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RESISTANCE TESTING OF STATIC DISSIPATIVE WORKSURFACES

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Summary

There are numerous tests which have been offered to characterize the static dissipative properties of worksurfaces, including various types of charge decay and resistance testing. After consideration of all these alternatives, the most practical for general use in material acceptance and workstation qualification appears to be direct measurement of the total resistance between two selected locations. This work describes two types of total resistance measurements. One involves the resistance from the top of the worksurface to ground, while the other involves the resistance between two locations on the top of the worksurface.

There are many methods for making such a measurement, depending on the choice of electrode fabrication and placement, as well as on the design of the resistance meter. The two criteria which should be met by any such test method require that the test be reproducible, and that its result be related to the functional demands of the worksurface. The reproducibility was determined by a series of measurements carried out at six different facilities throughout the United States, with each location employing a variety of electrodes based on the NFPA model, with various placements on different sizes of test samples. The measurements were performed at voltages ranging from 9 V to 1000 V, and relative humidities of 12% and 50%, using a variety of meters. The resistance values obtained in these measurements were analyzed statistically to determine which combination of conditions led to the least variability in results.

This analysis indicates that the best test method involves:

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Sample size of 10 inches x 24 inches,
NFPA electrodes with conductive rubber,
A meter with at least 10% accuracy,
Applied voltage of 100 V,
Relative humidity of 50%,
Repeated measurements with electrodes placed at different locations on the surface.

Since the functionality of the worksurface should be maintained under the range of conditions expected in the workplace, additional measurements with the combination of:

Applied voltage of 10 V, and
Relative humidity of (12 ± 3)%

should also be made to determine the changes in worksurface properties as the humidity and voltage change. These recommendations form the technical basis for the EOS/ESD draft standard for worksurfaces.

INTRODUCTION

The primary reason for using a static dissipative worksurface is to protect the device against ESD damage. Unfortunately, there are several methods of protection implied here, and they are often confused in practice. One involves the removal of charge residing directly on the surface of the material. A second removal task involves the charge on an object such as a tote box, which is placed on the surface. In this case, the charge must flow across the contact zone between the object and the worksurface, which can interpose considerable resistance to the current. A third type of protection is the limitation of the current which flows from a charged sensitive device placed on the surface. Unlike the first two cases, a low current flow is desirable here.

Resistance Measurements

Whether a fast or a slow decay of charge is needed, the degree of protection afforded by the worksurface is intimately related to the time needed to discharge the object of interest. In practical work, however, a resistance value is commonly given to indicate its efficiency. Strictly speaking, this is not the proper parameter, since discharge time depends on several other factors, such as the effective capacitance of the worksurface, the contact resistance, and the actual current path followed by the charge. The capacitance does not usually vary as much as resistance, however, and its effect is usually negligible compared to the range of resistances encountered in practice. The other effects are very dependent on the individual situation, and their prediction in a given arrangement has not yet been achieved. Thus we are left with resistance as the single best predictor of performance for static dissipative worksurfaces. This situation deserves further study, but we can not wait for this work before trying to bring some order into the specification of worksurface efficiency.

A number of ad hoc measurements have been made on worksurfaces for years, in an effort to characterize their protection ability. Most are based either on general standards providing guidance for a wide range of situations, such as ASTM D-257 [ASTM 1983], while others were intended for specific situations with different requirements, such as NFPA 56A [NFPA 1961]. The general standards offer a variety of methods for measuring a resistance, many of which are inappropriate for the problem at hand. The specialized methods may also be inappropriate, of course, but in addition they often offer acceptable ranges for resistance which may not be suitable for worksurfaces. To correct these shortcomings, and to clear up the confusion arising when different laboratories use different techniques to measure the same quantities, the Standards Committee of EOS/ESD decided to develop a standard for measuring the static dissipative ability of a worksurface.

All resistance measurements involve two separate components. One is the resistance meter itself, which applies a voltage or current to the object, and measures the resulting response. This meter can consist of a separate source and detector, or can be a combined unit, called an ohmmeter or megohmmeter. The second component is the electrode pair, which conducts the current from the meter to the worksurface. The same meter can, in fact, be used to measure any of the resistances considered here, so long as the electrodes are connected in the appropriate way to the sample.

Three types of total resistance measurements are considered here. The first (R_{TG}) is the net resistance from the top of the worksurface to ground. Since the ground connection may be made to various places, such as the top of the surface or to a buried scrim, this resistance will depend on the actual construction of the worksurface, as well as on the material properties. It is the only measurement which tests the entire path from top to ground, however, so it can reveal the net resistance in the discharge path, which is a very good predictor of the speed of discharge. Normally a low value of R_{TG} is desirable for discharge of the surface.

The surface resistivity, R_S, is measured by placing electrodes on the top of the worksurface. The basic assumption in this measurement is that the current flows through a thin conducting sheet at the top of the surface, while the underlying substrate is an insulator. This type of measurement is well suited to specifying very thin conducting coatings placed on materials like plastic or oxides, but can prove misleading on other structures in that situation, such as scrim layers, because the actual current flow there is down through the top surface, rather than along it. Surface resistivity is most useful when used with the charged device model (CDM) for ESD damage, in which a device with a charge is dropped onto a worksurface. To avoid static damage, the surface resistivity of the surface should be high enough to limit the resulting current flow to safe values.

The third type of resistance measurement (R_{TT})was a special case of a surface resistance measured between two electrodes placed at specified locations on the top of the surface. If there is a true surface resistivity, this electrode combination will measure a resistance related to R_S by a constant depending on the size and position of the electrodes. This measurement was included as an indicator of the relative protection against CDM damage which is relatively simple to determine.

Goal of the Present Work

Resistance tests have been used in ESD classification of worksurfaces for some time, but different organizations have used different values for acceptable resistances, as well as different techniques and equipment, so that the results may not be directly comparable. The second question is addressed in the present paper. We would like to define a method of measuring R_{TG} and R_{TT} so as to give readings which are consistent for a given material, no matter where performed. While this may seem to be a simple task, we shall see from the results presented below that measurements of high resistances can rarely be given with the precision normally expected in engineering work, and that the choice of a reproducible measurement technique is not straightforward. This report does not address the question as to what values of resistance are acceptable, but it does give values obtained for a sampling of currently available static dissipative worksurfaces.

Many of the effects which are thought to influence resistance measurements on worksurfaces were included in this study. The most fundamental of these are the physical effects, such as the particular nature of the worksurface, including the materials used, fabrication techniques, and geometrical relations. In addition, we expect the voltage to play a role in the results, as well as the relative humidity. There are a number of variables associated with the measurement technique itself, such as the size and shape of the sample, its cleaning and conditioning, the size, shape, hardness, and placement of the electrode, and the meter used to read the resistance. In addition, there are other effects which are hard to quantify, but which can arise when different personnel perform the same test in different laboratories. All of these factors were considered in the testing. There are additional effects, such as temperature and the pressure placed on the the electrode, which may also be important, but were not included.

PROCEDURES

Measurement Procedures

Six different laboratories participated in the testing of 75 specimens of 8 different worksurfaces. One laboratory first tested every one of the specimens under all of the test conditions. Afterward, the specimens were divided into 5 batches which were shipped to the other five laboratories for testing. All of the test data were then sent to a single location for analysis and interpretation.

The eight worksurfaces were representative of the mats and tabletops in current use. There were 5 hard specimens of dissipative tabletops (A,B,C,D,G), 2 soft dissipative mats (E,F), and one hard conductive table top (H). Two sizes were available. The smaller was a square 10 inches on a side, and the larger was a rectangle of 10 inches x 24 inches. Each specimen was mounted to a 1 inch industrial grade particle board using non water-based contact cement. Ground snaps were connected to two corners of the specimen to aid in making RT_G measurements.

Testing was carried out under two different relative humidities. One, labeled 'A' (for ambient), was at a relative humidity of (52±7)%, and the other, labeled 'L' (for long), was at (12±3)%. In either case, the samples were conditioned for at least 24 hours at the appropriate humidity, and measured under the same conditions.The temperature for all measurements was held at 70°±5° F.

Resistance readings were made on a number of meters, depending on their availability at the laboratories. Some gave only a decade readout (for example, 10^9 Ω), while others could be read to two or more significant figures (for example 2.35 x 10^9 Ω). The electrodes used to connect the meter to the specimen were of different types. Some had hard metal surfaces, while others were softer, with braid or elastomer coverings. Some were based on the NFPA design, using either foil or conductive elastomer to make contact with the sample.

Before each test, the sample was cleaned by wiping with isopropyl alcohol. The electrodes were then placed on the surface in one of several allowed positions, and the voltage applied. At least three different voltages were used at each location, if available from the meter. Typical values usually included a low voltage of approximately 10 V, an intermediate voltage on the order of 100 V, and a high voltage of approximately 500 V. The resistance value was then read from the meter. If the value appeared to vary with time, a reading was taken 15 seconds after applying the voltage.

Data Analysis Procedures

The data from the various laboratories came in different forms, as the team members adapted the suggested procedures and operating parameters according to the equipment available. All of this data was converted into a common format, so that the statistical analysis could be performed on all results simultaneously, where possible. The procedures used to co-ordinate the data are described below.

A small, but appreciable fraction of the data was reported as not available, or as greater or lesser than some value. Usually this was due to a meter which could not read at resistances as high or as low as the worksurface exhibited under those operating conditions. In all cases, the data were coded as 'missing' It should be pointed out that this procedure omits the very values which might be expected to increase the spread in the data, and it will tend to give an average resistance which appears to be more precise than it is. In addition, the average will be skewed toward the more normal range of the meter (usually lower R) so that the high resistance samples will appear to be better than they really are.

The data were then entered into a spreadsheet (Microsoft Excel running on a Macintosh Plus) with each column indicating the experimental conditions and each row representing a resistance measurement. Obvious errors in the values were located by sorting for highest and lowest resistance values, to eliminate gross errors, and sorting by experimental conditions to ensure that only the allowed parameters were listed. The database was then split into three parts, one for R_{TT}, one for R_{TG} and one for R_S. Each of these three databases was then imported into Statview 512^{+}, a statistical analysis program. The resistance values were transformed into logarithmic form as $\log_{10}(R)$, due to the wide range of values normally encountered in high resistance measurements. Thus a value given here as 9.5 is equivalent to a resistance of $3 \times 10^9\ \Omega$.

The first step in analyzing each of the three databases was a coarse search for the parameters which had the greatest effect on the measured value of resistance. The database was too large, and there were too many missing cells, to perform a full ANOVA of the data, so an alternate approach was followed. The entire database was split into groups according to the value of the parameter under study. For example, all resistance values associated with low relative humidity ('L') were split from all those associated with relative humidity near 50% ('A'). The mean and standard deviation of each group was then calculated and compared for significant differences.

This method can only be used as a guide, since there is no guarantee that each group contains all of the same cases. Many values are missing, for example, and these tend to come from the measurements which have very high resistances. One of the labs was not able to make measurements at low humidity, so there will be some correlation between RH and the other parameters, such as meter, electrode, and voltage. Concerns of this nature will be left to the succeeding sweeps of the data which are described below.

On the other hand, some variables had no effect, such as sequence number. This was to be expected, so we felt justified in leaving it out of further analysis. There were other parameters, however, which also showed no coarse effect on the outcome but which were retained anyway. One of these was the electrode position on the long samples. Despite this early indication, electrode placement was included in the more detailed analysis, because the physics of the measurements strongly suggested that it might be an important physical parameter.

In the first pass, only a few of the recorded parameters could be eliminated from consideration completely, indicating that our choice of variables in the study included mostly those which influence the measured value of the resistance. The next step was to select the combination of measurement techniques which gives the least variation for a given set of physical conditions. This is equivalent to seeking the most reproducible measurement technique. This step involved a detailed statistical analysis of resistance measurements for each of the three sample types in both ambient and low RH environments. The three samples selected represent a hard static dissipative tabletop (Sample C), a soft static dissipative mat (Sample F), and a hard conductive tabletop (Sample H). They were selected as being representative of the various classes, as determined by the analysis in the proceeding step. To increase accuracy, only the measurements made on meters which can be read to several significant figures were included.

For each of these cases, the mean and standard deviation of the whole sample was calculated, and then compared with the corresponding values for subgroups formed by splitting according to voltage level, electrode placement, sample size, and electrode type. From the standard deviations calculated for each case, the measurement conditions which gave the smallest variation could be located. These conditions gave the most reproducible results, and served as a reference for further analysis.

At this point, the most reproducible measurement technique has now been identified, but this combination may not represent the conditions needed in practice. For example, high RH gives a more reproducible resistance measurement, but it is at low RH that static protection is most needed. Thus it may be advisable to measure the worksurface under those conditions. At this stage of the analysis, the data were re-analyzed to determine how much more variation is introduced by changing one of the conditions, like the RH. A one-way ANOVA was performed for each of the changes, and the means and standard deviations compared for significant differences.

The last step in the analysis involved fitting a curve to the relation between resistance and applied voltage for each sample at each environmental condition. The values used for the fit were those corresponding to the optimum combination, so the resistance values are as reproducible as possible for this data. Since voltage and RH are thought to be the primary 'real' influences on the resistance, these curves represent the results that might be obtained from measurements using the recommended procedure. These regressions were performed for one lab which had tested every sample in the program and for all labs together, so that interlab variation could be studied.

RESULTS OF THE TESTING

In general, the measurements of R_{TT} and R_{TG} gave similar results for the reliability of the various techniques. These results are illustrated in this section for the variables studied.

Voltage and Humidity

Voltage had a strong effect on the resistance of the hard tabletops, with low voltages always giving higher resistance values. A typical hard tabletop (Sample C) is shown in Figure 1.The apparent resistance is much higher at 10V than at 1000V, by an approximate factor of 100. This means that a resistance value must be accompanied by a voltage in order to describe this worksurface. The effect was even stronger at low relative humidity, where reducing the voltage from 100 to 10 could increase the resistance by a factor of 50 in some cases. A typical result, for the same sample at low RH, is shown in Figure 2. The mean resistance is higher at each voltage, but disproportionately so at low voltage. Thus measurements at high voltages are expected to be less dependent on humidity. The standard deviation is also higher for low RH, as a rule, indicating that this is a less reproducible measurement.

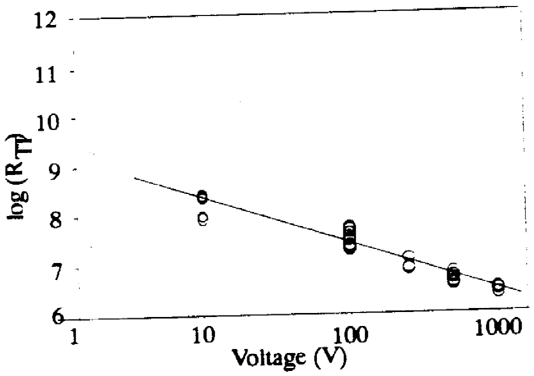

Fig. 1. Voltage effect for Sample C at moderate humidity (~ 50%)

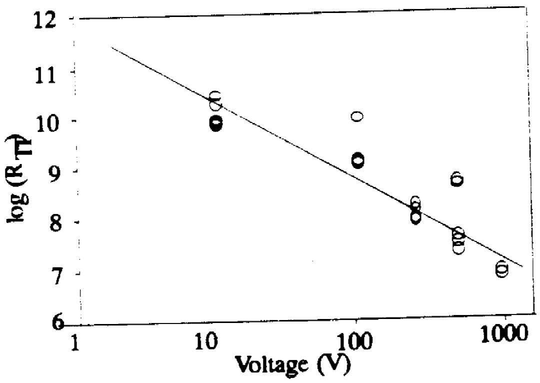

Fig. 2. Voltage effect for Sample C at low humidity (~ 12%))

For the soft mats, the effect of both the humidity and the voltage could be very weak or absent. An example is Sample F, with the voltage dependence at low humidity shown in Figure 3. In contrast to the previous sample, there is very little change in the measured resistance as the voltage changes from 10V to 1000V. In fact the resistance for these mats seems to be unaffected by either voltage or relative humidity. Comparing samples A and F shows that we can not predict in advance how a particular sample would be affected by voltage or humidity.

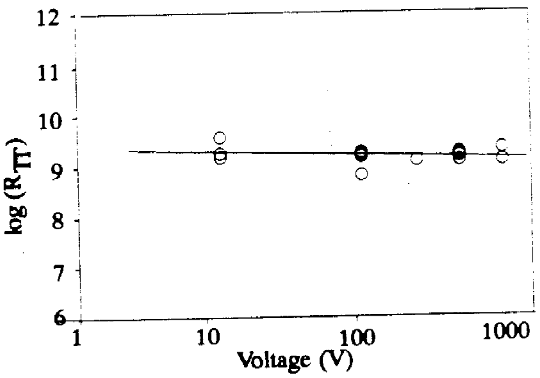

Fig. 3. Voltage effect on Sample F for moderate humidity

When only the single lab which tested every specimen is considered, the standard deviation for ambient and low RH is the same, indicating that the resistance can be measured equally well under both conditions. When all labs are included, however, the deviation is significantly higher for the testing carried out at low humidity. This may reflect differences in test chambers, technique, or RH monitoring among the labs. It is well known that accurate measurement of relative humidity is very difficult at the 12% level, and differences between different meters may well account for the increased spread in the results when the various labs are compared. The size of the chamber also plays a role, since a large chamber shows less change in relative humidity when a sample is introduced. On the other hand, the relative humidity read in a large chamber may not indicate whether the sample has reached equilibrium with the atmosphere, because the water vapor it emits while drying can not change the total amount in a large chamber by very much. All of these effects should be considered in estimating the accuracy of a value reported for low RH.

Sample Size and Electrode Location

On the longer specimens, the electrodes could be placed at three location, labelled left ('L'), middle ('M'), and right ('M'). The small sample had only one position. For the R_{TG} measurement, This was in the center. The locations for the electrodes are indicated in Figure 4.

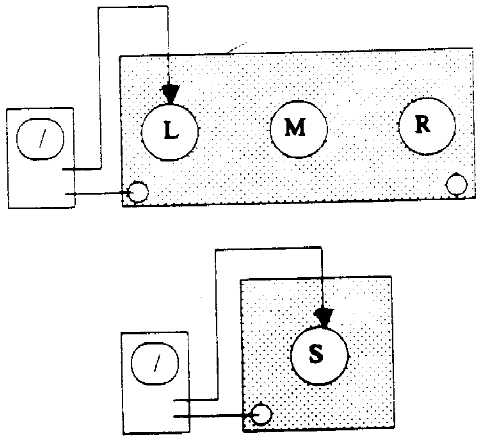

Fig. 4. Electrode locations for the large and small samples

The effect of sample size and electrode configuration, is shown in Figure 5 for all of the specimens lumped together. In these charts, the solid dot indicates the average value, while the tic marks above and below correspond to the standard deviation. There is no significant difference among the three choices for electrode position (L, M, R) on the long sample. This seems strange, since we expect the resistance to be higher over a longer distance. It suggests that most of the resistance appears directly adjacent to the electrode, either as contact resistance or as the resistance of a thin layer over a conducting scrim. Another cause of the insensitivity might lie in the logarithmic dependence of the resistance on the electrode spacing (Appendix.)

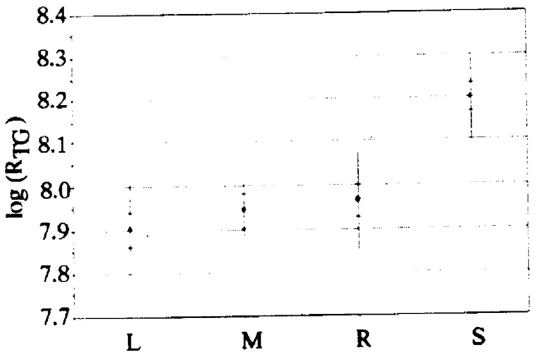

Fig. 5. Effect of electrode position and sample size

The short samples (S) give significantly higher resistance values than the long ones. Fine analysis of these results showed that, in addition, smaller samples had a higher standard deviation, indicating more variation in resistance measurement than the long samples. The larger variation might be related to the difficulty in placing the electrodes on the small sample accurately. There is no plausible reason for the resistance to be higher on a small sample. Neither of these effects is very large, but the longer sample seems to be a better choice, due to its lower variability.

Electrodes

Hard electrodes gave higher and more variable readings than soft electrodes, so they were excluded from consideration in the search for a consistent measurement technique. This agrees with the general view that a hard surface, which is not able to conform to the sample as well, will always give a poorer electrical contact than a soft surface. Of the remaining contenders, the main choice was between soft faced electrodes of the NFPA type. Some of these used foil, as in the NFPA specification, while others used a conductive elastomer (Figure 6). Three of the laboratories had both types available, so their results were analyzed to select the best method.

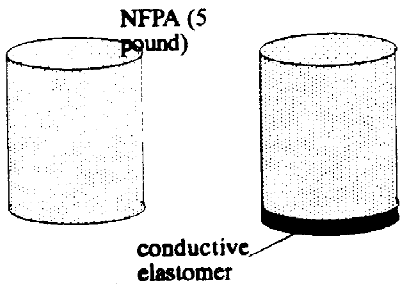

Fig. 6. NFPA electrodes with foil or with conductive elastomer surfaces

A typical hard sample (D) gave the results shown in Figure 6. The conductive elastomer clearly provides the more reproducible result. In addition, the value it gives is lower by about 1/2 decade (a factor of 3). This is consistent with better contact with the sample surface. Similar results are obtained for measurements at low humidity, as shown in Figure 8. The spreads are lower with the foil covered electrode, but the readings follow the same trend as before.

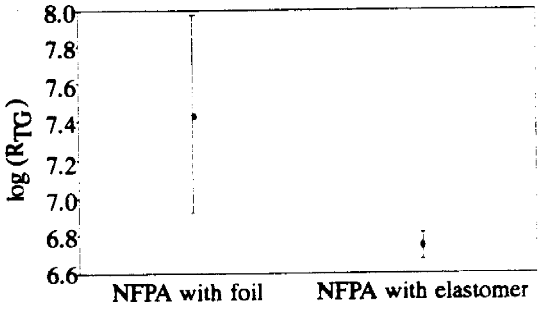

Fig. 7. Effect of electrode surface (sample D, moderate humidity)

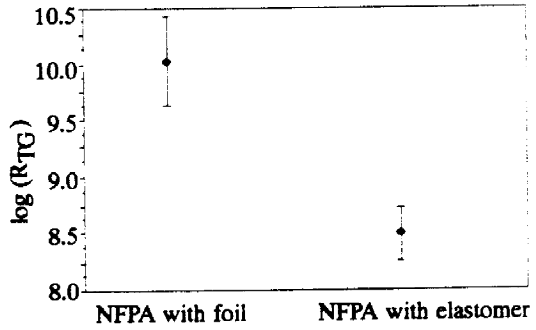

Fig. 8. Effect of electrode surface (Sample D, low humidity)

Other samples, notably the soft mats, showed less variation in resistance. A typical soft sample (F) gave the results shown in Figure 9 at ambient humidity levels. Again, the value is lower for the conductive elastomer, and the spread is somewhat less. At low humidity, the results follow the same general trend, as shown in Figure 10. Here the values are not significantly different, but the spread is less with the conductive elastomer.

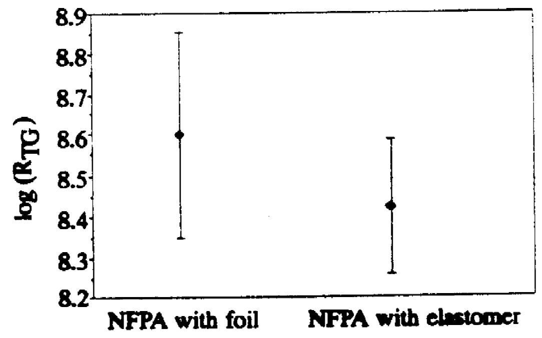

Fig. 9. Effect of electrode surface (Sample F, moderate humidity)

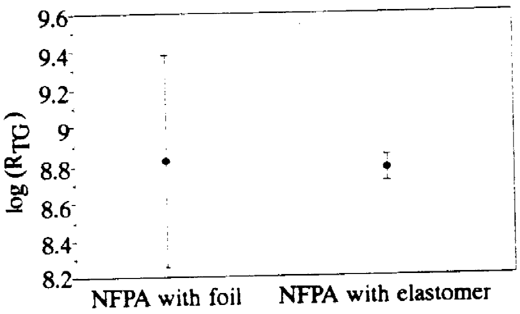

Fig. 10. Effect of electrode surface (Sample F, low humidity)

All four cases were considered here to illustrate the statistical nature of the results. We conclude that the conductive elastomer is, in general, a better choice for the electrode covering, but that does not mean that it will give better results in every case. Instead, it means that if measurements are repeated over a number of cases, the resulting averages are likely to be more reproducible.

Meters

The meters which give several significant figures read more accurately than the LED type, and are preferred for most measurements. Two laboratory grade meters which were used in many of the participating labs, gave the same averages and standard deviations. This is not too surprising, since the variation in measurements is much greater than the accuracy to be expected of such a meter.

Interlab Variation

The analysis also detected variation in the results reported in the different laboratories, as shown in Figure 11. The vertical scale is expanded but this is a significant effect, and appears to be as important as any of the others. There are several possible reasons for the increased variance. Each lab has its own meters and electrodes, some of which are home-made following the same written description, but with some differences in construction. The labs are located in different climates, and although all the measurements were made in the summer, there are large variations in the ambient environment, even in air-conditioned rooms. For some samples, the temperature variation allowed in the testing may have been large enough to cause significant variations in resistance. Also, the samples were shipped from one lab to another, and may have been altered in some way in transit. Whatever the cause, the interlab variation must be considered when assessing the reproducibility of the measurement.

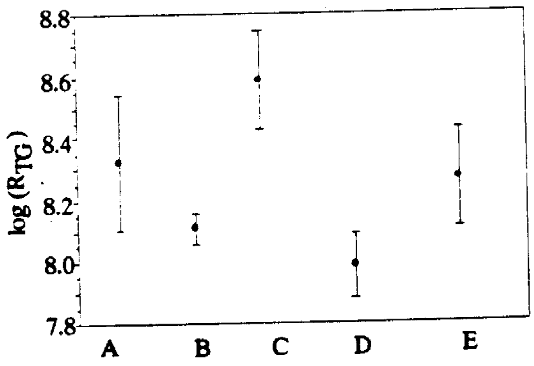

Fig. 11. Inter-laboratory effect for sample D

Surface Resistivity

Since the main thrust of the study was to recommend a method for measuring both R_{TT} and R_{TG}, the analysis of the surface resistivity measurements was not as extensive as that for the other resistances. In general, the same conclusions were reached for the factors which were comparable, such as sample size and electrode position. Some conditions were unique to the surface resistivity, and will be discussed in more detail.

Because there are numerous electrode types used in the surface resistivity measurements, there were often too few cases to justify statistical analysis. In the interests of the analysis, all of the electrodes were divided into two classes, depending on the hardness of the surface which contacts the worksurface. Electrodes with hard surfaces always gave larger SD than the soft surfaced electrodes. This is reasonable, since hard surfaces can not conform at the contact area, and the contact is expected to occur only at isolated points. This increases the contact resistance, and also makes it more variable. Soft surfaces do not suffer as much from this problem, and should be used whenever possible. The NFPA electrodes used for R_{TT} and R_{TG} measurements are both soft, and show less variation than any hard electrode.

Even with the optimum conditions, the surface resistivity measurements all exhibited higher standard deviation than the other two cases. This is somewhat surprising, since the R_{TT} is closely related to surface resistivity. The most likely explanation is the heavier weight of the NFPA electrodes. It is known from other work that increasing the force on the contact, especially with a soft electrode, tends to flatten the peaks and bring more of the surfaces into contact. This will lower the resistance, and also reduce the variability associated with contact. The electrodes used for the surface resistance are all much lighter than 5 pound NFPA electrode, so they would be expected to have a higher, more variable reading.

CONCLUSIONS AND OBSERVATIONS

Recommended Method

Based on the analysis of the data, the optimum configuration for measurement of R_{TG} and R_{TT} with the smallest standard deviation is given in Table 1.

Table 1. Optimum Test Conditions

RH	Approximately 50%
Voltage	Mid (100V) or Hi (500 V)
Size	Large
Position	Average over various locations
Electrode	NFPA with conductive elastomer
Meter	Reads to several significant figures

When a test is run under these conditions, the standard deviation should be on the order of 0.3 (in units of log R). Thus, if the true value is 1.0x10^9, we would expect most of the measurements to lie between 0.5x10^9 and 2.0x10^9. Repeating the test in another laboratory might double that range.

Measurements at low relative humidity show more variability than those at ambient conditions, but many users will have to work at those conditions, or at least qualify workstations there. The results of the testing, as well as general experience, leads to the conclusion that the resistance values can be much higher at low humidity. For this reason, a worksurface should also be tested at a lower value. The value used in the testing (12±3%) is suitable. The temperature should also be specified.

The resistance is least variable for measurements at 100 V or higher, so this is the best choice for single measurements. It is also a convenient value which is available on many meters. Since some materials are strongly affected by changes in voltage, it would be wise to give the resistance at more than one voltage. A good choice for the second voltage is 9 or 10 V, which is also available on meters, and represents a voltage range of current interest in the protection of new devices.

Recommended Method Applied to All Samples

The recommendations presented above have been incorporated, with minor changes, into the proposed draft standard for worksurfaces [EOS 1988]. This is a standard for a measurement procedure, and does not specify values which are required for a worksurface to be acceptable for static protection. It is certainly of interest, however, to know what values the measurement might give on typical worksurfaces.

The results of using the recommended procedure, as culled from the data used in the present report, are presented below for each of the six samples of worksurfaces included in the study. R_{TG} and R_{TT} are presented for the case with the least variation (nominally 50% RH and 100V) and for the stress case which is expected to offer the greatest challenge to a static dissipative worksurface (nominally 12% RH and 10V).

The results are all plotted to the same scale, for ease of comparison with the results obtained under other conditions, and presented below. The first set of results, showing the resitance to ground at moderate humidity and voltage, is presented in Figure 12. The sample types are, from left to right:

D,E	hard dissipative tabletops
F,G	soft dissipative mats
A,B,C	hard dissipative tabletops
H	hard conductive tabletop

The results for each individual worksurface show very little variation, as expected. There is a large variation in the magnitude of the resistance for different worksurfaces, which range from above 10^9 Ω for sample F to less than 10^4 Ω for sample H (below the window of the chart).

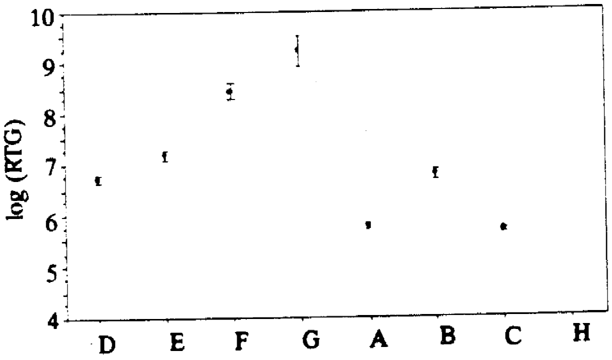

Fig. 12. Measured R_{TG} for all samples (moderate humidity, 100V)

At low humidity and voltage, the variation in the individual measurements (Figure 13) is greater, as expected. Also expected is the general rise in resistance values under these stress conditions. Closer comparison of this figure with the previous one shows that the soft mats (E,F) give different results from the hard tabletops. The mats have a relatively high but constant resistance regardless of the voltage or relative humidity. The hard surfaces, on the other hand, have lower resistances at moderate voltage and humidity, but the values rise to the level of the soft mats under stress. Of course, only a few samples of the available worksurfaces are included here, so individual products may show different results.

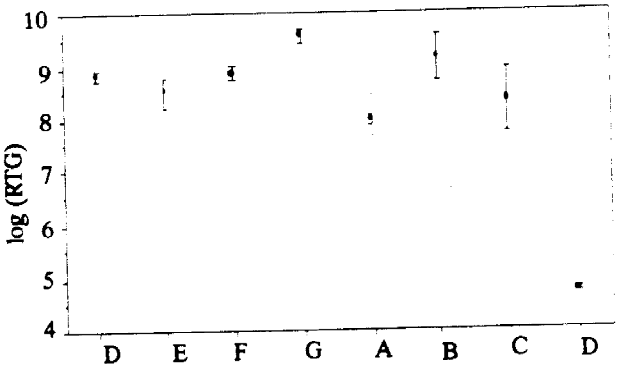

Fig.13. Measured R_{TG} for all samples (lowhumidity, 10V)

It is also interesting to compare these numbers with the values which might be desired to control charge. For example, if a human body with a capacitance of 200 pF makes contact with a worksurface, the charge will be lost in a time which is on the order of the RC time constant of the circuit composed of the body and the worksurface, connected to ground. A desirable value of the time constant might be 1 second, so the resistance to ground (R_{TG}) should be no larger than

$$R_{TG} \le \frac{1 \text{ second}}{200 \times 10^{-12} \text{ farad}} = 5 \times 10^{9}\ \Omega$$

This is comparable with the highest values exhibited by any of the samples tested, even under conditions of low humidity and voltage.

The measurements of the top-to-top resistance (R_{TT}) show similar trends. Results at moderate humidity and voltage are shown in Figure 14. The individual samples show the same relative location as they did for R_{TG}.

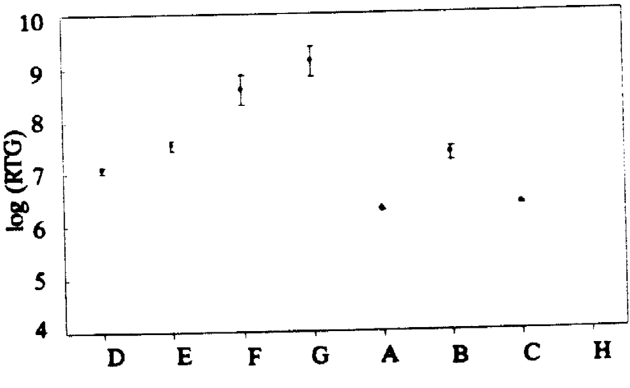

Fig.14. Measureed R_{TT} for all samples (moderate humidity, 100V)

The measurements at low humidity and voltage are shown in Figure 15. Again these are similar to the R_{TG} results, with the exception of the conductive sample (H) which has a resistance too low to make the chart. It should be kept in mind that a high value is to be preferred for R_{TT}, since this parameter is related to the surface resistivity, which must be kept above a certain level to prevent CDM damage. In the Appendix, simple modelling suggests that the value of R_{TT} will be

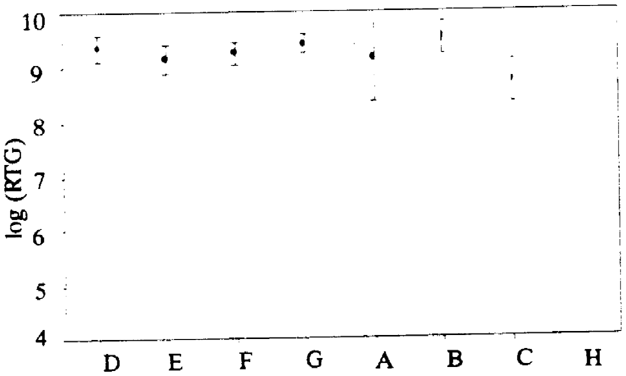

Fig.15. Measured RTT for all samples (low humidity, 10V)

approximately equal to the surface resistivity (within the factor of two to four which is inherent in the test method). Using the minimum surface resistivity of 10^5 Ω/square, as suggested by Bossard et al [1980], and converting this to the approximate value of R_{TT} gives a suggested minimum value for this parameter as

$$R_{TT} \geq {\sim}10^5\ \Omega$$

This minimum value is exceeded by all of the tested samples except for the conductive worksurface. Thus the measurement technique suggested here not only provides a result that is relatively reproducible, but it also gives resistance values consistent with the performance to be expected from a static dissipative worksurface, based on both the human body model and the charged device model.

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ACKNOWLEDGMENTS

We would like to thank Harold Aronson, who obtained and prepared all of the speciments used in the testing. This work was supported in part by the EOS/ESD Association.

APPENDIX: RELATION BETWEEN R_S AND R_{TT}

If two circular electrodes of diameter d make perfect contact with an infinite surface having a surface resistivity of R_S, the resistance between the electrodes is given [Edmonds and Corson 1986] as

$$R = \frac{R_S}{\pi} \ln\left[\frac{L}{d} + \sqrt{\left(\frac{L}{d}\right)^2 - 1}\right]$$

where L is the center to center spacing of the electrodes.

This resistance is equivalent to the resistance R_{TT} described above, if the worksurface is truly represented by a thin conductive surface layer which extends very far away from the electrodes over an insulative substrate. If the current can penetrate into the depth of the worksurface, then surface resistivity is too simple a concept to represent the conduction of current between the electrodes, and the relation above is only approximate. This is likely to be the case when the lateral conduction is furnished by a conductive layer buried inside the worksurface, when a lower measured resistance is expected.

If the sides of the sample are not very far away, then the current flow will be constricted, and the measured resistance will be higher than expected based on the formula given above. This will be true for both of the sample sizes used in the testing, but especially for the smaller sample. In both samples, as least one of the electrodes is placed within 2 inches of the edge in making R_{TT} measurements, so we normally expect the measured values to be higher.

While these restrictions mean that surface resistivity and R_{TT} are not simply related, this formula can still be used as an approximate relation. For the electrodes used in the tests, the diameter of the electrodes is 2.5 inches (6.35 cm). The center to center spacing of the electrodes is 8.75 inches (22.2 cm) when the center and side locations are selected on the 10 x 24 inch specimen, or 17.5 inches (44.5 cm) for the side to side configuration. Using these values gives an estimated relation as

$$R_{TT} \approx 0.61\ R_S$$

for side to center spacing, and

$$R_{TT} \approx 0.84\ R_S$$

for side to side spacing. Compared to the reproducibility expected in this measurement (a factor of two), there is very little difference in the estimated value forR_{TT}, indicating that electrode spacing may not be crucial. Coincidentally, the magnitude of the predicted R_{TT} value is close to the magnitude of R_S, indicating that theR_{TT} measurement can also serve as a fairly good estimate of surface resistivity.