AR-008-909

DSTO-GD-0014

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Electrostatic Measurements of the In-Service Brown GP Boot and Associated Garments

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DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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ABSTRACT

Army Explosive Ordnance Demolition/Improvised Explosive Device Demolition (EOD/IEDD) teams routinely use electro-explosive devices (EEDs). A constant concern with EEDs is an unintended initiation from an unplanned source of electrical energy. Electrostatic discharge from charged personnel can under some circumstances be the source of unintended EED initiation. Electrostatic hazards from personnel are minimized by the appropriate use of footwear and garments. The Brown GP boot is tested for its electrostatic properties to determine its suitability for use by personnel engaged in EOD/IEDD operations.

Approved for public release

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Published by

DSTO Aeronautical and Maritime Research Laboratory
GPO Box 4331
Melbourne Victoria 3001

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AR No. 008-909
August 1994

APPROVED FOR PUBLIC RELEASE

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1. Introduction

Army Explosive Ordnance Demolition/Improvised Explosive Device Demolition (EOD/IEDD) teams are routinely required to use electro-explosive devices (EEDs) during ordnance disposal. Since EEDs can inadvertently be initiated by electrostatic discharge it is imperative that EOD/IEDD operators avoid acquiring dangerous levels of electrostatic charge.

Army EOD/IEDD teams have formerly utilized the Black GP Boot. As a result of trials [1] the black boots were found to be effective in dissipating static charge to earth. However, the Black GP Boot has been superseded in-service by the Brown GP Boot for which the electrostatic properties were unknown. The Army has therefore tasked MRL to determine the electrostatic properties of the Brown GP Boot.

An associated law enforcement agency that may be required to work with Army EOD/IEDD teams uses sports shoes as part of its uniform. Garments or footwear used by this agency could pose a hazard to combined operations. A series of tests on these shoes is accordingly included for comparison.

2. Experimental

2.1 Materials

A selection of footwear and garment samples was provided by the Army since garments worn can affect the electrostatic charges generated. These are listed below in Tables 1 (a) to (f) together with the MRL identification labels. A pair of sports shoes (Puma Hurricane) similar to those worn by a State law enforcement agency is included for comparison.

Table 1(a): Footwear

Description of Sample	Identification Label
Pair of Black GP Boots, Rossiters	B1
Pair of Black GP Boots, Dunlop	B2
Pair of Black GP Boots, Tuf Footwear	B3
Pair of Black GP Boots, Oliver	B4
Pair of Brown GP Boots, Highmark	B5
Pair of Brown GP Boots, Oliver & Stevens	B6
Pair of Sports Shoes, Puma Hurricane	Sp

Table 1(b): Shirts

Description of Sample	Identification Label
Cotton Khaki Shirt, King Gee, Neck Size 43-44 cm	S1
Cotton Khaki Shirt, King Gee, Neck Size 41-42 cm	S2
Disruptive Pattern Shirt, Size 107 L	S3
Disruptive Pattern Shirt, Size 92 R	S4

Table 1(c): Trousers

Description of Sample	Identification Label
Cotton Khaki Trousers, King Gee, Size 4	T1
Cotton Khaki Trousers, King Gee, Size 6	T2
Disruptive Pattern Trousers, ADI, Size 85 R	T3
Disruptive Pattern Trousers, AGCF, Size 92 L	T4

Table 1(d): Sweaters

Description of Sample	Identification Label
Olive Drab Sweater, Elegant Knitting Co., 80 % Wool / 20 % Nylon, Service No. 006	SW1
Olive Drab Sweater, Elegant Knitting Co., 80 % Wool / 20 % Nylon, Service No. 005	SW2
Khaki Sweater with Disruptive Pattern Patches, Elegant Knitting Co., 80 % Wool / 20 % Nylon, Service No. 003	SW3
Khaki Sweater with Disruptive Pattern Patches, Elegant Knitting Co., 80 % Wool / 20 % Nylon, Service No. 004	SW4

Table (1e): Jackets

Description of Sample	Identification Label
Disruptive Pattern Hooded Jacket, Cantas Pty. Ltd.	J1
Disruptive Pattern Hooded Jacket, Cantas Pty. Ltd.	J2
Olive Drab Jacket, Lakeview Sportswear Co. Inc., Outer Covering: 100 % Nylon, Batting: 100 % Polyester	J3
Olive Drab Jacket, Lakeview Sportswear Co. Inc., Outer Covering: 100 % Nylon, Batting: 100 % Polyester	J4

Table (1f): Overalls

Description of Sample	Identification Label
Olive Drab Overalls, ADI, Size 100 R	O1
Olive Drab Overalls, ADI, Size 110 L	O2

2.2 *Apparatus*

Resistances were measured on a Radiometer IM6 Megohmmeter. Capacitances were measured on a General Radio Company Type 1650-A impedance bridge. Voltages were measured on a Rothschild R-1020 electrostatic voltmeter. The data from the voltmeter were relayed to a Hewlett Packard HP 54111 D digitizing oscilloscope and recorded on a Hewlett Packard Thinkjet printer. Samples were discharged before testing by means of a Simco Aerojet XC ionizing air blower. The humidity was controlled by a Munters M-120 dehumidifier. The temperature was controlled by a Mitsubishi Electric air conditioner. Some measurements were conducted in the open air without temperature or humidity control.

3. *Measurements*

3.1 *Resistance Measurements*

Body-to-ground resistance measurements were conducted on the footwear at two voltages. Unless otherwise stated, the subject was wearing thin socks which had been worn for at least 4 hours prior to the commencement of testing [2]. The resistances were measured while the subject stood with both feet on an aluminum plate.

Table 2: *Footwear Body-to-Ground Resistance Measurements. Measurements Performed at 200 V (T = 20°C, RH = 35-40%)*

Sample	Resistance ($10^9\Omega$)
B5	1.5
B6 *	3.7
B1	5.5
B2	3.9
B3	3.4
B4	6
B4 (bare feet)	5.5
Sp**	2000

Table 3: *Footwear Body-to-Ground Resistance Measurements. Measurements Performed at 500 V (T = 19°C, RH = 50%)*

Sample	Resistance ($10^9\Omega$)
B5	2
B6*	6
B1	7.5
B2	5
B3	4
B4	7
B5 (without socks)	2
Sp**	1000

* On 8.12.93, after a large number of tests had been completed, a re-check was conducted on B6 (on an aluminum plate, T = 28 °C, RH = 38 %) at 500 V. R = $2.7 \times 10^9\ \Omega$.

** T = 23 °C, RH = 56 %.

3.2 *Capacitance Measurements*

The body-to-ground capacitance of a subject wearing GP boots and other footwear was measured. The measurements were obtained for the subject standing on both feet and on one foot.

Table 4: *Footwear Body-to-Ground Capacitance Measurements. Using an Aluminum Plate in the Laboratory. Both Feet on the Plate. T = 22°C, RH = 28%*

Sample	Capacitance pF
B5	128
B6	132
B1	129
B2	132
B3	137
B4	142
Sp**	90

Table 5: *Footwear Body-to-Ground Capacitance Measurements. Using an Aluminum Plate in the Laboratory. For Various Stances. T = 22°C, RH = 28%*

Sample	Capacitance With Both Feet Down pF	Capacitance With Left Foot Raised pF	Capacitance With Right Foot Raised pF
B5	127	103	97
B6	130	103	101
B1	130	103	101
B2	129	105	99
B3	138	110	103
B4	139	112	107
Sp**	90	73	72

** T = 23°C, RH = 56 %.

Further capacitance measurements were made at various stages of a person exiting a motor vehicle. The vehicle used was a Daihatsu Charade CS (1988 model).

Table 6: *Capacitance Measurements on Exiting a Vehicle. Earth Was a Metal Spike in the Ground (Unless Stated Otherwise)*

Footwear/Garments	Description of Situation	Capacitance pF
S3, T4, B6	Both feet in car	140
"	Heel of right foot contacting earth. Leaving right front seat.	140
"	Flat of right foot contacting earth. Leaving right front seat.	162
"	Sitting on right driver's seat. Both feet out on road.	160
"	Standing next to car. Both feet flat.	125
"	Standing away from car. Both feet flat.	108
"	Standing away from car. Both feet flat. No leads.	110
"	Standing on Al plate on road. Without leads.	120
"	Car capacitance to ground	880
S3, T4, B3	Both feet in car	154
"	Heel of right foot contacting earth. Leaving right front seat.	140
"	Flat of right foot contacting earth. Leaving right front seat.	157
"	Sitting on right driver's seat. Both feet out on road.	190
S3, T4, Sp	Both feet in car	150
"	Heel of right foot contacting earth. Leaving right front seat.	130
"	Flat of right foot contacting earth. Leaving right front seat.	126
"	Sitting on right driver's seat. Both feet out on road.	160

3.3 *Charging Experiments*

Charging experiments were conducted in order to determine the maximum voltage and energy for different garment and footwear combinations. The time required for the voltage to decay to half the initial value was also recorded. Tests were conducted, in a laboratory, under conditions of controlled temperature and humidity, and outdoors on a bitumen roadway using a motor vehicle.

For the tests conducted in the environmentally controlled room, the footwear and garment samples were conditioned in the room for several days prior to testing. For the vehicle tests, the garments were left in the motor vehicle for approximately an hour before testing.

A set of tests was carried out for sports shoes with two combinations of garments.

Table 7: *Charging Experiments in the Environmentally-Controlled Room. T = 22 °C, RH = 28-30%*

Footwear/Garments	Contacting Surface and Charge Generating Process	Peak Voltage kV	Time to Decay to Half Peak Voltage s
B6, S3, T4	60 cm x 60 cm polyethylene (PE) sheet on metal backing. Rub back against this while standing on a polystyrene (PS) panel then step off onto earthed aluminum (Al) plate.	2.8	0.9
B6, S3, T4	"	2.6	1.1
B6, S3, T4, J2	"	3.5	0.8
B6, S3, T4, J2	"	3.0	0.8
B6, S3, T4, J2	"	4.3	0.8
B6, S3, T4, J4	"	3.6	0.6
B6, S3, T4, J4	"	4.5	0.8
B6, S3, T4, SW1	"	4.5	0.8
B6, S3, T4, SW1	"	4.5	0.8
B6, S3, T4, SW3	"	3.7	0.6
B6, S3, T4, SW3	"	4.7	0.6
B6, S3, T4, SW3	"	4.5	0.6
B6, S3, T4	Colored polyvinylchloride (PVC) covered stool. Rub against this & then step onto a PS panel & then step onto earthed Al plate.	4.3	0.5
B6, S3, T4	"	4.5	0.6
B6, S3, T4	"	4.7	0.5
B6, S3, T4	90 cm x 80 cm PE sheet on metal backing. Standing on PS panel then getting off onto Al sheet. (Take 3 steps & stop).	1.3	0.6
B6, S3, T4	"	1.5	0.8
B6, S3, T4	"	2.4	0.8
B6, S3, T4	"	2.6	0.6
B6, S3, T4	"	4.5	0.6
B6, S3, T4, J2	"	5.8	0.5
B6, S3, T4, J2	"	5.2	0.6

Table 7 (Contd): *Charging Experiments in the Environmentally-Controlled Room. T = 22 °C, RH = 28-30%*

Footwear/Garments	Contacting Surface and Charge Generating Process	Peak Voltage kV	Time to Decay to Half Peak Voltage s
B6, S3, T4	Single PVC sheet (cleaned) against metal backing 90 cm x 80 cm. Standing on PS panel then getting off onto Al sheet (stepping up & down on the spot). *	2.2	0.9
B6, S3, T4, J2	"	5.6	0.6
B6, S3, T4, J4	"	4.5	0.6
B6, S3, T4, SW1	"	4.1	0.8
B6, S3, T4, SW3	"	3.7	0.8

* For the last 5 rows, T = 21 °C and RH = 25-27 %.

3.4 *Charging Tests in a Motor Vehicle*

These tests were conducted by rubbing against surfaces (detailed in the table below) in the motor vehicle, separating and stepping out onto the road.

The motor vehicle was the Daihatsu Charade. The peak energy values for the GP Boots were calculated from $E = \frac{1}{2}CV^2$. Slightly different capacitances were measured for the two boots. Accordingly, the calculations use C = 162 pF for the brown boot B6 and C = 157 pF for the black boot B3. It was observed that the peak voltage used for the calculations occurred when the subject was in the process of leaving the motor vehicle with one foot in contact with the road. The time required for the voltage to decay from its peak value to below 458 V for B6 or 465 V for B3 is tabulated. Voltage values of 458 V and 465 V correspond to an energy of 17 μJ for B6 and B3 respectively. A proposed safe energy level of 17 μJ is used based on the electrostatic no-fire threshold energy for an M52A3B1 primer [3].

A time to safe charge level is measured for each boots type. This is measured as the time taken for decay from maximum voltage to the relevant safe level for each type of service boot.

Charge dissipation tests were also conducted with the Puma Hurricane sports shoes. The subject showed greater charge retention qualities while wearing the sports shoes. This is measured as a residual energy and is tabulated together with the time to half maximum value and time to safe value in Table 8. The capacitance used to determine the energy values for the sports shoes was 130 pF.

Table 8: *Charging Tests in the Motor Vehicle. Conducted for Brown and Black GP Boots*

Definition of symbols:

T is the test temperature,
RH is the test relative humidity,
V_{Peak} is the peak voltage,
E_{Peak} is the peak energy,
$t_{1/2}$ is the time taken for the voltage to decay to a value of 0.5 V_{Peak},
t_{M52} is the time taken for the energy to decay to a value equivalent to the No-Fire Threshold of an M52A3B1 primer.

Footwear and Garments.	T/RH	Rubbing Surface	V_{Peak}	E_{Peak}	$t_{1/2}$	t_{M52}
	°C/%		kV	mJ	s	s
S3, T4, B6	25/41	PVC covered car seat. Then walk onto road.	2.1	0.34	1.2	1.8
S3, T4, B6	27/39	"	2.4	0.48	0.9	1.8
S3, T4, B6	26/41	"	3.0	0.72	0.6	1.8
S3, T4, B6	27/30	"	3.9	1.25	0.9	2.1
S3, T4, B6	26/30	"	3.9	1.25	0.6	1.8
S3, T4, B6	27/29	PVC covered car seat and original vinyl of car door. Then walk onto road.	3.0	0.72	0.9	2.1
S3, T4, B6	33/15	PVC surfaces on door and seat.	3.0	0.72	1.2	3.0
S3, T4, B6	33/15	PVC surfaces on door and seat.	2.8	0.64	0.9	2.4
S3, T4, B6	33/15	"	2.8	0.64	0.8	2.4
S3, T4, B6	33/15	PVC on seat only	4.3	1.5	0.5	1.5
S3, T4, B6	33/14	"	4.1	1.4	0.6	1.4
S3, T4, B6, SW1	33/17	"	6.7	3.7	0.5	1.2
S3, T4, B6, SW1	31/19	"	6.7	3.7	0.5	1.5
S3, T4, B6, SW1	30/27	PVC on seat & door	4.9	1.9	0.6	1.7
S3, T4, B6, SW1	30/27	"	5.0	2.1	0.6	1.7
S3, T4, B6, SW3	33/22	PVC on seat only	3.9	1.25	0.3	1.1
S3, T4, B6, SW3	32/26	"	3.7	1.1	0.5	1.5
S3, T4, B6, SW3	31/27	PVC on seat and door	2.8	0.6	0.3	0.9
S3, T4, B6, SW3	32/26	"	3.2	0.8	0.5	1.1
S3, T4, B6, J2	34/23	PVC on seat only	8.2	5.5	0.3	1.2
S3, T4, B6, J2	34/23	"	7.5	4.5	0.5	1.2
S3, T4, B6, J2	29/25	PVC on seat & door	6.0	2.9	0.8	2.4
S3, T4, B6, J2	31/25	"	7.8	5.0	0.6	2.3
S3, T4, B6, J4	26/28	PVC on seat only	3.7	1.1	0.3	1.5
S3, T4, B6, J4	26/28	"	2.2	0.41	0.5	1.1
S3, T4, B6, J4	30/26	PVC on seat & door	2.2	0.41	0.9	2.3
S3, T4, B6, J4	30/24	"	2.2	0.41	0.5	1.4
S2, T1, B6	30/26	PVC on seat only	5.6	2.5	0.6	1.7
S2, T1, B6	30/26	"	6.0	2.9	0.3	1.5
S2, T1, B6	34/22	PVC on seat & door	4.9	1.9	0.5	1.2
S2, T1, B6	33/20	"	3.7	1.1	0.5	1.2
S2, T1, B6, SW1	35/21	PVC on seat only	6.0	2.9	0.3	1.1
S2, T1, B6, SW1	37/15	"	6.4	3.3	0.5	1.2

Table 8 (Contd): *Charging Tests in the Motor Vehicle. Conducted for Brown and Black GP Boots*

Footwear and Garments.	T/RH °C/%	Rubbing Surface	V_{Peak} kV	E_{Peak} mJ	$t_{1/2}$ s	t_{M52} s
S2, T1, B6, SW1	34/21	PVC on seat & door	4.5	1.6	0.5	1.5
S2, T1, B6, SW1	29/25	"	4.9	1.9	0.5	1.1
S2, T1, B6, SW3	28/30	PVC on seat only	7.1	4.1	0.5	2.0
S2, T1, B6, SW3	30/29	"	5.6	2.5	0.3	1.4
S2, T1, B6, SW3	30/28	PVC on seat & door	4.1	1.4	0.3	0.8
S2, T1, B6, SW3	28/32	"	4.1	1.4	0.5	1.5
S2, T1, B6, J2	26/33	PVC on seat only	6.0	2.9	0.6	1.5
S2, T1, B6, J2	28/32	"	6.7	3.7	0.5	1.2
S2, T1, B6, J2	28/30	PVC on seat & door	6.0	2.9	0.5	1.2
S2, T1, B6, J2	28/32	PVC on seat & door	5.2	2.2	0.5	1.4
S2, T1, B6, J4	29/29	PVC on seat only	2.2	0.41	0.5	1.2
S2, T1, B6, J4	27/31	"	2.6	0.55	0.3	0.9
S2, T1, B6, J4	30/30	PVC on seat & door	2.2	0.41	0.5	1.2
S2, T1, B6, J4	29/31	"	1.9	0.28	0.3	1.1
S2, T1, B6, O1	27/33	PVC on seat only	5.2	2.2	0.3	1.4
S2, T1, B6, O1	28/30	"	5.2	2.2	0.3	1.2
S2, T1, B6, O1	29/32	PVC on seat & door	4.1	1.4	0.5	1.2
S2, T1, B6, O1	28/32	"	3.7	1.1	0.5	1.2
S3, T4, B6, O1	29/31	PVC on seat only	5.2	2.2	0.5	1.4
S3, T4, B6, O1	29/32	"	6.4	3.3	0.3	1.2
S3, T4, B6, O1	24/37	PVC on seat & door	5.2	2.2	0.6	1.7
S3, T4, B6, O1	27/40	"	4.1	1.4	0.5	1.2
S3, T4, B3	33/32	PVC on seat only	3.7	1.1	0.5	1.1
S3, T4, B3	34/32	"	3.4	0.89	0.3	0.8
S3, T4, B3	33/32	PVC on seat & door	2.2	0.39	0.5	0.8
S3, T4, B3	33/32	"	2.2	0.39	0.5	1.2

Table 9: *Charging Tests in the Motor Vehicle. Conducted for the Sports Shoes. The capacitance used to determine the energies was 130 pF*

Footwear and Garments	T/RH °C/%	Rubbing Surface	V_{Peak} kV	E_{Peak} mJ	$t_{1/2}$ s	Residual Energy at stated time after Peak mJ/s***
Sp, S3, T4	29/36	Car seat (covered with PVC sheet). Door open.	5.2	1.8	51.9	0.23/77
"	27/40	"	6.0	2.3	42.1	0.33/77
"	27/40	"	4.5	1.3	44.4	0.15/77
Sp, S3, T4, O1	26/40	"	15	14.5	38.3	2.0/72
"	28/38	"	17	18	36.1	2.0/68
"	26/40	"	19	23	31.6	2.0/71

*** This column presents the residual energy on the subject after the time indicated (this time is measured from the occurrence of the peak voltage).

4. *Conclusions and Recommendations*

The body-to-ground resistance and capacitance for the Brown GP Boot are essentially the same as those for the Black GP Boot. The decay times to half maximum voltage for the submitted footwear samples may be estimated from the data in tables 3 and 4 and range from 0.2 s to 0.7 s. The corresponding value for the sports shoes is 62 s. There is good agreement (within an order of magnitude for this type of measurement) between the calculated and observed decay half-times.

The electrostatic charge dissipation rates to ground of both the Brown and Black GP Boot provide a satisfactorily short decay time for the operator to reach a safe potential. The decay times for the Black GP Boot are comparable with those for the Brown GP Boot. The longest observed time period for the electrostatic energy to decay below the no-fire threshold energy of a sensitive primer (M52A3B1) when wearing Brown GP Boots was 3 seconds.

Some submitted garments that can be used in conjunction with the GP Boots are capable of generating large static charges on a wearer.

The highest level of charging observed (for the tests conducted with the GP Boots) occurred for a combination of disruptive pattern (DP) shirt, DP trousers, Brown GP Boots and DP Cantas hooded jacket at a humidity of 23 % when rubbing against a PVC covered car seat. In this case the energy on the subject decayed below the no-fire threshold of an M52A3B1 primer in 1.2 seconds.

The charging tests for the sports shoes indicate that very high peak energies are possible and that the decay time is very long. The highest voltage obtained was 19 kV corresponding to an energy of 23 mJ. There was considerable residual energy on the subject even a minute (or more) after the occurrence of the peak. This residual energy ranged in value from 0.15 mJ to 2.0 mJ. It should be noted that an energy of 0.15 mJ is nine times the no fire threshold of the M52A3B1 primer. It should also be noted that the 0 % and 100 % firing energies for the Type E fuzehead (which is used by EOD/IEDD teams) are 2.3 mJ and 5.4 mJ, respectively [4].

A more extensive knowledge of the electrostatic sensitivities of electro-explosive devices used by the EOD/IEDD teams should be acquired if more detailed electrostatic safety hazard assessment is desired. This report has addressed the hazard of human electrostatic discharge. Electrostatic discharge may also be possible from other sources, e.g. the garments themselves [5, 6, 7]. It is suggested that future work be conducted to determine other possible sources of electrostatic hazard and, if necessary, means for their suppression.

5. *Acknowledgements*

The collaboration of Mr. Gunars Bajinskis (Explosives Ordnance Division) in the planning and execution of the tests and the preparation of the report is acknowledged. Mr. James Quinn (Explosives Ordnance Division) is acknowledged for his assistance in preparing the report. Mr Graeme Manzie (Programs Office) is acknowledged for refereeing the report.

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REPORT NO.	AR NO.	REPORT SECURITY CLASSIFICATION
DSTO-GD-0014	AR-008-909	Unclassified

TITLE

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REPORT DATE	TASK NO.	SPONSOR
August 1994	ARM 92/503	DORD

FILE NO.	REFERENCES	PAGES
510/207/0073	7	15

CLASSIFICATION/LIMITATION REVIEW DATE

CLASSIFICATION/RELEASE AUTHORITY
Chief, Explosives Ordnance Division

SECONDARY DISTRIBUTION

Approved for public release

ANNOUNCEMENT

Announcement of this report is unlimited

KEYWORDS

Improvised explosives device demolition
Electro-explosive devices
IED
Electrostatic properties
Static charges
Electrostatic charges
EED

ABSTRACT

Army Explosive Ordnance Demolition/Improvised Explosive Device Demolition (EOD/IEDD) teams routinely use electro-explosive devices (EEDs). A constant concern with EEDs is an unintended initiation from an unplanned source of electrical energy. Electrostatic discharge from charged personnel can under some circumstances be the source of unintended EED initiation. Electrostatic hazards from personnel are minimized by the appropriate use of footwear and garments. The Brown GP boot is tested for its electrostatic properties to determine its suitability for use by personnel engaged in EOD/IEDD operations.

Electrostatic Measurements of the In-Service Brown GP Boot
and Associated Garments

H. Billon

(DSTO-GD-0014)

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