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Electrostatic Properties of the Army Combat Soldier Ensemble Garments

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***Combatant Protection and Nutrition Branch**

#Maritime Platforms Division

Aeronautical and Maritime Research Laboratory

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ABSTRACT

The electrostatic properties of the combat ensemble worn by Australian soldiers have been assessed. The resistance-to-ground, capacitance-to-ground, peak potential, peak energy and decay times were measured for a subject wearing various garment combinations. It was found that under favourable conditions a subject wearing the garments can generate sufficient energy to initiate electro-explosive devices, damage electronic devices and ignite fuel/air mixtures. However the threat level is dependent on the operational scenario and a threat analysis is required to determine the hazard for any given situation.

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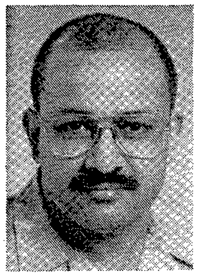
Executive Summary

Army personnel are sometimes required to handle electrically-initiated explosive devices that may be sensitive to electrostatic discharge. They can also be required to perform operations in the presence of explosive fuel/air mixtures. As modernisation of the Army proceeds, advanced electronics will become an accepted part of the combat soldier's basic equipment. These electronics could also be susceptible to electrostatic discharge. Little information is currently available on the electrostatic properties of the garments and webbing worn by the Australian combat soldier. To overcome this deficiency MAT-A tasked DSTO to investigate the electrostatic properties of clothing and carriage equipment worn by the Australian combat soldier.

Garments worn either individually or as part of an ensemble were assessed. An electrostatic charge was generated by rubbing the garments against a wide variety of commonly encountered surfaces. The peak potential on the subject and the half time for potential decay were measured. The resistance-to-ground and the capacitance-to-ground of the subject were also measured and the peak energy was calculated. The peak potential and energy values offer an indication of the hazard arising from a particular garment and footwear combination while the half time is the time required for the potential to decrease to half the peak value. It was discovered that the peak potential is unaffected by the inner garments or by garments worn under the pack whereas garments worn under the webbing influence the peak potential. There was no consistent difference in the peak energies when washed coat/trousers combinations were compared with their as-received counterparts.

The longest observed half time during the charging experiments was 1.1 s and the longest half time measured for a stationary subject was 1.5 s. The garments are capable of generating high peak energies (a maximum energy of 10662 μJ was observed). The garments when worn with the footwear samples can generate sufficient electrostatic charge to damage some electronic devices, to initiate some electro-explosive devices and to ignite fuel/air mixtures. A more specific analysis is required to determine whether a hazard exists in a particular situation. The substitution of antistatic footwear for the in-service khaki combat boot, however, reduced the maximum peak energy from 10662 μJ to 31 μJ. This is only slightly higher than the no-fire threshold sensitivity to personnel electrostatic discharge of an M52A3B1 primer. Substituting antistatic footwear for the in-service combat boot was, therefore, an efficient way to reduce the electrostatic hazard.

Authors



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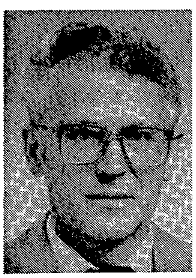
Horace Billon graduated from the Royal Melbourne Institute of Technology with a B.Sc. in Applied Physics. He also has a Graduate Diploma in Mathematical Methods from the Royal Melbourne Institute of Technology. After working in the RAAF Quality Assurance Laboratories at Highett he joined AMRL in 1986. He works in the Combatant Protection and Nutrition Branch and his primary areas of interest are explosives rheology, electrostatics and ballistic protection.



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Gunars Bajinskis joined AMRL in 1961 and was responsible for electrical evaluation of components and materials in the Type Approval Section. In 1967 he was requested to set up an electrostatics investigations unit to serve Defence and industry. Since then his work has covered a wide range of electrostatic topics in manufacturing, clothing, explosives safety, munitions handling and related accident investigations. He has also investigated sealant problems in the fuel tanks of F-111 aircraft and played a major part in the local development and manufacture of new high power HF antennas for the Navy. His current work as Senior Technical Officer involves electrostatic consultancy to the Services and to Australian Defence Industries.

Contents

1. Introduction

Army personnel are sometimes required to handle devices that are sensitive to electrostatic discharge. Such devices include electro-explosive devices (EEDs) that are used for the initiation of ammunition and missiles. The expected incorporation of electronic devices such as closed-circuit television (CCTV), head-up displays and computers into the soldier's equipment might result in further susceptibility to electrostatic discharge. In addition, Army personnel might be required to perform operations in the presence of explosive fuel/air mixtures [1]. The Australian Army is concerned by such hazards and tasked the Defence Science and Technology Organisation (DSTO) to investigate the electrostatic suitability of garments and carriage equipment used by combat soldiers.

The aims of this paper are to:

(1) Determine the propensity of the combat soldier ensemble garments to generate an electrostatic charge when contacted by a wide range of commonly encountered surfaces.

(2) Quantify the hazard by measuring the maximum electrostatic energy level generated by personnel wearing the garments and comparing this level with the previously measured electrostatic sensitivities of electro-explosive devices, the damage levels of electronic devices and the ignition energy of fuel/air mixtures.

(3) Measure the time required for the electrostatic potential to decay to one half of its peak value. This time value will be used to assist the evaluation in (2).

2. Experimental

2.1 Garment Samples

A range of garments, footwear and equipment was obtained for test purposes. A list, describing the submitted items, is presented in Table 1. This list includes samples which were not submitted by the Army but which had previously been in the possession of AMRL. To aid in identification an AMRL code was assigned to each item.

Table 1: Test Samples

Sample	Description	AMRL ID
Coat, Camouflage	Size 115R. AGCF, Victoria, 1988. 8415-66.130.0035.	CES1
Coat, Man's, Flyers, Twill	Size 100L. ADI, Victoria, 1995. Cotton. FR(1) treated. 8415-66-128-7174.	CES2
Coat, Man's, Flyers, Twill	Size 100L. ADI, Victoria, 1995. Cotton. FR treated. Washed 8415-66-128-7174	CES3
Coat, Man's, Armoured Fighting Vehicle	Size 95L. ADA, Victoria, 1996. Cotton. 8415-66-128-7214	CES4
Coat, Man's, Armoured Fighting Vehicle	Size 95L. ADA, Victoria, 1996. Cotton. Washed. 8415-66-128-7214	CES5
Coat, Camouflage Pattern, Oxford	Size 92L. ADI, Victoria, 1995. Polyester/Cotton 50/50. 8415-66-130-0037	CES6
Coat, Camouflage Pattern, Oxford	Size 92L. ADI, Victoria, 1995. Polyester/Cotton 50/50. Washed. 8415-66-130-0037	CES7
Trousers, Camouflage	Size 71/85L. 8415-66.130.0053	CETR1
Trousers, Camouflage, Armoured	Size 90L. ADA, Victoria, 1996. Cotton. 8415-66-128-7196	CETR2

Sample	Description	AMRL ID
Trousers, Camouflage, Armoured	Size 90L. ADA, Victoria, 1996. Cotton. Washed. 8415-66-128-7196	CETR3
Trousers, Camouflage, Twill	Size 90L. ADI, Victoria, 1992. Polyester/cotton 50/50. 8415-66-134-8917	CETR4
Trousers, Camouflage, Twill	Size 90L. ADI, Victoria, 1992. Polyester/cotton 50/50. Washed 8415-66-134-8917	CETR5
Trousers, Flyers	Size 90L. ADA, Victoria, 1996. Cotton. FR treated. 8415-66-128-7157	CETR6
Trousers, Flyers	Size 90L. ADA, Victoria, 1996. Cotton. FR treated. Washed 8415-66-128-7157	CETR7
Sweater, Khaki, DPCU	Size 95-105R. Elegant Knitting Company, Penrith, NSW, 1991. Wool/Nylon 80/20.	CESW1
Liner Vest DPCU	7-94. Inner: Nylon; Outer: Polyester filled. 8415-66-138-9416	CEJ1
Jacket Wet Weather	Size XSM (75 cm). Equipage Pty. Ltd., NSW 1993. 8405-66-128-2428	CEJ2
Hat, Camouflage Pattern	Size 63. AGCF, Victoria, 1988. 8415-66.129.9995	CEH1
Boots, Khaki.	Size 10. Fitting H. Oliver & Stevens.	CEB1

Sample	Description	AMRL ID
Boots, Khaki.	Size 11. Fitting H. Highmark.	CEB2
Shoes, Antistatic	"Statsafe". Purnell Shoe Company.	ASB1
Socks	Nylon/Wool/Cotton/ Elastomer etc. 24.04/40.91/34.83/0.22	CESK1
Socks	Nylon/Wool/Cotton/ Elastomer etc. 27.1/24.8/42.8/5.3	CESK2
Belt Individual DPP	WVC 6/91. 8465-66-128-3863	CEBL1
Pad Belt DPP	Size 95 cm. Cantas 4/92. 8465-66-132-6864	CEBL2
Field Pack Canvas	Outgear. 6 August 1991. 8465-66-130-1283	CEP1
Field Pack Patrol	Outgear. Nov. 1993. 8465-66-132-6859.	CEP2
Field Pack Small Com.	8465-66-130-1284	CEP3
Pouch Ammo. Minimi	SOS. 8-91. 8465-66-132-6860	CEPA1
Pouch Ammo. Steyr	July 1991. 8465-66-132-6861	CEPA2
Pouch Ammo. Minimi	Cantas 2/93. 8465-66-132-6860	CEPA3
Pouch Ammo. Steyr	3/93. 8465-66-132-6861	CEPA4
Canteen	Nylex. 1990. 8465-66-086-8349	CEC1

Sample	Description	AMRL ID
Canteen	ACMIL 1981. 8465-66-086-8349	CEC2
Cover, Canteen, Water	Robco products. August 1995. 8465-66-130-1287.	CECC1
Cover, Canteen, Water	Robco products. August 1995. 8465-66-130-1287.	CECC2

(1) FR: Flame Retardant.

2.2 Apparatus

2.2.1 pH Determination and Washing of Garments

A Leeds and Northrup 7411 pH/mV meter and Burroughs Wellcome and Co. pH 4 and pH 7 buffer solution tablets were used for measuring the pH of the fabric specimens. Fabric samples were extracted under reflux. Clothing samples were subjected to a standard wash with a 50 litre Cubex International Shrinkage Testing machine, Mk II, manufactured by Floataire Ltd., UK.

2.2.2 Electrostatic Measurements

Resistance-to-ground was measured with a Monroe Electronics ME 278 picoammeter and capacitance-to-ground was measured with a General Radio Company 1650-A impedance bridge. The half time was also measured independently with a Rothschild R-1020 electrostatic voltmeter and a Hewlett-Packard HP54111D storage oscilloscope. The electrostatic potential was measured with the R-1020 voltmeter and the oscilloscope. Resistance variation with time was measured with the picoammeter and a strip chart recorder.

Samples were discharged before testing by means of a Simco Aerojet XC ionising air blower. Testing was conducted in an environmental chamber where the humidity was controlled by a Munters M-120 dehumidifier and the temperature was controlled by a Mitsubishi Electric air conditioner.

Wall-mounted panels were used to simulate a wide range of surfaces that are encountered in daily activities. In order to provide a consistent test configuration, the frames of the panels were electrically earthed during the tests. The panels were of the following types:

(a) Foam covered with vinyl

(b) Untreated plywood

(c) Metal (aluminium)

(d) Plywood covered with glass

The vinyl covered foam panel simulates the electrostatic charging that occurs when a subject rises from the seat of a vehicle [2].

2.3 Experimental Method

2.3.1 pH Determination of Garment Samples

The pH values of garment samples were determined before washing, since, according to Method A16 of DEF(AUST) 5037 [3], washing is restricted to garment samples with pH values between 4 and 9. The pH was determined according to method B2 of [3]. The pH meter was calibrated using standards derived from the buffer solution tablets.

2.3.2 Washing of Garment Samples

The garment samples were washed in accordance with method A16 of reference [3]. The pH apparatus was used to test the suitability of tap water and distilled water for use in the preparation of washing solutions.

2.3.3 Determination of the Fibre Content of the Socks

Since no identification numbers were available for the socks their compositions were determined so that test results obtained with them could be identified. The socks were visually examined and sample fibres were taken from the different components and examined under the microscope. Fibre identification was accomplished by comparison with the photomicrographs in reference [4]. The different varieties of fibres were then subjected to burn tests to verify the results of the microscope examination. These burn tests established a number of possible categories to which the individual fibre types might belong. A more detailed analysis was then conducted by dissolving the fibres in a range of solvents [4].

2.3.4 The Environmental Chamber

Resistance, capacitance and electrostatic potential measurements were conducted on a human subject in the environmental chamber where the air temperature was maintained at 20 ± 2°C and the relative humidity was maintained at 20 ± 2 %. A relative humidity of 20 percent may be considered most favourable for the generation of triboelectric charge [5]. Garments, footwear and combat ensemble equipment samples were conditioned in the environmental chamber for at least 24 hours prior to testing.

2.3.5 Resistance Measurements

Body-to-ground resistance measurements were conducted, at an applied potential of 500 V, on a subject standing on an earthed metal plate. The maximum current through the subject was restricted to a value of 2 mA by a current limiter in the picoammeter. The picoammeter was calibrated by means of standard resistors before each series of tests.

2.3.6 Capacitance Measurements

The body-to-ground capacitance of a subject standing on an earthed metal plate was measured. The impedance bridge was calibrated, using standard capacitors, before each series of tests. Capacitance values were measured for the subject in a variety of configurations while the subject separated from the panels. The capacitance, C at the peak potential position and the peak potential, V were used to calculate the peak energy, E using:

$$E = \tfrac{1}{2} C V^2 \tag{1}$$

2.3.7 Decay Time Tests

The time required for the potential on the subject to decay to one half of a nominated value (the half time) was also measured. The half time was measured with the R-1020 voltmeter which possesses an internal voltage source. The output from the voltmeter was recorded on the HP54111D storage oscilloscope as a potential-time plot. The subject used the voltage source to charge himself to an initial potential of 500 V and the time required for the potential to decay to 250 V was measured from the oscilloscope trace.

From a knowledge of the subject's resistance-to-ground, R, and capacitance-to-ground, C, it is possible to calculate the half time, $t_{1/2}$ from equation (2) [6]:

$$t_{1/2} = 0.7RC \tag{2}$$

The calculated and measured half-times presented in this paper serve as an indication of the time during which the electrostatic energy stored on the subject remains hazardous. It should be emphasized that these half-times are not an indication of the duration of the static discharge that can occur in the event that the charged subject either contacts, or is in proximity to, an earthed conductor.

2.3.8 Electrostatic Charging Tests

Electrostatic charging tests were performed with the aid of the electrostatic voltmeter for the human subject clad in a variety of garments and while the subject was carrying the submitted equipment samples. In one series of tests the subject rubbed his back against the panel and separated quickly from the panel. In another series of tests the subject stood approximately 0.5 m from the panel and, while wearing the hat sample, rubbed his head against the panel and then rose to his full height. The subject carried out these activities while standing or walking on an earthed metal sheet. A continuous reading of the electrostatic body potential to earth of the subject was obtained as a function of time in the form of a trace on the oscilloscope. The peak potential and the time required for the potential to decay to half its peak value were measured. The capacitances measured in Sections 3.4.3 and 3.4.4, together with the peak potential values, were used to calculate the peak energy [7].

The subject used for these experiments is, on the basis of past experience, expected to generate values of resistance, capacitance and potential that are typical of values encountered in practice and variation in these measured values caused by use of different subjects is not expected to be large. The human body is a conductor [8] and, because of this, every point on the body possesses the same potential value. For these charging experiments the potential was measured with a hand-held electrode. However, because of the equipotential nature of the human body, the potential measured at any other location on the body would have had the same value.

2.3.9 Analysis of Repeated Electrostatic Charging Tests

It was sometimes necessary to repeat charging tests a number of times. The appropriate method for comparing the results of such tests is the Student t-distribution. This distribution was used with a significance level of 0.05 to test for differences in the population means [9].

3. Results and Discussion

3.1 pH Determination of Garment Samples

The pH values for all the garment samples that were chosen for washing lay between 4 and 9. This means that washing of the garment samples is permissible in accordance with DEF (AUST) 5037 method A16.

3.2 Washing of the Garment Samples

According to DEF (AUST) 5037 method A16 the pH of the washing solution must be 7.0 ± 0.2. pH tests revealed that either tap water or distilled water would make suitable washing solutions. For convenience the garments were washed in tap water.

3.3 Fibre Content Determination of the Socks

The fibre content of the socks was determined according to the procedure outlined in 2.3.3 and the results are detailed in Table 2.

Table 2: Fibre Content of the Socks

Sock Identification No.	CESK1	CESK2
Nylon Weight Percentage	24.04	27.1
Wool Weight Percentage	40.91	24.8
Cotton Weight Percentage	34.83	42.8
Elastomer and Other Weight Percentage	0.22	5.3

3.4 Resistance, Capacitance and Half time Measurements

3.4.1 The Variation of Resistance & Capacitance with Time for the Combat Ensemble Footwear

For meaningful measurements with the socks/footwear combinations it was necessary to determine whether the combinations would result in reproducible results. It was therefore necessary to determine whether the chosen socks/footwear combination would provide stable resistance-to-ground and capacitance-to-ground measurements. The subject wore the khaki boots, CEB1 and the high wool content socks, CESK1. The resistance test was conducted by using the analog output of the picoammeter together with the strip chart recorder. The resistance was measured at an applied potential of 500 V. It was found that the resistance changed from $9.1 \times 10^9\ \Omega$ to $7.8 \times 10^9\ \Omega$ over an interval of 20 minutes and that the resistance stabilised at the end of this interval.

The capacitance-to-ground was measured while the subject wore the combat ensemble boots CEB1 and the socks CESK1 and stood on an earthed metal sheet. The capacitance of the subject was monitored with the GRC bridge over a period of about 20 minutes. The capacitance varied between 127 pF and 130 pF over this period.

These results indicate that the variation in resistance and capacitance over a period of 20 minutes is 10 % and 2 %, respectively, and that the resistance and capacitance are therefore approximately constant over a time period that is typical of the time period during which experimentation takes place.

3.4.2 The Determination of the Socks/Footwear Combination with the Highest Resistance-to-Ground

The resistance-to-ground, capacitance-to-ground and half time values were determined for different socks/footwear combinations. This approach identified the socks/footwear combination with the worst electrostatic properties so that this combination could be used to provide a worst case in future tests with various garment combinations.

Table 3 details the resistance, capacitance and half time measurements for different footwear samples while the subject wore socks with the following composition: Nylon: 24.04 %, Wool: 40.91 %, Cotton: 34.83 %, Elastomer etc.: 0.22 % (High wool content sample). Table 4 details the same for the subject wearing socks with the following composition: Nylon: 27.1 %, Wool: 24.8 %, Cotton: 42.8 %, Elastomer: 5.3 % (Low wool content sample). All resistance measurements were conducted at an applied potential of 500 V. The half time for potential decay was measured for decay from an initial potential value of 500 V. The subject stood with both feet on earthed metal sheeting during the potential decay measurements. Test results for the antistatic footwear sample were included in Table 3 for comparison with future tests.

Table 3: Resistance, Capacitance and Half Time Measurements for the High Wool Content Socks

Footwear	Foot Down	Resistance (Ω)	Capacitance (pF)	RC *ln* 2 (s)	Measured Half Time(2) (s)
Boots, khaki Size 10.	Right	1.0×10^{10}	86	0.6	
Fitting H.	Left	1.1×10^{10}	87	0.7	1.4
Oliver & Stevens.	Both	7.0×10^{9}	112	0.6	

Footwear	Foot Down	Resistance (Ω)	Capacitance (pF)	RC *ln* 2 (s)	Measured Half Time(2) (s)
Boots, khaki Size 11.	Right	8.0×10^9	82	0.5	
Fitting H.	Left	9.0×10^9	84	0.6	1.2
Highmark.	Both	6.0×10^9	108	0.4	
Antistatic Footwear	Right	7.0×10^7	145	0.007	
ASB1	Left	4.0×10^7	137	0.003	Less than 0.03
	Both	3.5×10^7	208	0.005	

Table 4: Resistance, Capacitance and Half time Measurements for the Low Wool Content Socks

Footwear	Foot Down	Resistance (Ω)	Capacitance (pF)	RC *ln* 2 (s)	Measured Half Time(2) (s)
Boots, khaki Size 10.	Right	8.0×10^9	86	0.5	
Fitting H.	Left	8.0×10^9	88	0.5	1.4
Oliver & Stevens.	Both	6.0×10^9	110	0.5	
Boots, khaki Size 11.	Right	5.0×10^9	86	0.3	
Fitting H.	Left	6.0×10^9	84	0.3	1.5
Highmark.	Both	4.0×10^9	106	0.3	

(2) The charge decay measurements were conducted with both feet on the floor

By comparing results obtained for different feet some variation is observed in the resistance and capacitance values. The results in Table 3 and Table 4 indicate that resistance values can vary by as much as 50 % from one sample to another while the capacitance can vary by 5 %.

From Table 3 and Table 4 it is possible to identify the sock/footwear combination with the worst electrostatic characteristics. Although the difference is not great, the combination of the high wool content sock with the size 10 boot gives a slightly higher resistance and RC product than the other combinations. This footwear combination was therefore chosen for further testing with a variety of garments from the ensemble.

3.4.3 Capacitance Measurements of the Subject while Stepping away from the Wall-Mounted Panels

The subject rested his back against the wall-mounted panel and then stepped away. The potential on the subject was monitored during this process. It was found that the peak potential was attained when the subject's left foot was near the panel and the subject's right foot was raised at a distance of one step away from the panel. The body-to-ground capacitance of the subject was measured at this position and this capacitance value was used to calculate the peak energy. Table 5 presents the capacitance values measured at this peak potential position for various panels. During all the measurements the subject wore the high wool content socks together with the indicated footwear. The approximate error in the measured value of the capacitance is 5 %.

Table 5: The Capacitance Measured at the Peak Potential Position

Panel	Footwear	Capacitance (pF)
Vinyl/Foam	CEB1 (Boots, Khaki, Size 10)	117
Plywood	CEB1 (Boots, Khaki, Size 10)	113
Glass/Plywood	CEB1 (Boots, Khaki, Size 10)	119
Metal	CEB1 (Boots, Khaki, Size 10)	137
Vinyl/Foam	ASB1 ("Statsafe" Antistatic Footwear)	173

3.4.4 Capacitance Measurements for the Head Rubbing Tests

The subject wore garments CES6, CETR4, CESK1, CEB1 together with the submitted hat sample CEH1. The subject stood on an electrically earthed metal sheet at a distance of 0.5 m away from the earthed panel. The subject then rubbed his head against the panel and separated. The potential was monitored on the electrostatic voltmeter and the peak potential position occurred when the subject rose to full height away from the panel. The capacitance at the peak potential position, for various panels, is presented in Table 6. The approximate error in the measured value of the capacitance is 5 %.

Table 6: The Capacitance Measured at the Peak Potential Position for the Head Rubbing Tests

Panel	Capacitance (pF)
Vinyl/Foam	112
Plywood	119
Glass/Plywood	119
Metal	120

3.5 Electrostatic Charging Tests

3.5.1 Footwear

During the charging tests the subject wore the high wool content socks and the size 10 khaki boots since this footwear combination had previously been shown to possess the highest resistance-to-ground values (Section 3.4.2).

3.5.2 Charging Tests with the Coats and Trousers

The effect of different coat and trousers combinations on the electrostatic potential was investigated. These investigations were undertaken to provide data for later measurements of the effect of the inner and outer garments on the charging process. In order to obtain statistically meaningful results charging tests were repeated a number of times. The peak potential was measured during these tests and was used as a parameter for comparing results. Results were obtained for the metal panel and for the vinyl/foam panel.

Table 7: Charging Tests with Different Coat and Trouser Combinations. Metal Panel

Number of Samples	Garments	Potential Mean (kV)	Potential Variance ($[kV]^2$)
10	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	-0.5	2.2×10^{-2}
10	CES2 (Coat, FR treated Cotton) CETR6 (Trousers, FR Treated Cotton)	-0.5	2.3×10^{-3}
10	CES6 (Coat, Polyester/Cotton 50/50) CETR4 (Trousers, Polyester/Cotton 50/50)	-0.3	1.8×10^{-3}

When the t - test was applied to the data from Table 7 it was found that there was no difference in the behaviour of the cotton coat and trousers and the FR treated cotton coat and trousers when a subject charged himself by rubbing against the metal panel. There was however a significant difference in the behaviour of the cotton coat and trousers and the polyester/cotton coat and trousers when the subject charged himself against the metal panel.

Table 8: Charging Tests for Different Coat and Trouser Combinations. Vinyl/Foam Panel

Number of Samples	Garments	Potential Mean (kV)	Potential Variance ($[kV]^2$)
10	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	8.0	1.3

Number of Samples	Garments	Potential Mean (kV)	Potential Variance ([kV]^2)
10	CES2 (Coat, FR treated Cotton) CETR6 (Trousers, FR Treated Cotton)	10.5	0.4
10	CES6 (Coat, Polyester/Cotton 50/50) CETR4 (Trousers, Polyester/Cotton 50/50)	7.0	2.1

For charging with the vinyl/foam panel it was found that there was a difference in the behaviour of the cotton coat and trousers and the FR treated cotton coat and trousers. There was also a difference in the behaviour of the FR treated cotton coat and trousers and the polyester/cotton coat and trousers. However the t - test indicated that there was no significant difference between the mean potentials of the cotton coat and trousers and the polyester/cotton coat and trousers for the case of a subject rubbing against the vinyl/foam panel.

3.5.3 The Contribution of the Inner Garments to the Charging

It is essential to determine whether the inner garments have any effect on the amount of charge accumulated by the subject. If the inner garments make only a minimal contribution to the total charge then the number of measurements could be reduced since it would be unnecessary to perform measurements with different combinations of inner garments. In order to determine the contribution of the inner garments to the charging, experiments were conducted with a variety of inner garments and the same outer garments. The results in Table 9 represent charging tests conducted on the metal panel. The results in Table 9 where the subject wore the DPCU liner were analysed using the t-test and no difference was detected in the population means. The same analysis was conducted for the tests where the subject wore the wet weather jacket as the outer garment and again no difference was detected in the mean peak potential. This proves that the inner garments do not influence the charging process.

The results in Table 10 were obtained for triboelectric charging with the vinyl/foam panel. The t-test was applied to the results obtained for the DPCU sweater and the results indicated that there is no difference in the population means.
The same analysis was conducted on the results obtained when the DPCU liner was the outer garment and again the analysis indicated that there was no difference in the

population means. These analyses again show that the inner garments have no influence on the charging process.

Table 9: The Influence of the Inner Garments. Metal Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ($[kV]^2$)
10	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	4.9	0.28
10	CES2 (Coat, FR treated Cotton) CETR6 (Trousers, FR Treated Cotton)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	5.2	0.24
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	5.1	0.13
10	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	CEJ2 (Jacket, Wet Weather)	2.4	0.14
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ2 (Jacket, Wet Weather)	2.5	0.07

Table 10: The Influence of the Inner Garments. Vinyl/Foam Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ($[kV]^2$)
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20)	10.0	0.17
10	CES2 (Coat, FR treated Cotton) CETR6 (Trousers, FR Treated Cotton)	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20)	10.2	0.21
20	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	11.3	1.00
20	CES2 (Coat, FR treated Cotton) CETR6 (Trousers, FR Treated Cotton)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	10.4	0.94
20	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	10.8	1.2

The above results and analyses that were obtained for triboelectric charging with the metal and vinyl/foam panels indicate that the effect of the inner garments may be neglected during electrostatic charging tests.

3.5.4 The Contribution of the Outer Garments to the Charging Process

The influence of the outer garments on the charging process was determined by conducting tests where the same inner garments were worn but the outer garments were varied. Tests were performed with the metal panel and the vinyl/foam panel.

Analyses conducted on the results presented in Tables 11 and 12 indicated that the outer garments have a significant effect on the charging process.

Table 11: The Influence of the Outer Garments. Metal Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ([kV]^2)
10	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	4.9	0.28
10	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	CEJ2 (Jacket, Wet Weather)	2.4	0.14

Table 12: The Influence of the Outer Garments. Vinyl/Foam Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ([kV]^2)
20	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	10.8	1.2

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ($[kV]^2$)
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ2 (Jacket, Wet Weather)	6.4	0.19

3.5.5 The Contribution of the Webbing to the Charging Process

The webbing is the harness system consisting of the items listed in Table 13.

Table 13: Items in the Webbing

AMRL ID	Sample Description
CEC1	Canteen
CEC2	Canteen
CECC1	Cover, Canteen
CECC2	Cover, Canteen
CEP2	Field Pack Patrol
CEP3	Field Pack Small Com.
CEPA1	Pouch Ammo. Minimi
CEPA2	Pouch Ammo. Steyr

AMRL ID	Sample Description
CEPA3	Pouch Ammo. Minimi
CEPA4	Pouch Ammo. Steyr
CEBL1	Belt Individual DPP
CEBL2	Pad Belt DPP

The influence of the webbing when worn over a variety of clothing combinations was investigated. In practice it is likely that the webbing will be used for the storage of items. The webbing was therefore filled with garments and tests were performed to determine the influence of this on the charging process. The results in Table 14 that were obtained with the metal panel were analysed using the t-test and the results of this analysis indicated that the empty webbing had a significant effect on the charging when the webbing was worn over either the DPCU liner or the wet weather jacket. In either case the webbing reduced the magnitude of the peak potential. There was also a significant difference in the peak potential when the DPCU liner was worn under the webbing and when the wet weather jacket was worn under the webbing. This analysis indicated that the garments worn under the webbing affected the peak potential value obtained from tests during which the subject wore the webbing.

Table 14: The Influence of the Empty Webbing. Metal Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ([kV]^2)
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	5.1	0.13

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ($[kV]^2$)
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Webbing	2.0	0.47
10	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	CEJ2 (Jacket, Wet Weather)	2.4	0.14
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ2 (Jacket, Wet Weather) Empty Webbing	-0.5	3.4×10^{-2}

The results in Table 15 were obtained for charging with the vinyl/foam panel and were analysed by means of the t distribution. A comparison of the two results for the DPCU liner indicated that the empty webbing had little influence on the peak potential. However the same analysis of the results in Table 15 for the wet weather jacket indicated that the webbing had a significant influence on the peak potential.

A comparison of the two results in Table 15 that were obtained when the subject wore the webbing indicated that there is a difference in the means. This indicates that the garments worn under the webbing can influence the peak potential. The above discussion may be summarised as follows:

(a) The webbing contributes to the charging process

(b) The garments worn under the webbing influence the charging process.

Table 15: The Influence of the Empty Webbing. Vinyl/Foam Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ([kV]^2)
20	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	10.8	1.2
20	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Webbing	10.5	0.13
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ2 (Jacket, Wet Weather)	6.4	0.19
20	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ2 (Jacket, Wet Weather) Empty Webbing	8.1	0.51

When the webbing is used in the field, it is likely that it will be employed for storage of items. The results in Table 16 were obtained, using the vinyl/foam panel, to determine whether filling the webbing influences the charging process. The webbing was filled with garment samples and the peak potential obtained as before. It is evident from Table 16 that a higher peak potential is obtained for charging with the empty webbing than with the filled webbing. A statistical analysis indicates that this difference is significant. It may be concluded from these results that charging with the empty webbing represents a worst case. It is therefore unnecessary to conduct extensive tests with the filled webbing.

Table 16: The Influence of the Filled Webbing. Vinyl/Foam Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ($[kV]^2$)
20	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Webbing	10.5	0.13
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Filled Webbing(3)	8.2	0.17
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Filled Webbing(4)	9.3	0.58

(3) Webbing filled as follows: CEP2 filled with CEJ2 and CEP3 filled with CETR1 and CETR7.

(4) Webbing filled as follows: CEP2 filled with CES2 and CES3. CEP3 filled with CETR1 and CETR7.

3.5.6 The Influence of the Pack and Webbing when Worn Together

The webbing and pack comprise the following items: The field pack canvas, CEP1 together with the webbing items listed in Table 13. The contribution to charging from the pack (filled or unfilled) together with the webbing was investigated for the metal and vinyl/foam panels. A comparison of the two results presented in Table 17 (metal panel) where the empty pack and webbing was worn indicates that the garments worn under the pack and webbing have no influence on the charging process. A comparison of the results obtained when the subject wore the DPCU liner indicated that wearing the pack and webbing over the liner significantly decreased the potential mean. A similar result is evident when the pack and webbing are worn over the wet weather jacket.

Table 17: The Influence of the Empty Pack and Empty Webbing. Metal Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ($[kV]^2$)
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	5.1	0.13
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Pack and Empty Webbing	-1.3	7.1×10^{-3}
10	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	CEJ2 (Jacket, Wet Weather)	2.4	0.14
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ2 (Jacket, Wet Weather) Empty Pack and Empty Webbing	-1.4	1.2×10^{-2}

The results in Table 18 were obtained using the vinyl/foam panel and they indicate that the empty pack and webbing influence the peak potential when they are worn over the DPCU liner or the wet weather jacket. A comparison of the two results in Table 18 involving the pack and webbing indicate that the garments worn under the pack and webbing do not influence the peak potential. Therefore the results for the metal and the vinyl/foam panels may be summarised as follows: (a) The empty pack and webbing can influence the value of the peak potential. (b) The garments worn under the empty pack and webbing have no influence on the peak potential.

Table 18: The Influence of the Empty Pack and Empty Webbing. Vinyl/Foam Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ([kV]^2)
20	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	10.8	1.2
15	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Pack Empty Webbing	5.6	0.13
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ2 (Jacket, Wet Weather)	6.4	0.19
15	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ2 (Jacket, Wet Weather) Empty Pack Empty Webbing	5.9	0.19

The effect on the peak potential of filling the pack and webbing with various garment items was investigated and the results are presented in Table 19. A comparison of the results indicates that there is no difference in the peak potential values. However, statistical analysis indicated that the result of the comparison between the first two sets of results presented in Table 19 was only marginal and that filling the pack may lower the peak potential. Therefore these results indicate that a worst case is obtained if the pack and webbing are empty.

Table 19: The Influence of the Filled Pack and Webbing. Vinyl/Foam Panel

Number of Samples	Inner Garments	Outer Garments	Potential Mean (kV)	Potential Variance ([kV]^2)
15	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Pack Empty Webbing	5.6	0.13
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Filled(5) Pack Empty Webbing	5.2	0.42
10	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Filled(5) Pack Filled(6) Webbing	5.6	0.78

(5) Top of pack filled with: CETR6, CEJ2, CESW1. Bottom of pack filled with: CES1, CES5.

(6) Webbing filled as follows: CEP2 filled with CES2 and CES3. CEP3 filled with CETR1 and CETR7.

3.5.7 Charging Tests with Different Panels

The measurements presented in Sections 3.5.2 - 3.5.6 have established the conditions under which the garments and/or the pack and webbing influence the charging process. This information was used to design experiments so that the electrostatic properties of the combat ensemble garments could be assessed for a variety of combinations.

Table 20: Tests with the Vinyl/Foam Panel.

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
None	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	10.3	6206	0.8
None	CES5 (Coat, Cotton, Washed) CETR3 (Trousers, Cotton, Washed)	7.9	3651	0.8
None	CES2 (Coat, FR treated Cotton) CETR6 (Trousers, FR Treated Cotton)	11.9	8284	0.6
None	CES3 (Coat, FR Treated Cotton, Washed) CETR7 (Trousers, FR Treated Cotton, Washed)	8.7	4428	0.6
None	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	10.3	6206	0.6

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
None	CES7 (Coat, Polyester/ Cotton 50/50, Washed) CETR5 (Trousers, Polyester/ Cotton 50/50, Washed)	10.3	6206	0.8
CES4, CETR2	CESW1 (Sweater, Khaki, DPCU Wool/nylon 80/20)	11.9	8284	0.6
CES4, CETR2	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	13.5	10662	0.6
CES4, CETR2	CEJ2 (Jacket, Wet Weather)	9.2	4951	0.8
CES4, CETR2	Empty Webbing	8.7	4428	0.6
CES5, CETR3	Empty Webbing	9.5	5280	0.6
CES2, CETR6	Empty Webbing	10.3	6206	0.6
CES3, CETR7	Empty Webbing	10.3	6206	0.6
CES6, CETR4	Empty Webbing	7.9	3651	0.6
CES6, CETR4, CEH1	Empty Webbing	7.1	2949	0.6
CES7, CETR5	Empty Webbing	8.7	4428	0.5

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
CES2, CETR6	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20) Empty Webbing	10.3	6206	0.6
CES2, CETR6	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Webbing	11.9	8284	0.6
CES2, CETR6	CEJ2 (Jacket, Wet Weather) Empty Webbing	9.5	5280	0.5
CES6, CETR4	Empty Webbing Empty Pack	5.7	1901	0.6
CES6, CETR4, CEH1	Empty Webbing Empty Pack	8.7	4428	0.5
CES6, CETR4	CEJ2 (Jacket, Wet Weather) Empty Webbing Empty Pack	6.3	2322	0.5

The highest peak energy observed during tests with the vinyl/foam panel was 10662 μJ at a peak potential of 13.5 kV and this value was attained while the subject wore the liner vest DPCU. The maximum half time was 0.8 s. From Table 20 it may be seen that most of the washed coat and trousers produce a lower peak energy than their as-received counterparts. However, this difference in energy is less than an order of magnitude. The peak energies generated by the different coat and trousers combinations when worn together with the webbing do not differ by an order of magnitude. This is also true when either the sweater, liner or the jacket was worn under the webbing. Moreover the results for the webbing and pack do not differ greatly (in magnitude).

Table 21: Tests with the Glass/Plywood Panel

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
None	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	-0.4	10	0.6
None	CES5 (Coat, Cotton, Washed) CETR3 (Trousers, Cotton, Washed)	-1.1	72	0.9
None	CES2 (Coat, FR Treated Cotton) CETR6 (Trousers, FR Treated Cotton)	-0.6	21	0.6
None	CES3 (Coat, FR Treated Cotton, Washed) CETR7 (Trousers, FR Treated Cotton, Washed)	-1.1	72	0.9
None	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	-0.9	48	0.6

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
None	CES7 (Coat, Polyester/ Cotton 50/50, Washed) CETR5 (Trousers, Polyester/ Cotton 50/50, Washed)	-1.4	117	0.8
CES6, CETR4	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20)	-1.2	86	0.6
CES6, CETR4	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	-1.0	60	0.5
CES6, CETR4	CEJ2 (Jacket, Wet Weather)	-1.4	117	0.8
CES4, CETR2	Empty Webbing	-2.6	402	0.6
CES5, CETR3	Empty Webbing	-2.4	343	0.5
CES2, CETR6	Empty Webbing	-2.2	288	0.8
CES3, CETR7	Empty Webbing	-3.2	609	0.6
CES6, CETR4	Empty Webbing	-2.0	238	0.8
CES6, CETR4, CEH1	Empty Webbing	-2.6	402	0.8
CES7, CETR5	Empty Webbing	-2.4	343	0.6

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
CES2, CETR6	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20) Empty Webbing	-3.4	688	0.8
CES2, CETR6	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Webbing	-3.7	815	0.8
CES2, CETR6	CEJ2 (Jacket, Wet Weather) Empty Webbing	-2.6	402	0.8
CES6, CETR4	Empty Webbing Empty Pack	-1.4	117	0.5
CES6, CETR4, CEH1	Empty Webbing Empty Pack	-2.4	343	0.5

The largest peak energy value observed during tests with the glass/plywood panel was 815 μJ at a peak potential of -3.7 kV and this energy value was obtained when the subject wore the liner and webbing. The longest observed half time value was 0.9 s. The results in Table 21 indicate that the washed coat/trousers combinations charge to a higher energy than the as-received combinations. However, as with the vinyl/foam panel, the difference in magnitude between the peak potential of the washed and as-received coat/trousers combinations is not great. The peak potentials obtained when the subject wore the sweater, liner and jacket do not vary greatly either. The energies obtained when wearing different coat/trouser combinations together with the empty webbing do not vary greatly, however they are, in general, an order of magnitude higher than the corresponding energies obtained without the webbing. When the sweater, liner or jacket are worn under the webbing there is little difference between the magnitudes of the generated energies. This is also true when the webbing and pack are worn together.

Table 22: Tests with the Metal Panel.

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
None	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	-0.8	44	0.9
None	CES5 (Coat, Cotton, Washed) CETR3 (Trousers, Cotton, Washed)	-0.7	34	0.6
None	CES2 (Coat, FR Treated Cotton) CETR6 (Trousers, FR Treated Cotton)	-1.0	68	0.9
None	CES3 (Coat, FR Treated Cotton, Washed) CETR7 (Trousers, FR Treated Cotton, Washed)	-1.4	134	1.1
None	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	-1.8	222	0.9

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
None	CES7 (Coat, Polyester/ Cotton 50/50, Washed) CETR5 (Trousers, Polyester/ Cotton 50/50, Washed)	-0.8	44	0.8
CES4, CETR2	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20)	-1.2	99	0.8
CES2, CETR6	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	6.0	2466	0.8
CES4, CETR2	CEJ2 (Jacket, Wet Weather)	3.0	616	0.7
CES4, CETR2	Empty Webbing	-0.6	25	0.5
CES5, CETR3	Empty Webbing	-0.9	55	0.5
CES2, CETR6	Empty Webbing	-1.0	68	0.3
CES3, CETR7	Empty Webbing	-1.4	134	0.6
CES6, CETR4	Empty Webbing	-1.0	68	0.8
CES6, CETR4, CEH1	Empty Webbing	-0.7	34	0.5
CES7, CETR5	Empty Webbing	-0.6	25	0.3

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
CES2, CETR6	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20) Empty Webbing	-0.8	44	0.3
CES6, CETR4	CEJ2 (Jacket, Wet Weather) Empty Webbing	-0.9	55	0.5
CES6, CETR4, CEH1	Empty Webbing Empty Pack	-1.5	154	0.5
CES6, CETR4	CEJ2 (Jacket, Wet Weather) Empty Webbing Empty Pack	-1.6	175	0.5

The highest peak energy value observed for tests conducted with the metal panel was 2466 μJ. This value was obtained when the subject wore the DPCU liner vest. The longest observed half time was 1.1 s. The results in Table 22 indicate that there is no consistent difference in the peak energies obtained with the washed or unwashed coat/trouser combinations and there is no difference in terms of order of magnitude. The peak potentials obtained when the subject wore the sweater tend to be less than the peak potentials obtained when the subject wore the liner or the wet weather jacket. Similar peak potential values were obtained when different coat/trouser combinations were worn under the webbing.

Table 23: Tests with the Untreated Plywood Panel

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
None	CES4 (Coat, Cotton) CETR2 (Trousers, Cotton)	1.0	56	0.3

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
None	CES5 (Coat, Cotton, Washed) CETR3 (Trousers, Cotton, Washed)	-0.5	14	0.5
None	CES2 (Coat, FR Treated Cotton) CETR6 (Trousers, FR Treated Cotton)	4.1	950	0.8
None	CES3 (Coat, FR Treated Cotton, Washed) CETR7 (Trousers, FR Treated Cotton, Washed)	2.5	353	0.6
None	CES6 (Coat, Polyester/ Cotton 50/50) CETR4 (Trousers, Polyester/ Cotton 50/50)	-0.5	14	0.5
None	CES7 (Coat, Polyester/ Cotton 50/50, Washed) CETR5 (Trousers, Polyester/ Cotton 50/50, Washed)	-0.9	46	0.6

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
CES2, CETR6	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20)	2.7	412	0.6
CES2, CETR6	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled)	11.1	6961	0.5
CES2, CETR6	CEJ2 (Jacket, Wet Weather)	3.8	816	0.8
CES4, CETR2	Empty Webbing	1.6	145	0.5
CES5, CETR3	Empty Webbing	1.9	204	0.5
CES2, CETR6	Empty Webbing	-0.6	20	0.2
CES3, CETR7	Empty Webbing	3.2	579	0.6
CES6, CETR4	Empty Webbing	-1.1	68	0.8
CES7, CETR5	Empty Webbing	1.7	163	0.6
CES2, CETR6	CESW1 (Sweater, Khaki, DPCU Wool/Nylon 80/20) Empty Webbing	2.7	412	0.6
CES2, CETR6	CEJ1 (Liner Vest DPCU, Nylon Inner/Outer, Polyester Filled) Empty Webbing	7.3	3011	0.6

Inner Garments	Outer Garments	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
CES2, CETR6	CEJ2 (Jacket, Wet Weather) Empty Webbing	3.0	508	0.6
CES6, CETR4	Empty Webbing Empty Pack	-0.9	46	0.6
CES6, CETR4, CEH1	Empty Webbing Empty Pack	-1.0	56	0.5

The highest peak energy value that was observed for tests conducted with the untreated plywood panel was 6961 μJ and this value occurred when the subject wore the DPCU liner as an outer garment. The longest half time observed during tests with the plywood panel was 0.8 s. For the untreated plywood panel there was some variation in the peak energy values generated by the coat/trousers combinations. The flame retardant treated cotton coat/trousers combination exhibited the highest peak energy value of 950 μJ. There is no consistent difference in the peak energies when the as-received coat/trousers combinations are compared with their washed counterparts. When the DPCU liner was worn as the outer garment a higher peak energy was observed than was observed when either the DPCU sweater or the wet weather jacket were worn by the subject.

Tests were also conducted during which the subject wore the camouflage pattern hat and rubbed his head against the panel before separating (see Section 2.3.8). The results of these tests are presented in Table 24. The energy was calculated using the capacitance values in Table 6 and it is evident that the energy generated by the hat is insignificant for all the panels except for the case of the vinyl/foam panel. The energy generated by the hat is small, for all panel types, when compared with the energy generated when the subject's back was rubbed against the panel.

Table 24: Tests with the Camouflage Pattern Hat.

Panel	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
Vinyl/Foam	2.1	247	0.8
Glass/Plywood	-0.2	2	0.8

Panel	Peak Potential (kV)	Peak Energy (μJ)	Half Time (s)
Metal	-0.1	0.6	0.8
Untreated Plywood	0.05	0.1	0.5

An examination of Tables 20 - 24 reveals that the highest energy was obtained from the vinyl/foam panel when the subject wore the DPCU liner. The peak energy in this case was 10662 μJ and the half time was 0.6 s. The longest observed half time was 1.1 s. The half times lie in the range 0.2 s to 1.1 s and the peak energy lies in the range 0.1 μJ to 10662 μJ.

3.5.8 The Influence of Antistatic Footwear on the Peak Energy and Decay Time

Previous work [7] had indicated that antistatic footwear was the most efficient means of lowering the peak energy as well as the time for the energy to decay to half the peak value. In order to see what effect a change in footwear would have on the maximum peak energy value obtained in this paper, it was decided to repeat the test that led to this maximum value but to substitute antistatic footwear for the khaki boots. The subject wore the cotton coat CES4, the cotton trousers CETR2, socks CESK1 and the DPCU liner CEJ1 during the test. Charging was accomplished by rubbing against the vinyl/foam panel. The peak potential was 0.6 kV and the time required for the potential to decay to half its peak value was 0.2 s.

Using the capacitance value of 173 pF from Table 5 the peak energy generated while wearing antistatic footwear was calculated as 31 μJ. The peak energy of 10662 μJ in Table 20, which was obtained under identical conditions except for the wearing of antistatic footwear, is 340 times the peak energy that was obtained when antistatic footwear was worn. The antistatic footwear also reduced the decay half time from 0.6 s to 0.2 s.

3.6 Hazard Determination

3.6.1 Electronic Devices

By comparing the results presented in Tables 20-24 with the damage thresholds for known electronic devices it is possible to determine whether the submitted garments could damage such devices. Table 25 is reproduced from [10]. It is evident from the table that the sensitivity of electronics depends on the magnitude of the potential at which an electrostatic discharge occurs. The maximum peak potential observed during the tests was 13.5 kV and this potential value was observed while the subject was wearing the DPCU liner during the test with the vinyl/foam panel.

A comparison of the peak potentials listed in Tables 20-24 with the damage levels in Table 25 indicates that some of the submitted garments are capable of generating sufficient potential on a subject to damage devices chosen from any of the classes listed in Table 25. However, it is necessary for the electronic device to be exposed to an electrostatic discharge (directly or indirectly) and in an unshielded state for any damage to occur. The body and device impedances must also be considered because these affect the severity of the discharge [11]. It is therefore essential that an analysis is conducted in order to quantify the hazard arising in a particular situation.

Table 25: ESD Damage Levels for Electronic Devices.

Device	ESD Damage Level
Bipolar operational amplifier	≥ 500 V
Bipolar transistors	380-7000 V
MOS device with 1000 Å oxide layer	80-120 V 60-100 V
MOSFET	100-200 V
CMOS	250-2000 V
VMOS	30-1800 V
256K MOS memory with 250 Å oxide layer	25 V
JFET	140-17000 V
GaAs FET	200-300 V
Soft failure due to ESD-induced EMI	≥ 2500 V
Schottky-barrier diode with Pt-Ti-Mo-Au metallization	1600 V
Schottky-barrier diode with Ti-Mo-Au or Ti-Au metallization	300-400 V
Schottky diodes	300-2500 V

Device	ESD Damage Level
Schottky TTL	1000-2500 V
SCR	680-1000V
Film resistors	300-2500 V
EPROM	100 max
OP AMPS	190-2500 V
SAW	150-500 V
ECL (Hybrid, PB level)	500-1000 V

3.6.2 Electro-Explosive Devices

Electro-explosive devices (EEDs) are electrically-initiated devices designed to produce an explosive output by converting chemical energy into heat. EEDs may be classed as high-voltage, low-voltage, single pole or double pole devices. There are various mechanisms by means of which an electrostatic discharge might initiate an EED [10].

By comparing the peak energies in Section 3.5 with the threshold initiation energies of EEDs, the data presented in Section 3.5 may be used to determine whether personnel wearing the combat ensemble garments could inadvertently initiate an electro-explosive device (EED). For this purpose a comparison will be made with the energy required to initiate the M52A3B1 primer. This primer is chosen because it is one of the most sensitive EEDs currently fielded by the Australian Defence Force (ADF) and possesses a no-fire threshold of 17 μJ [12].

Many of the peak energies presented for the different clothing combinations in Section 3.5 exceed the no-fire threshold for the M52A3B1 primer by a wide margin and many of the half times presented in Section 3.5 are of the order of a second. Therefore it is possible that a subject wearing some combinations of the submitted garments might possess sufficient energy to initiate an M52A3B1 primer. However, a determination of whether a hazard exists in a particular situation will require a hazard analysis of that situation.

3.6.3 Fuel/Air Mixtures

The minimum ignition energy (MIE) for a hydrocarbon-based fuel-air mixture is 250 μJ [1]. The current investigation has shown that the combat ensemble garments generated a maximum peak energy of 10662 μJ with a half time of 0.6 s. Since this peak energy exceeds the MIE for hydrocarbon-air mixtures, the submitted garments are capable of initiating such mixtures. A hazard analysis of a given situation is required in order to determine whether a hazard exists.

4. Conclusions

(1) The resistance-to-ground and capacitance-to-ground values (measured with both feet on the ground) for the submitted sock/khaki boot combinations lie in the range $4.0 \times 10^9\ \Omega$ to $7.0 \times 10^9\ \Omega$ and the capacitance lies in the range 106 pF to 112 pF. The resistance-to-ground does not depend on the type of sock sample worn.

(2) The peak potential is influenced neither by the inner garments nor by garments worn under the pack. However the peak potential does depend on the type of garment worn under the webbing.

(3) There is no consistent difference between the peak energy values when the washed coat/trousers combinations are compared with the corresponding as-received garments.

(4) The half times calculated from the resistance-to-ground and capacitance-to-ground values are in good agreement with the observed half times.

(5) The longest observed half time during the charging experiments was 1.1 s. The longest half time measured for a stationary subject was 1.5 s.

(6) The submitted garments are capable of generating high peak energies (a maximum energy of 10662 μJ was observed).

(7) The submitted garments when worn with the submitted footwear samples generate potentials that are capable of damaging some electronic devices. They are also capable of initiating some electro-explosive devices and of igniting fuel/air mixtures.

(8) The wearing of antistatic footwear with a resistance of $3.5 \times 10^7\ \Omega$ (while standing on a low-resistance surface) reduced the maximum peak energy of 10662 μJ, that had been obtained while wearing khaki boots, to 31 μJ. The value of 31 μJ is only slightly higher than the no-fire threshold of a M52A3B1 primer to personnel electrostatic discharge (17 μJ).

(9) The antistatic footwear reduced the decay half time from 0.6 s to 0.2 s.

(10) In order to determine whether these garments pose a hazard for a particular operational scenario it is necessary to conduct a hazard analysis of the situation. Such an analysis will include a knowledge of the rubbing surfaces and a knowledge of the sensitivity of any devices that might be damaged or initiated.

An additional aspect is the actual configuration in which devices are encountered in practice. For example, quantifying the damage to electronics will require comparative measurements conducted with contacts similar to those made by a subject handling the equipment.

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6. References

1. Bajinskis, G., Billon, H., Quinn, J. (1995) *Electrostatic and General Hazards Associated with Cleaning Army Fabric Bulk Fuel Tanks (TFCs),* (DSTO Technical Report DSTO-TR-0254). Aeronautical and Maritime Research Laboratory, Maribyrnong, Victoria,Australia.

2. Billon, H. (1994) *Electrostatic Measurements of the In-Service Brown GP Boot and Associated Garments,* (DSTO General Document DSTO-GD-0014). Aeronautical and Maritime Research Laboratory, Maribyrnong, Victoria,Australia.

3. —. (1974). *Washing Shrinkage of Fabrics and Garments.* Method A16. Methods of Test for Textile Materials. Australian Defence Standard. DEF(AUST)5037.

4. —. (1965). *Identification of Textile Materials,* 5th Ed. The Textile Institute.

5. Sereda, P. J. and Feldman, R. F. (1964) Electrostatic Charging on Fabrics at Various Humidities, *J. Text. Inst.*, **55**, T288.

6. Bajinskis, G. and Lott, S. A. (1972) *Electrostatic Hazards from Insulated Operators,* (DSL Report 521). Department of Supply. Australian Defence Scientific Service. Defence Standards Laboratories, Maribyrnong, Victoria,Australia.

7. Bajinskis, G., Billon, H. and Quinn, J. (1996). *An Electrostatic Hazards Evaluation of RAAF Flightline Clothing* (DSTO Technical Report DSTO-TR-0372). Aeronautical and Maritime Research Laboratory, Maribyrnong, Victoria,Australia.

8. — (1995). *The Control of Undesirable Static Electricity.* AS/NZS 1020 : 1995. Australian / New Zealand Standard.

9. Mendenhall, W., Wackerly, D. D. and Scheaffer, R. L. (1990). Mathematical Statistics with Applications. 4th Edition. PWS-Kent Publishing Company. Boston.

10. Billon, H. (1994). *The Protection of Electro-explosive Devices (EEDs) and Electronics from Electrostatic Discharge (ESD) Hazards* (DSTO Technical Report DSTO-TR-0100). Aeronautical and Maritime Research Laboratory, Maribyrnong, Victoria, Australia.

11. Davies, D. K. (1985) Harmful Effects and Damage to Electronics by Electrostatic Discharges, *J. Elect.*, **16**, 329.

12. Billon, H. and Redman, L. (1994). *Electrostatic Testing of M52A3B1 Primers* (DSTO Technical Report DSTO-TR-0029). Aeronautical and Maritime Research Laboratory, Maribyrnong, Victoria, Australia.

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19. ABSTRACT
The electrostatic properties of the combat ensemble worn by Australian soldiers have been assessed. The resistance-to-ground, capacitance-to-ground, peak potential, peak energy and decay times were measured for a subject wearing various garment combinations. It was found that under favourable conditions a subject wearing the garments can generate sufficient energy to initiate electro-explosive devices, damage electronic devices and ignite fuel/air mixtures. However the threat level is dependent on the operational scenario and a threat analysis is required to determine the hazard for any given situation.

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