuration. Apparently, an instrument which measures rate of decay, such as the Hayek and Chromey instrument, cannot carry out this evaluation and leads to erratic results. By the same token, devices which measure resistivity, *per se*, give only part of the total information with respect to the static propensity of fiber blends.

d. *Criterion necessary for completion evaluation.* As was noted in Part I, interest is not so much on the distribution of charges on the clothing layers, but rather on the voltage produced on the individual. This voltage, in turn, is dependent upon:-

1. The degree of insulation from ground as determined basically by his footgear;

2. The amount of static electricity developed by interaction of the fabric layers in the clothing system;

3. The rate of charge dissipation across the component layers of the clothing system;

4. The capacitance of the system being considered (that is, the capacitance of the man and his clothing).

Accordingly, for a complete evaluation of the static behavior of a fabric or an ensemble of fabrics, it is necessary to establish all of these factors thus encompassed. In addition, a mechanical means for generating the charge is preferred because of the obvious shortcomings of manual methods. In Table XIII, the authors have listed those features which they believe must be met by instrumentation if a realistic appraisal of static propensity is to be achieved.

e. Where specific instruments fail to meet criteria. Table XXXI also indicates where the instrumentation reported in the literature, or otherwise in use at this time, fails to fulfill the developed criteria.

TABLE XXXI: FAILURES (X) OF PREVIOUS INSTRUMENTS* TO MEET CRITERIA FOR COMPLETE EVALUATION

Desired parameters for complete evaluation	Failures							
	a	b	c	c^1	d	e	e^1	f
1. Mechanical means of generating charge	X		X	X		X		X
2. Mechanical means which simulate movement of ensemble layers	X	X	X	X	X	X	X	X
3. Investigation of one fabric against any given second fabric		X					X	
4. Investigation of fabric systems which simulate ensemble layers	X	X	X	X	X	X	X	X
5. Charge dissipation to ground	X	X	X					X
6. Charge dissipation to ensemble component layers	X	X	X	X	X	X	X	X

*Instruments are coded in the table, according to the list given in the Appendix.

An inspection of the foregoing table shows:

1. None of the methods reviewed utilizes a mechanical means of generating the charge which in any way approximates the motions imparted to garment layers.

2. Although 6 of the 8 schemes conceivably could be used to study various fabric combinations, only 1 of these, (d), employs a mechanical means of charge generation. However, there are other problems with this device, as previously mentioned.

3. With four of the methods listed, charge dissipation to ground can be investigated but not one of these methods is capable of observing the rate at which a charge would dissipate to component ensemble layers.

It is also important to note that with the majority of these instruments, the results are recorded as so many "volts potential." Experience shows that the potential exhibited by a charged fabric is peculiar to the apparatus used to observe it. This is so because it depends on the proximity of the fabric to the detector element and on the capacitance of the detector circuit. The quantity that creates a hazard is not the "potential" of a piece of cloth but instead the amount of static electricity on it. None of the instruments reviewed attempts a quantitative estimate of the charge developed. It is only with such a quantitative measure that calculations may be extended in an effort to gauge the hazard which a fabric or fabric combination may produce on the wearer.

2. Description of the Quartermaster device.

In the preceding section the various instrumental techniques which have been described in the literature were discussed. It was stated that for military uses one must be capable of predicting quantitatively the hazard inherent in a clothing assembly, and that none of the instruments investigated provide this capability. As a consequence, a device has been designed and constructed which, it is believed, is capable of meeting the requirements. This is shown in Figure 9.

Figure 10 illustrates the essential features of this device. Engineering drawings are given in Appendix D. A and B in the schematic are a pair of rubber rollers. These rollers are adjustable for pressure of contact and are driven in a reciprocating fashion by a system of motor, reducer, and gear train. B is a steel beaker which rests on a paraffin base (P) and which is connected to an electrometer and voltmeter (V). C represents any one of a series of capacitances used to scale down the voltages produced on the beaker, so as to have these beaker voltages fall within the range of the voltmeter V.

3. Operation and Calculations

In operation, a sample of fabric is cut to specific size with a die. The rollers are covered with the second fabric of the combination being investigated (i.e., with whatever the sample fabric comes in contact in use). The sample then is made to pass through the covered rollers and in so doing falls into the beaker below. The charge that was generated on the fabric by passing through rollers produces a voltage on the beaker which is indicated by a meter (V). Since the surface area of sample, as well as the shunting capacitance are known, the charge/unit area of cloth can be immediately calculated. Knowing the charge/unit area, the total area of contact between garments involved, and the capacitance of the individual, we can calculate the voltage that would be produced on him when a man removes a garment of the sample fabric from over an inner garment of the second fabric (on the device, the fabric covering the rolls).

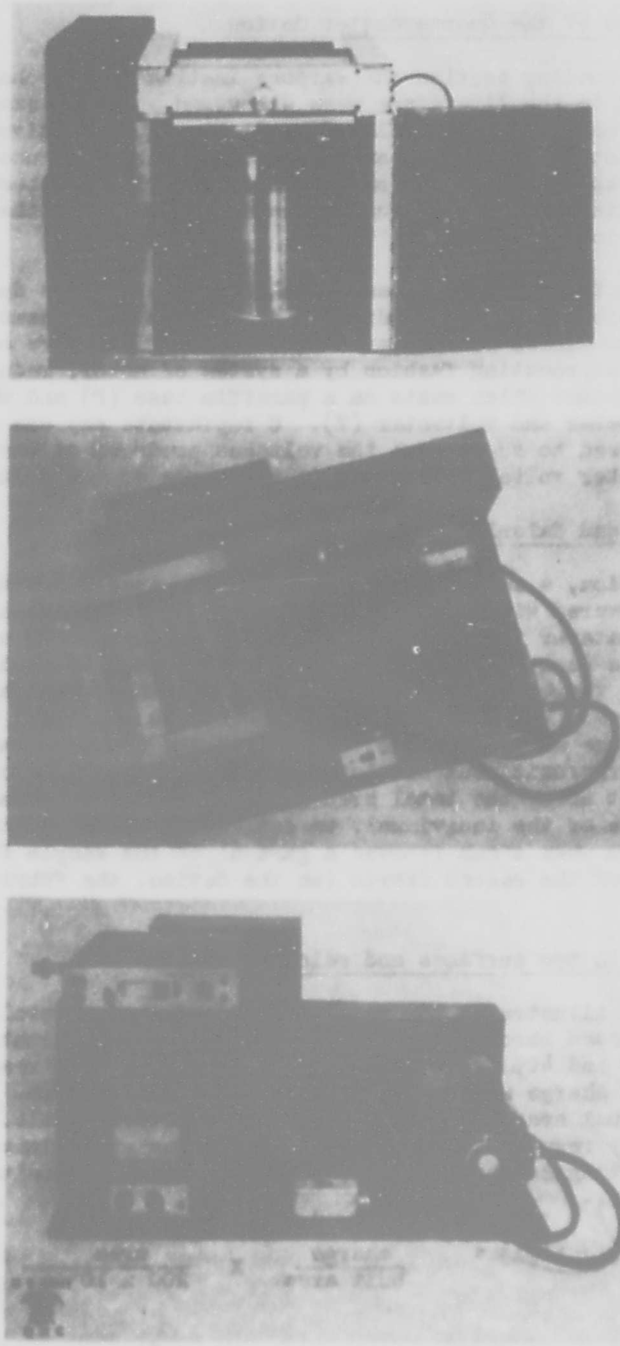
4. Results with two surfaces and related hazard

Figure 11 illustrates the results obtained when several different samples are in turn passed through the rollers covered with antistatically treated dynel, at 80°F and 40% R.H. The results in electrometer reading and corresponding static charge may be read to the left of the graph. Resulting voltages on the individual are indicated on the right vertical scale. Also shown is the level of energy required to ignite gasoline fumes and primers. These voltages and their igniting capabilities are based on a man's capacitance (200×10^{-12} farads) so that:-

$$V \text{ (potential)} = \frac{\text{charge}}{\text{unit area}} \times \frac{\text{area}}{200 \times 10^{-12}} \quad \text{volts}$$

and

$$W \text{(energy)} = \tfrac{1}{2} CV^2 = \tfrac{1}{2}\, 200 \times 10^{-12} \; (V^2) \quad \text{joules}$$



a. Side

b. Top

c. Front

Figure 9 Quartermaster device for measuring static electricity

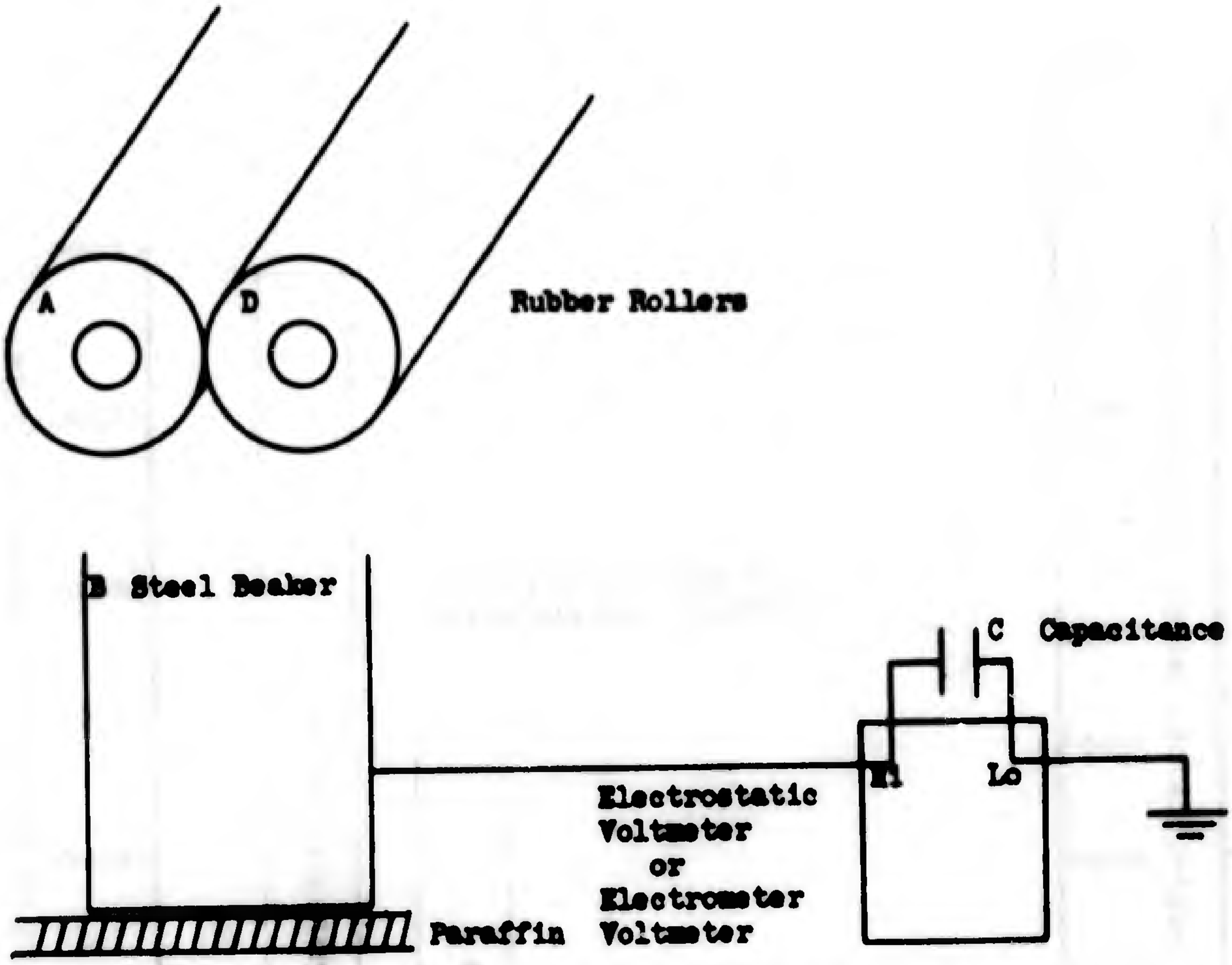
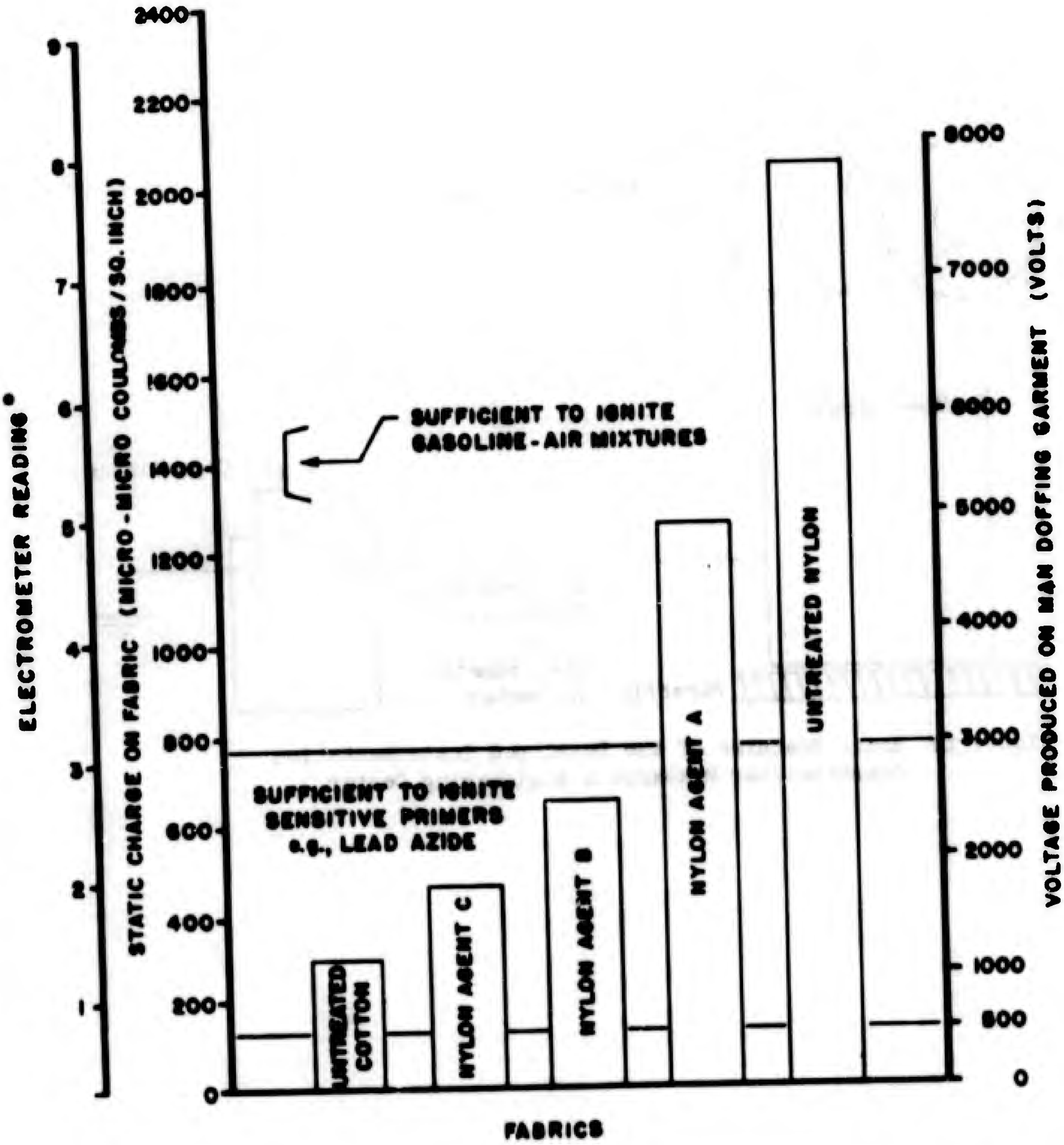


Figure 10 Basic Features of the Developed Instrumentation
Quartermaster Research & Engineering Center



* THE CHARGE DENSITY WHICH THE ELECTROMETER READING ESTABLISHES DEPENDS, OF COURSE, ON THE PARTICULAR CAPACITANCE PLACED IN THE MEASURING CURCUIT

Figure 11 Static Charge Developed on Five Fabrics Compared with Hazardous Levels

In the data of Figure 11, 12 samples were used for each determination and thus the average value obtained represents an area of cloth equal to about one-fourth of the armor vest, as an example.

5. Comparison of results with on-the-individual data

In order to compare results obtained with the device with results obtained on individuals, 7 fabrics were studied in various combinations, by each method. The fabrics used were wool/nylon, viscose/dacron, cotton, nylon, nylon with an antistatic finish, dynel, and dynel with an antistatic finish. The testing was accomplished in the Quartermaster Cold Chamber at 20°F and 50% R.H.

Evaluation of these fabric combinations with the device was carried out in the manner described above. The "on-the-individual" type testing was performed by wrapping one of the two fabrics about Subject A and then having Subject B rub the second fabric across A's back and then remove it. The voltage produced on A was measured by his touching the high terminal of the voltmeter.

The results obtained with each method were then submitted to a statistical correlation (see Figure 12). In such an analysis, a coefficient is calculated which is a measure of the extent of linearity between the two methods. When all the sample combinations are included, the coefficient of correlation is .37, which is low (exact linearity would require coefficient of 1.0). If, however, those combinations involving the wool/nylon are excluded, then the correlation coefficient becomes .73.

The results obtained by the National Bureau of Standards show considerable voltage variation among garments manipulated in various ways. This was particularly apparent when the garment assemblies included the wool/nylon fabric; in one case, voltages of 4900, 1600 and 400 were recorded with the same garment combination and under the same conditions.

It was concluded that the coefficient of .73 is a significant one and that the deviation from absolute linearity (a coefficient of 1.0), arises not from the device but instead from the lack of uniformity of the "on-the-individual" type tests.

6. Typical information available with various second surfaces

Table XI illustrates the type of information obtainable with the instrument. These data were recorded in a cold room in the Quartermaster Climatic Chambers Building at 20°F and 50% R.H. Three blends are included, as well as nylon and dynel, both untreated and treated with certain antistatic finishes. The results are listed as the number of micro-micro coulombs developed per square inch of fabric surface.

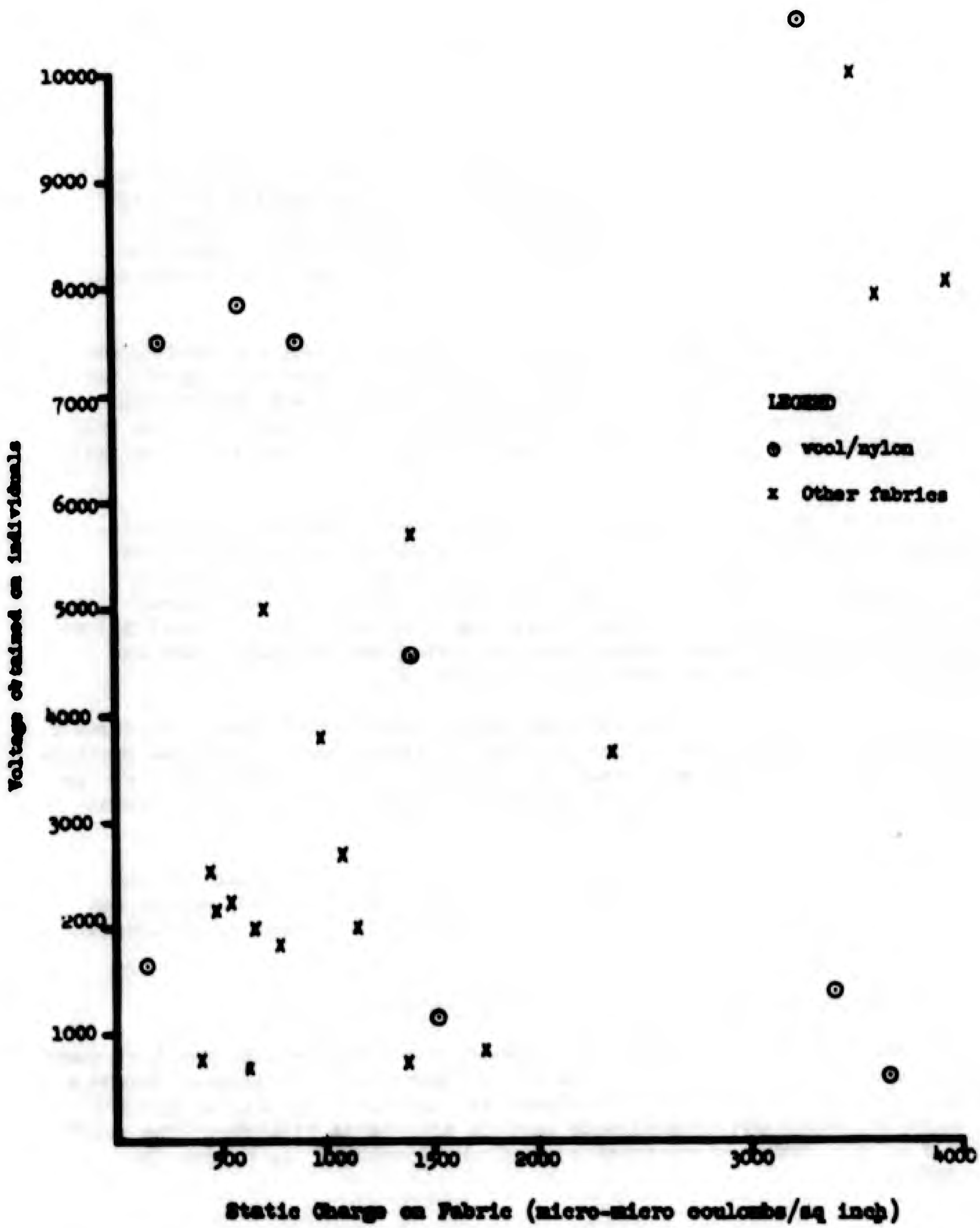


Figure 12 Correlation Between the Charge Density on Clothed Individual and Readings Obtained on New Quartermaster Device

TABLE XIV: CHARGE DEVELOPED ON FABRIC RELATED TO SECOND FABRIC SURFACE
(in micro-micro coulombs/in^2)

Sample Fabric	Anti-Static Finish	Cotton (untr)	Second Fabric Surface*: Dacron/ Rayon	Uncov- ered**	Nylon (untr)	Wool/ Nylon	Nylon & Fin 7
Nylon	untr	980	1080	840	560	870	440
Nylon	7		510	540	770	600	880
Nylon	9		220	70	560	290	280
Nylon	2		540	100	380	370	70
Nylon	1		2800	2170	1600	3250	1890
Dynel	untr	3500	2350	870	3600	3250	3950
Dynel	8		1370	560	1400	1520	720
Wool/nylon	untr	3400	3650	1350	1400	2800	240
Cotton	untr	1220	1750	230	150	720	490
Dacron/ rayon	untr	400	540	60	630	140	650
Dynel/ cotton	untr	1180	90	60	1250	1010	880

*In the Quartermaster device, the second fabric covers the roller.
**That is, no second fabric; the other surface was that of the base roller, coated with conductive carbon black.

It may be seen that ineffective finishes may actually become detrimental (viz., Agent 1 on nylon), and that blends of the more conductive fibers with non-conductive fibers are effective in lessening the static propensity of troublesome materials.

It should be mentioned that the relative merits are specific to the temperature/humidity conditions used (20°F and 50% R.H.). As the data given above have demonstrated, the new Quartermaster device thus gives a means of establishing the specific value of a fabric assembly system in terms which are meaningful in end use.

With this device, it has been possible to show the merits of blends, as well as antistats, as methods for the dissipation of a charge. However, it should be stated that the resistivity measurement is equally as suitable for those cases which involve a functional finish applied uniformly to a fabric surface. Where a fabric surface has discontinuities within it, a device such as that described or on the individual-type tests must be conducted for the results to be meaningful.

PART IV: COMPATABILITY OF ANTISTATS WITH OTHER FINISHES

In prior sections of this report we have discussed the selection of an antistatic finish to meet a military requirement and at least one facet of a general assessment of the problem of compatability. We have looked at the matter of storageability. We have determined that there is a possible cutoff in efficiency in relation to the physical environment, as controlled by temperature and humidity. But these are only two out of many factors in a military development.

Military requirements rarely achieve compliance through the use of a single finish; in most cases, several chemical systems are needed and used.

The antistatic finishes which meet the requirement of durability appear to be resins which react with and crosslink the fiber and contain moisture-sensitized groupings. As has been shown in earlier pages, there tends to be a degree of specificity of the antistat to the substrate. Thus, as we attempt to apply an antistat to a fabric surface which has already been modified with another additive finish, the problems of compatibility and specificity must be resolved.

Perhaps the extreme case, in the spectrum of additive finishes applied to military textiles for one purpose or another, is that of a water repellent finish. By its very nature, a water repellent resists normal moisture influences on a textile material and thus even a normally satisfactory textile material (from the standpoint of static development) can become troublesome when it is water repellent treated.

A case which has achieved a status approaching adoption has been that of Cloth, Polyester/Rayon Twill, 8.3 oz., used in the experimental mechanics coveralls. This fabric in its virgin state meets the basic criteria for low static propensity. In practice, the Industry gives this fabric a crease-resistant finish which is usually based on a cyclic ethylene urea formaldehyde resin. This addition causes a satisfactory fabric to become poor in static propensity. To meet the military requirement, an antistatic finish has been applied.

In the field tests conducted by CONARC and Arctic Test Board on the garments made from this fabric, the reports on static propensity were most favorable. However, there was a problem with battery acid penetrating the fabric. The problem was resolved by using a water repellent. Table XV gives data on 3 water repellent systems: a non-durable aluminum soap-wax emulsion, a silicone and a quarternary pyridinium hydrochloride complex. The antistat was a polyamine complex having good durability and high static efficiency.

TABLE XV: INFLUENCE OF WATER REPELLENT FINISH ON STATIC DISSIPATING POWER OF A POLYAMINE ANTISTAT
Polyester/Rayon Twill 65/35, 8.3 oz.

Treatment	Surface Resistivity* (ohms/sq unit)
1. Basic fabric - untreated	1×10^{11}
2. Crease resistant treated	1×10^{15}
3. Basic fabric - antistatically treated	5×10^{9}
4. #3 - overtreated with 8% silicone WR	3×10^{10}
5. #3 - overtreated with durable quarternary pyridinium hydrochloride WR	1.6×10^{10}
6. #3 - overtreated with an aluminum soap wax emulsion WR	1.6×10^{10}
7. #2 - antistatically treated	8×10^{9}
8. #7 - overtreated with aluminum soap wax emulsion WR	3×10^{10}
9. Silicone WR over basic fabric	10^{13} ca 10^{14}
10. Quarternary pyridinium hydrochloride WR over basic fabric	6×10^{12}
11. Non-durable aluminum soap - wax emulsion over basic fabric	1.6×10^{12}

It can thus be concluded that compatability exists between water repellents and the specific antistatic agent used. In these experiments, the water repellent was applied over the antistat. When the water repellent is on the fabric prior to application of the antistat, problems in durability of the antistat result. In general, the antistat becomes non-durable. Experiments conducted by simultaneously applying the water repellent and certain antistatic finishes which are compatible in the treating bath, have shown that both the water repellancy and the static propensity suffer in degree of effectiveness.

Thus, compatibility of antistats with other functional finishes appears to exist, but each combination must represent a special study. There appear to be no fixed rules to guide the experimenter.

*Surface resistivity of untreated cotton sateen, 9 oz. is: 3×10^{12}

SUMMARY AND CONCLUSIONS

The present study has shown that the generation of static electricity in clothing assemblies can create a hazard to the wearer. This study and the related NBS project sponsored by the Quartermaster Research & Engineering Command disclose that any garment system which develops a potential of approximately 3000 volts or more on the individual places him in a position in which, through a shock to a grounded conductor, he could release a spark of sufficient intensity to ignite gasoline-air mixtures. Voltages exceeding this value have been obtained with many standard clothing items at 75°F and relative humidities less than 35%. In addition, it has been demonstrated that the hazard is increased under lower temperatures and lower humidities.

The mechanism by which static charges generated on clothing layers can result in the wearer developing hazardous potentials has been discussed in Part I. It was concluded that this is a consequence of the lack of conductivity of the surfaces involved. In Part II (Antistatic Finishes), it was demonstrated how certain chemical compounds when applied to fabrics, make the fabric surfaces more conductive.

Also, we have considered how these finishes might be utilized in a garment assembly. Part I also explained that unless both surfaces involved are conductive, a complete discharge cannot take place when the surfaces are separated. Consequently, any two surfaces which may be separated in the vicinity of explosive mixtures must be made conductive. This does not include surfaces which are not separated in garment removal, e.g., the frieze surface of the liner which remains buttoned into the field jacket or the layers in the armor vest. Such an assembly is illustrated in Figure 13.

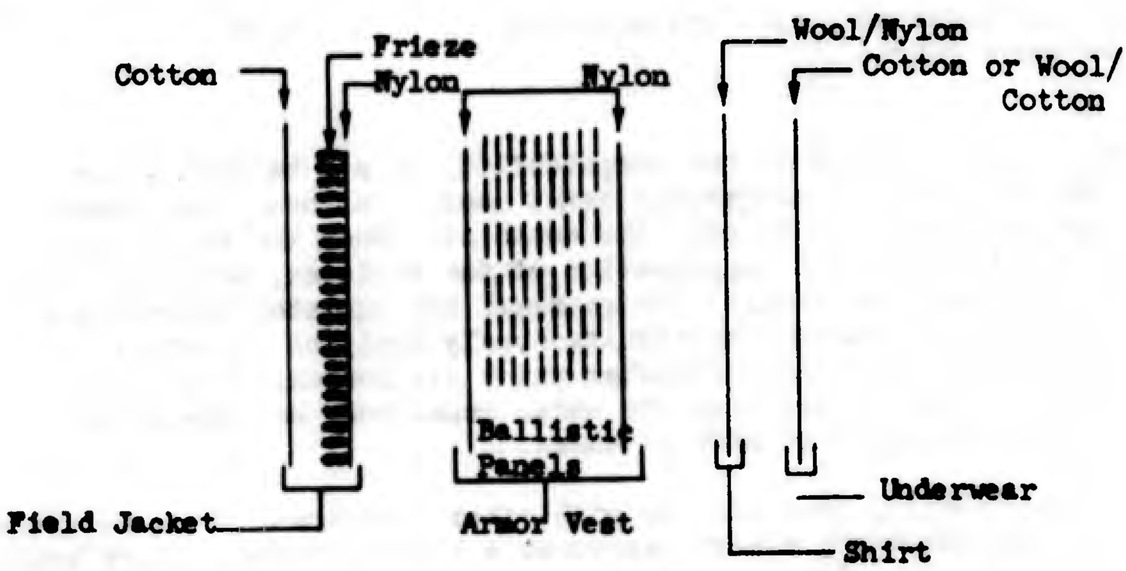


Figure 13 Schematic of Layers in a Cold/Wet Assembly Including Armor Vest

Also, under conditions of temperature and humidity which produce troublesome conditions, the use of antistatic finishes would be required on the nylon lining of the field jacket, the nylon lining of the armor vest, and the wool/nylon shirting and wool trousers of the basic underlayer. The all-cotton or the wool/cotton underwear does not require treatment for two reasons:

(1) The existence of a high moisture regain due to proximity to the skin.

(2) The fact that the cotton is a good conducting fiber under normal temperature and humidity conditions.

Normally, the outermost or shield layer of the ensemble need not be treated. However, where the wearer is likely to rub against the seat of the vehicle he is driving, or other equipment, the outer layer should be treated for maximum safety. The study has demonstrated that the conductivity characteristics of the footwear are fundamental to extreme safety even when the fabric layers have been treated.

An investigation of commercially available antistatic compounds has pin-pointed at least one finish, effective somewhat below 32°F and less than 1% R.H., which withstands 10 severe launderings on all the fabrics tested. The effectiveness appears limited by temperature because even the best agents available, though effective under almost bone-dry conditions, become ineffective as the temperature is lowered.

Antistatic agents show specificity with respect to surface. A change in surface properties due to the application of a functional finish to an otherwise satisfactory textile material may require antistatic treatment. Compatibility between antistats and other finishes has been discussed and it has been demonstrated that such exists with water repellents. However, the sequence of addition of the functional finish and the antistat may be found to bear significantly on the static propensity characteristics as well as on durability of the antistatic finish and the concomitantly applied functional finish.

A study has been made of the accepted procedures for the laboratory evaluation of the electrostatic propensity of fabrics, and this has demonstrated that none of these, because of certain inconsistencies, inaccuracies, or inadequacies, is capable of supplying the complete information believed necessary for Quartermaster Corps needs. As a consequence, it became necessary to design and construct a new instrument. It has been demonstrated that data from this instrument correlate well with data from "on-the-individual" tests. It has been further shown that the electrical properties of a fabric or fabric combination may be evaluated by the use of this device in a manner which provides a quantitative measure of the hazard incurred.

Also, it has been proved by use of this device, and confirmed by "on-the-individual" type tests, that fiber blends consisting of a more conductive fiber (such as cotton or viscose rayon) with a troublesome one (such as dynel or dacron), result in lowering the static propensity. The fibers in the blend or in combination must be in their purest state. It is obvious that the application of a functional finish to such a fabric may provide a new surface with entirely different properties. As such, if the finish is not conductive, the effect of the conducting fiber in the system will be void.

The device is a laboratory tool. Appendix C carries a suggestion for equipment and procedure which may be used for "on-the-individual" type tests. This may overcome some of the aberrations noted in this type of test due to the inability to reproduce such conditions.

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APPENDIX A

Items in wet-cold uniform

1. Upper body

a. Undershirt, man's 50% cotton, 50% wool, full length sleeve, natural.

b. Shirt, man's, wool/nylon, 16 oz. wt., OG QM shade 108.

c. Suspenders, trousers, scissors type back, OG QM shade 107.

d. Liner, coat, man's natural, mohair frieze, fortisan, 16 oz. wt.

e. Coat, man's, single breasted body style w/o hood, cotton, wind-resistant sateen, water repellent treated, OG QM shade 107 (Field Jacket).

f. Vest, body armor, nylon.

2. Lower body

a. Drawers, men's, ankle length, 50% cotton, 50% wool, ribbed knit, unbleached.

b. Liner, trousers, arctic, mohair frieze, natural.

c. Trousers, men's, cotton, wind-resistant sateen, 9 oz. wt., OG QM shade 107, water-repellent treated.

3. Head

a. Cap, field, cotton pile, OG

b. Hood, winter, OG.

4. Hands

a. Mitten inserts, wool and nylon, 3 finger, OD.

b. Mitten set, arctic, cotton oxford gauntlet, OD, Type I.

5. Feet

a. Socks, men's, wool, OD shade 9, w/cushion sole, 13 inch leg length.

b. Boots, combat, man's, rubber, black, plain toe, chevron, cleated sole and heel.

APPENDIX B

Methods and devices for measuring static charge generated

1. Attraction of dirt particles

The presence of an electrostatic charge on a surface is manifested by the forces of attraction or repulsion which the surface exhibits. This is the principle here used. The fabric under test is rubbed over a second fabric and then held above a "standard" soil. The sample is visually inspected: the heavier the dirt pickup, the greater the static propensity. Two such soils have been described:

Soil 1 - 20% coal ash, 40% pigment grade carbon black, 40% bone charcoal individually ground to pass a 200-mesh screen

Soil 2 - 80% fine sifted Pocahontas ash, 20% carbon black

2. Device for testing static accumulating properties of textile fibers

(R. V. Ott of Celanese Corporation. This device is described in Patent 2,421,430 dated 3 June 1947, and is illustrated in Figure 14.)

The static charge is generated by causing the sample fabric or fibers to be rubbed by a rotating disk. By pressing the cup (A) downward, a fabric is placed within it. When the counter weight (W) is released, it pushes the cup (A) and sample in it up against the frictioning and collector plate (B). The motor is then turned on for a number of revolutions or a given length of time. After it is stopped, the cup (A) is depressed and the key (K) made to touch the collector plate (B). Touching the collector plate (B) with the key (K) charges the condenser (C). Closing switch (D) causes a change in the potential of plate (E). A change in the plate potential alters the current flow in the grid circuit. This change in grid current is a measure of the charge generated.

The inventor states that the functioning disk may be made of different substances. It would appear that these different substances must of necessity be conductors, otherwise the contact key would discharge only a very small portion of the disk.

3. Beaker and electrostatic voltmeter

(D. J. Lehmicke, Rayon Department, E. I. duPont de Nemours & Company. This arrangement is described in the American Dyestuff Reporter, 28 Nov. 1949)

A charge is developed on a skein of fibers by manipulating the skein while wearing a synthetic rubber glove. The skein is then dropped into an aluminum beaker attached to the high end of an electrostatic voltmeter 0-5000V and the indicated voltage recorded as a measure of static buildup. All tests are performed by the same person.

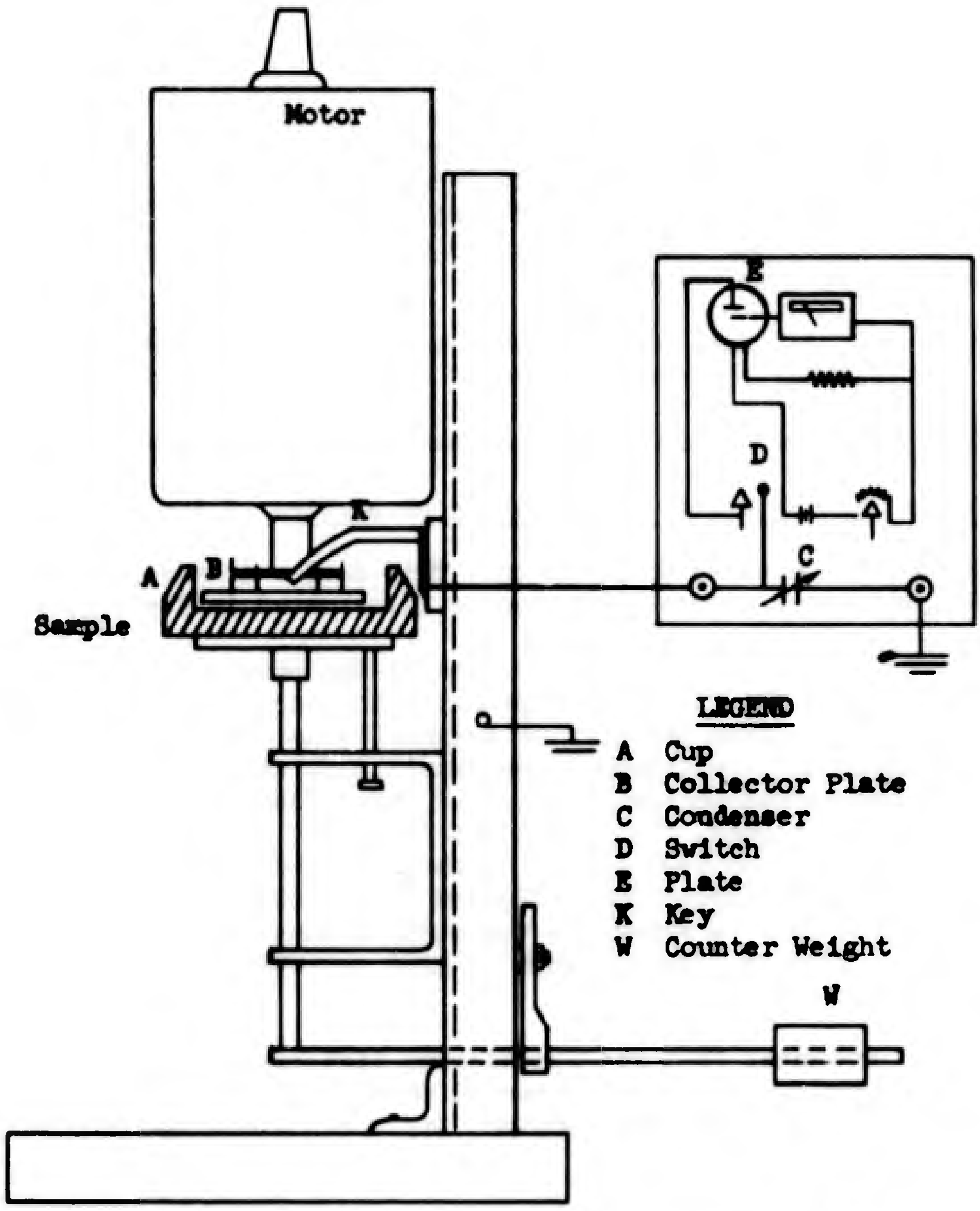


Figure 14 Ott Device For Testing Static Accumulating Properties of Textile Fibers

4. c^{1}= Method·c modified

A modification of this has been developed by Chemical Research Laboratories of General Aniline & Film Corp.

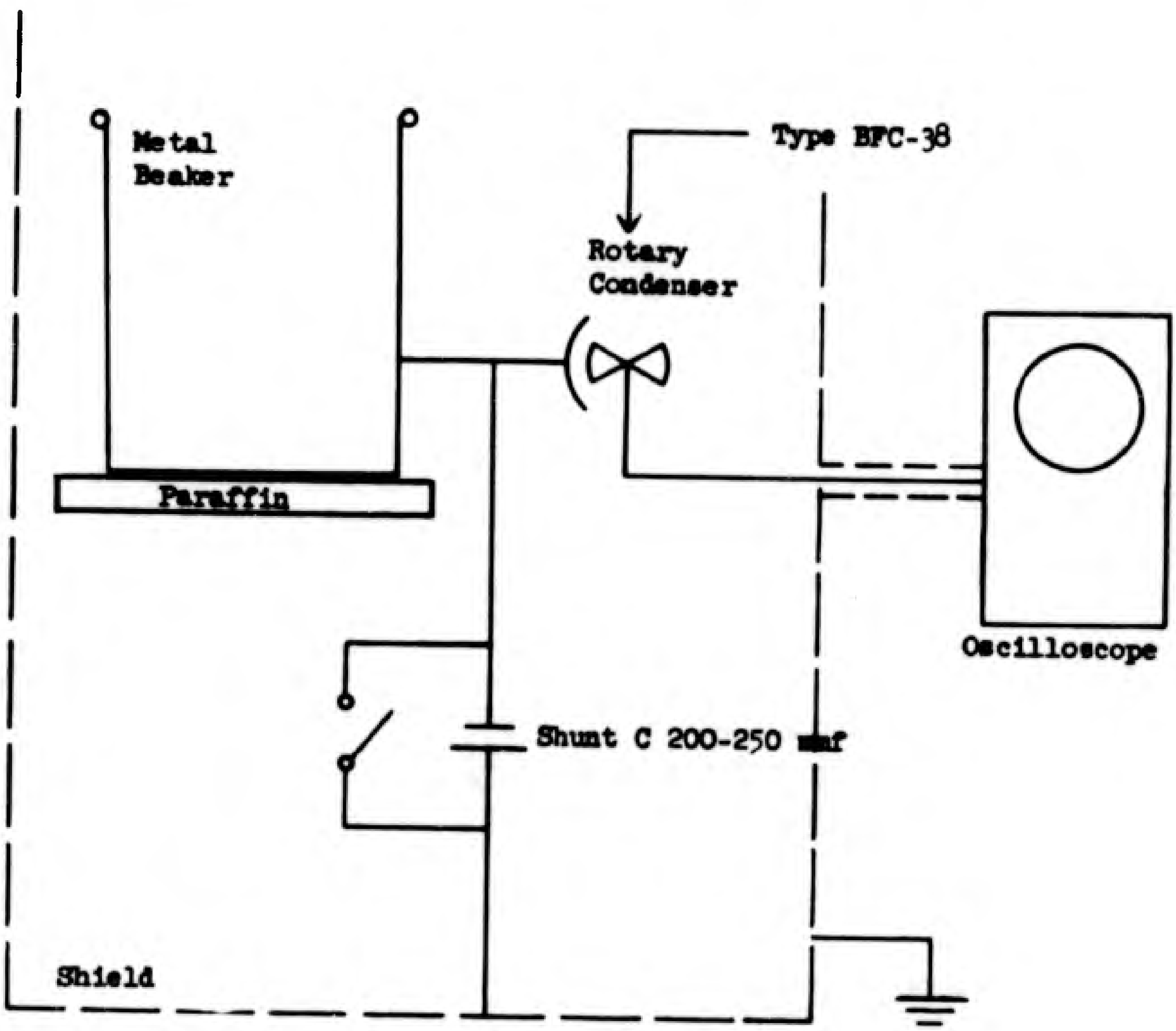


Figure 15 Modification of Lehmicke Device

To evaluate a fabric, a 6" x 6" square of cloth is squeezed vigorously in the hand, wearing a Neoprene glove, and immediately tossed into the metal beaker. This induces an equal and opposite charge on the beaker and in so doing, charges the rotary condenser to which the beaker is attached. The rotary condenser (3000 rpm) in turn induces an alternating potential on the oscilloscope. The amplitude of the resultant wave is a measure of the charge on the fabric. The results are reported in volts. The second condenser is used to scale down the voltages obtained. The gloves are washed in acetone before reuse.

Attention is directed toward the manual method used to develop the charge.

5. <u>The static propensity meter</u>

(Hayek & Chromey, Jackson Laboratories, E. I. duPont deNemours & Company. This instrument is described in American Dyestuff Reporter, 5 March 1951.)

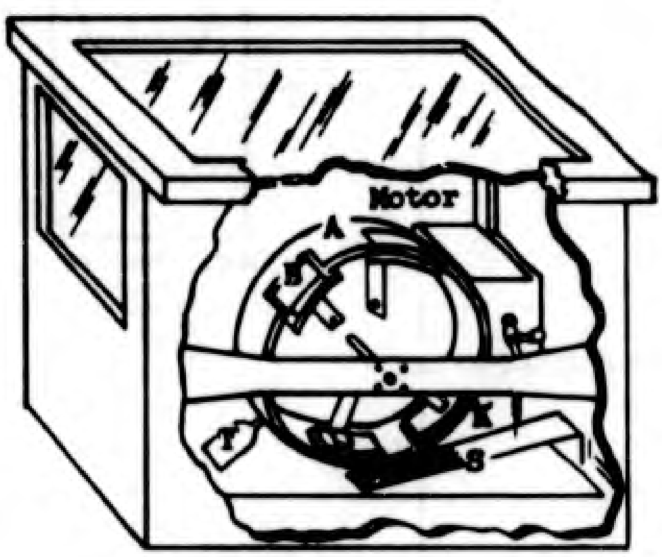


Figure 16 Hayek & Chromey Static Propensity Meter

In this device, a motor turns an aluminum wheel (A) at 300 rpm. There are six removable portions on the wheel 1-5/8" x 1½". These sections (B) are held in place by spring clamps and are designed to hold the fabric which is being tested. When the wheel (A) spins, it is made to rub against a second substance mounted on a brass strip (S). The pressure between the wheel and the strip is controlled by a spring (K). With the wheel in motion and rubbing against the second substance, a static charge is developed on the sample. Since the pieces are mounted intermittently along the wheel, an alternating potential is set up on the external grid of a 6 J 7 tube (T). The magnitude of change in plate current is a measure of the charge on the fabric.

If the rubbing is stopped but the wheel kept in motion, the rate at which the electrostatic charge leaves the fabric may be observed. The charge is dissipated to ground through the metal wheel.

It is in this manner that the device has been used in the Quartermaster laboratory.

6. The static modulator

(J. W. Ballou, Textile Fibers Department, E. I. duPont deNemours Company. This device is described in the Textile Research Journal, February 1954.)

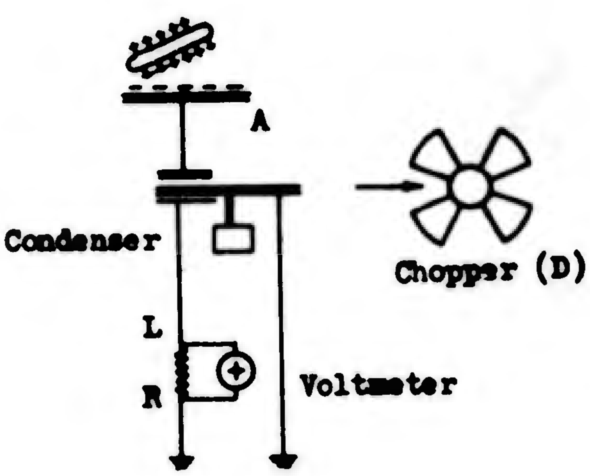


Figure 17 Ballou Static Modulator

A sample of electrified fabric is brought near the insulated top detector plate (A). A charge is induced on the plate (A) and a field set up in the condenser (C). The chopper (D) interrupts this field and in so doing produces an alternating current in the ground lead (L) which is measured with a vacuum tube voltmeter*(V). This voltmeter measures the potential drop through the resistor (R). The voltmeter reading indicates the relative magnitude of the charge on the fabric. This reading will change with the proximity of the charged fabric to the collector plate, because changing this distance will vary the induced charge.

*A vacuum tube voltmeter is a rectifier in which the input voltage causes a change in plate current. The d.c. plate current increases as the alternating current excitation of the grid increases. It is because of this, then, that a chopper is used in this arrangement, i.e., this type voltmeter requires an a.c. excitation for its operation.

7. e [1] Method e modified

A modifica'·'on of this arrangement has been made by the Rohm & Haas laboratory. A [illegible] hanical method of generating the static charge was added.

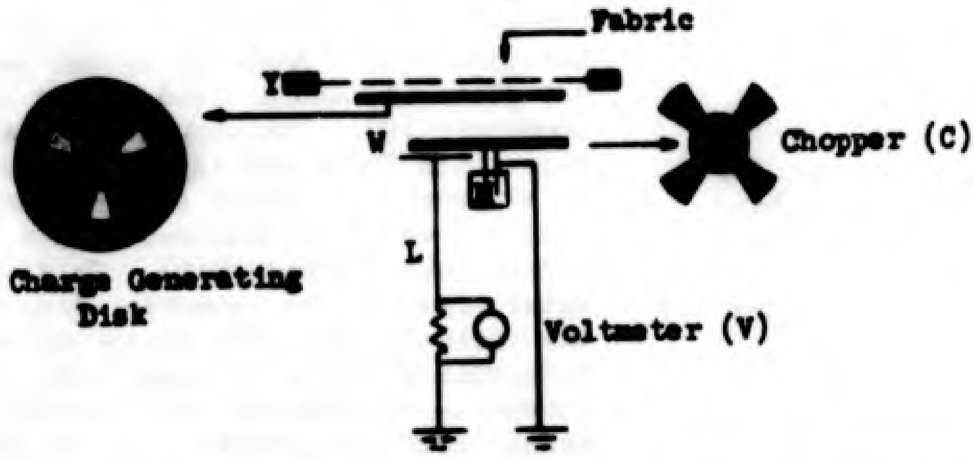


Figure 18 Rohm & Haas Modification of Ballou Static Modulator

To generate the static charge, a second aluminum chopper (Y) similar to that in the modulator (condenser) previously described is located above the first chopper and the detector plate components are removed. The fabric is mounted above the second chopper. When this second chopper turns, it alternately rubs the fabric and exposes it. When it is exposed, the charged fabric produces a field above the plate (W). This field is interrupted by the lower chopper and the a.c. current again set up in the ground lead (L). The range of potentials measured with this arrangement is as high as 14,000 volts on untreated fabric, as low as 8 volts on treated fabric. These voltages serve to illustrate the comparison range available.

8. The fabric potential meter

(H. T. McLean, General Engineering Laboratory, General Electric Company.) This device, (Figure 19) is described in the American Dyestuff Reporter of 15 July 1955.

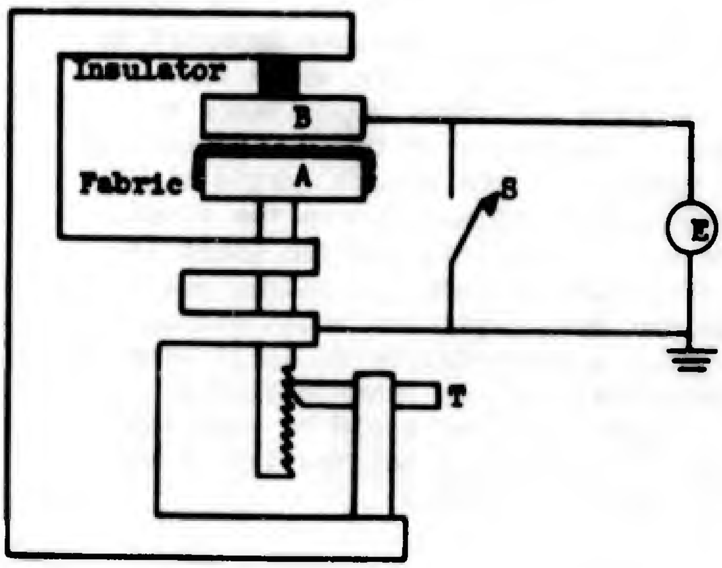


Figure 19 McLean Fabric Potential Meter

A fabric is mounted on the lower grounded electrode (A) and rubbed by hand with a second substance. The lower electrode (A) is then raised so that the fabric comes in contact with the upper electrode (B) with the switch (S) closed (that is, the upper electrode is at ground potential). The upper electrode (B) is then disconnected from ground and connected to an electrometer (E). The lower permanently grounded electrode (A) together with the fabric is now caused to move to a set distance from the upper one by tripping the trigger (T). The voltage registered is characteristic of the "electrostatic potential produced on the cloth."

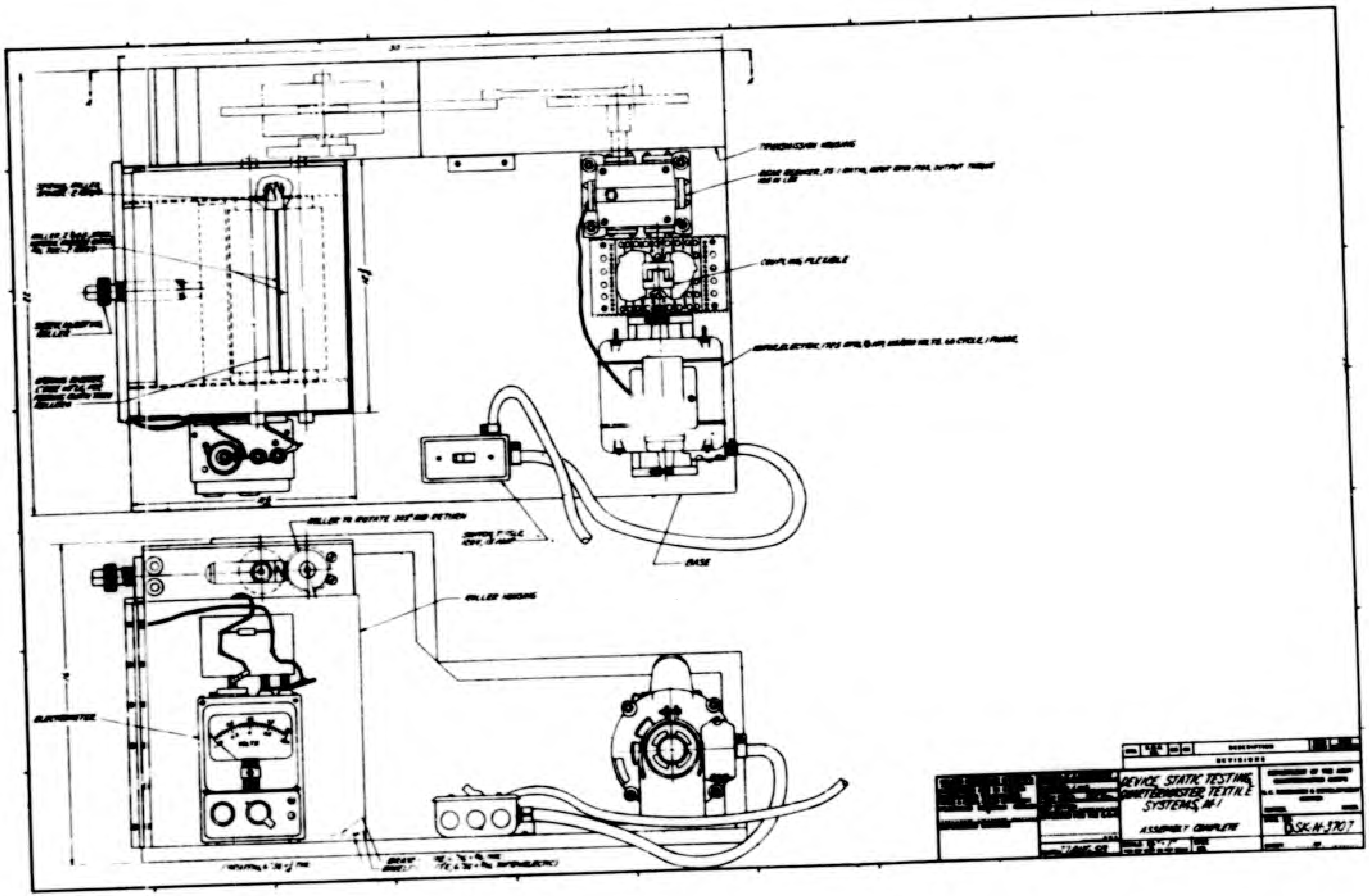
When the charged fabric is brought to the momentarily-grounded upper electrode, an opposite charge is induced on the electrode. It is this charge that produces the indicated potential and as such the indicated potential would be of a sign opposite to that of the fabric.

The time required to make the indicated manipulations will determine the extent to which the fabric is discharged before measurement is made. This would be more noticeable as the conductivity of the surface increases, that is, the error would be much more relevant when investigating treated fabrics.

APPENDIX C

A possible direct method of evaluating static electricity

It has been suggested that a direct method of evaluation should employ something similar in principle to the idea of the copper man, that is, to set up a dummy, clothe it with the fabrics of interest, and measure the potentials developed on the dummy as a result of motions imparted to it. Such an arrangement might employ a dummy or cylinder whose surface conductivity would approach that of the skin and whose capacitance to ground would be 200 micro-micro farads. One fabric of the combination in question would be draped around this cylinder. The second fabric might be mounted on the inside of a second cylinder which encloses the first. If then the inner were made to rotate in an eccentric fashion (that is, intermittently touching the wall of the outer cylinder),a charge would be generated. After an allotted time the outer cylinder would spring open, away from the inner. Voltage would be recorded by an electrostatic voltmeter connected to the conductive surface of the inner cylinder. In addition, the path to ground from the inner cylinder could be such that different materials could be inserted, thus enabling the testing of effectiveness of various footwear and flooring materials.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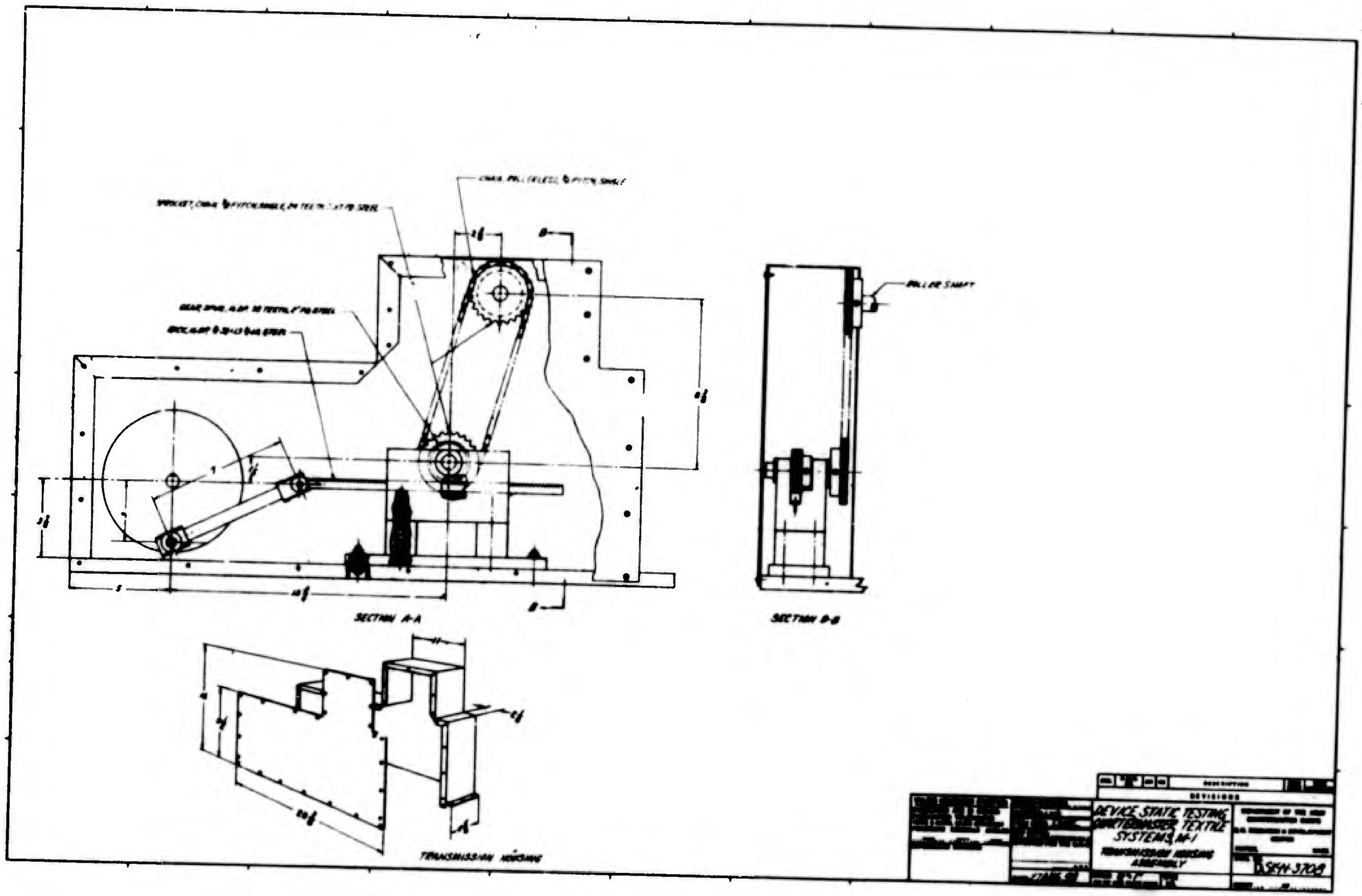

CHAIN, ROLLERLESS, PITCH, SINGLE
SPROCKET, CHAIN, PITCH SINGLE, 24 TEETH, STEEL
GEAR, SPUR, 38 TEETH, STEEL
SECTION A-A
SECTION B-B
ROLLER SHAFT
TRANSMISSION HOUSING
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