Evaluation of Materials for Cleanliness and ESD Protective Properties

Tom Lesniewski and Kenn Yates
TRW Space and Electronics Group, One Space Park R6/1575, Redondo Beach, CA 90278
Tel (310) 813 3860, fax (310) 813 2447, email tom.lesniewski@trw.com

Measurements were done on nearly 90 products to determine their cleanliness and ESD protective properties. Categories of materials tested include floor tiles and mats, gloves, finger cots, bags and sheeting materials, garments, swabs and wipes. A variety of test methods was used to evaluate the materials. The results showed that few products had both nonvolatile residue less than 1 mg/ft^2 and static dissipative properties. Suggestions for improvement are made for some of the products and materials.

Introduction

Electrostatic discharge (ESD) control in cleanrooms is becoming increasingly important as more companies build hardware that is sensitive to damage or degradation from both contamination and electrostatic discharge. Therefore, it is critical to control the materials that come in contact with or are near sensitive hardware.

"ESD protective materials" are desirable to since they have at least one of the following properties: they prevent the generation of static, dissipate electrostatic charges, or provide shielding from electrostatic fields/ESD. Moreover, an ESD protective material attracts less particulate contamination to its surface than an insulative material since fewer charges are generated and accumulated on its surface (particles are attracted to charged surfaces).

Although several vendors tout their products as "clean and ESD" materials, very little public data is available on electrical properties and cleanliness of the materials. Cohen and Blankstein (1998) reported on the hazardous airborne components that may outgas from materials, and related health issues. A study of cleanroom/ESD garment fabrics was done by Boone (1998). More data are needed to identify the best types of materials and areas where more development is needed.

In 1999, TRW Materials & Processes groups commenced a study of cleanliness and ESD protective properties of materials study. Nearly 90 products were tested for electrical properties and molecular residue. Particulate cleanliness and environmental testing were also performed on some of the products. Other considerations in the choice of packaging and handling materials include cost, outgassing, flame retardance, and fuel compatibility. These properties were not covered in this study.

The goals of the study were to

- Identify categories of materials commonly used in cleanrooms where ESD sensitive items were handled, and for which no product had been previously approved.
- Determine suitable test methods and standards/requirements for evaluating the materials.
- Obtain samples, test them, and report the results.
- Phase out the less effective materials currently being used at TRW and promote usage of better materials.

The purpose of this paper is to objectively report the results and trends of the study. The data should not be construed as recommendations by the authors for or against individual products. Rather, the results should be interpreted in terms of trends among different categories of materials and should be used as a guide for matching categories of materials with suitable applications. The reader should recognize that each application has a set of unique requirements, for which different products may be better suited than others.

I. Tests

I.a. Types of Materials Tested

Over the past several years, materials and processes engineers at TRW were repeatedly asked to provide recommendations and/or evaluations of materials that could be used to safely process hardware sensitive to both ESD and contamination. Specifically, there were needs for garments, gloves, finger cots, floor tiles, floor and table mats, packaging products, swabs and wipes. In the past, these products were typically tested in separate labs for cleanliness *or* ESD protection, but not both. In response to the requests, a concerted effort was made meet the needs.

To find products that might be suitable, brochures, catalogs and specification sheets were surveyed. In most cases, the tested products were samples sent by vendors or distributors. Wherever possible, attempts were made to avoid “cherry picked” samples that were given special treatment for qualification testing. The number of products tested is obviously a small subset of the products available on the market.

I.b. Methods and Standards

Table 1 summarizes the test methods used to evaluate different materials.

I.b.1. Cleanliness Testing

The ideal “clean” material would not transfer molecular or particulate species from its surface. In reality, most materials readily lose compounds by evaporation, extraction or friction. The amount of molecular contamination released from a material usually increases with temperature, while particle shedding is often exacerbated by agitation or stress on the edges of a material. Tests were chosen to simulate conditions that a product might see in a lab or manufacturing area.

Most of the products were tested for nonvolatile residue (NVR) with a modified version of ASTM E1731M or ASTM E1560. These two methods are very similar and determine the amount of extractable contamination, both molecular and particulate, on the surface of the sample.

For gloves, finger cots, and swabs, the sample was placed in a 50 ml, room temperature ultrasonic bath of isopropyl alcohol (IPA) at room temperature for 5 minutes. Wipes were immersed in acetone. Floor and bag/sheet materials were wiped with IPA. The reagents were suitable for residue analysis. The solution was then filtered (Whatman #41 ashless filters). Solvent was evaporated until the filter weight stabilized, and the residue remaining on the filter was weighed using a calibrated Mettler Toledo AT201 scale.

Results are given as mass of nonvolatile residue (NVR) per surface area of material. Standards for NVR vary company-by-company, based on product requirements. For example, a common benchmark is that materials used in Class 10,000 cleanrooms have NVR values less than 1 mg/ft^2.

“Tape pulls” per ASTM E1216 were used to test garments and wipers for fiber shedding and particulate contamination. A piece of pressure sensitive tape was pressed onto the material, then quickly removed. In this study, 3M type 610 tape was used. The number of fibers and particles adhering to the tape was counted under a microscope and translated to concentration of particles and fibers (per surface area of material).

Two other methods were used to evaluate airborne particulate, either by passing filtered air through the material per ASTM F51-68 or by agitating the material in a box (see Figure 1). The particle concentration was measured with a particle counter and normalized by the surface area of source material.

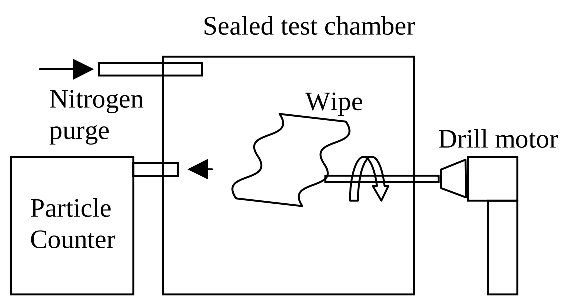

Figure 1. Modified agitation test for measuring airborne particulate from wipes.

Allowable particulate contamination is dictated by various classes of cleanliness, per FED-STD-209. For example, “Class 100 (at 0.5 μm)” describes areas where the maximum concentration of particles 0.5 μm and larger is less than 100 particles per cubic foot of air. Other documents, for example ASTM F51-68, describe tests to determine the particulate contamination in and on specific materials. In this study, airborne particulate and/or shedding

Table 1. Tests Methods for Material Evaluation								
		Category of Material						
Test	**Method/Reference**	**Floors**	**Bags/ Sheeting**	**Gloves**	**Finger Cots**	**Swabs**	**Wipes**	**Garments**
Electrical								
Surface Resistivity or Resistance 50% humidity	ASTM D257 or ANSI/ EOS/ESD-S11.11-1993	√	√	√			√	
Surface Resistivity 15% humidity	ASTM D257 or ANSI/ EOS/ESD-S11.11-1993	√	√	√			√	
Volume/Bulk Resistivity	ASTM D257 or point-to-point test	√	√	√		√	√	
Static Decay Time	FTM 101C Method 4046 or modified decay test	√	√	√	√		√	
Resistance to ground	ANSI/ESD-S7.1-1994	√						
Point-to-point resistance	ANSI/ESD-S7.1-1994, ESD STM2.1-1997, or ESD Journal ATP G1000	√		√	√			√
Finger-to-body resistance	ESD Journal Approved Test Procedure G1000			√	√			
Palm-to-body resistance				√	√			
Triboelectric charge generation	ESD Journal ATP G1000			√	√	√		
Electromagnetic Field Attenuation	EIA 541 Appendix E modified method		√					
Cleanliness								
Non Volatile Residue (NVR)	ASTM E1731M-95 or ASTM E1560M-95	√	√	√	√	√	√	
Tape Pull Test (particle shedding)	ASTM E1216-87						√	√
Airborne Particle Count	ASTM F51-68 or modified agitation test						√	√
Other								
Environmental/ Durability test	Properties tested after high temp & humidity or 50 washes (garments)	√						√
Solvent Resistance	Properties tested after exposure to solvents	√					√	

tests were completed for woven materials but not for plastic materials. Another relevant material property for cleanrooms, outgassing, was not evaluated in this study.

I.b.2. ESD Protection

As shown in Table 1, a variety of tests was used to evaluate the materials' electrical properties. Established test methods, as prescribed in ESD Association or ASTM Standards, were used on most of the materials. For evaluation of ESD protective materials, the most common property to test is surface resistivity or surface resistance of a material since that provides a measure of how well the material dissipates electrical charge incurred on its surface. The surface resistivity of static dissipative materials is between 10^5 and 10^{12} ohms/square when tested per ASTM D257 or ANSI/EOS/ESD-S11.11-1993.

The measurements were made with calibrated instruments. Surface and volume resistivity were measured with an HP 4329A high resistance meter, coupled with a HP 16008A Resistivity Cell, in a humidity chamber controlled with a Hygrodynamics humidity meter. A MILLI-TO 2 Dr. Thiedig resistance meter with ETS model 803B and 850 probes were also used to make resistance measurements.

For sleeve-to-sleeve resistance measurements on garments, a 3M 701 Megohmmeter was used. Static decay times were measured with an ETS 406C meter. Field attenuation was measured on shielding bags with a Monroe Electronics Model 268 Charged Plate Analyzer and a Simco SS-2X field meter. The charged plate was also used in the tribocharging experiments.

Most standard test methods required a minimum sample size, and some of the materials, such as finger cots and swabs, were too small to be tested. Nonstandard test methods were used to evaluate those materials. For example, the resistance across swab handles was measured across two clips placed at opposite ends of the handle.

In other cases, standard test methods provided results on material properties, but not a realistic evaluation of how the material would perform in its application.
For example, surface resistivity is an appropriate test for packaging materials, floors and garments, since charge dissipates across the surface of those materials.

However, for gloves or finger cots, although surface resistivity provides an indication of ESD protection, the more direct path to ground is *through* the material to a grounded hand, rather than *across* the surface. Another concern with gloves and finger cots is the amount of tribocharge that can be generated on the fingertips. Therefore, finger-to-body resistance and tribocharge generation were more insightful measurements than surface resistivity for gloves and finger cots, and were included in the evaluation.

I.b.3. Other Tests

Floor tiles and mats were conditioned at high temperature and humidity (85°C/85% RH) for 100 hours to determine if they would crumble and shed particles over time. Separate samples were immersed in IPA and acetone to test for solvent resistance. The electrical properties were also measured after the conditioning and solvent exposure.

To evaluate the durability of ESD garments, they were subjected to 50 washes and tested for point-to-point and sleeve-to-sleeve resistance both before and after washing. Washes were performed at company-approved industrial laundering facilities.

Besides performance, an overriding consideration for all materials was cost. Some cost estimates are provided, but thorough pricing assessments are left to the user.

II. Results

Tables 2-10 give data for different categories of materials. Each number represents the average of 2 or 3 data points for each material, depending on availability of material. Entries were marked “N/a” either because the test was deemed not appropriate or there was insufficient sample for test.

III. Discussion

For many types of materials, no product had both static dissipative properties and NVR less than 1 mg/ft^2, and a general trend was that there was a tradeoff between ESD protection and cleanliness.

III.a. Floor Materials

Almost all of the floor materials had acceptable ESD properties. Several floor mats showed excellent ESD properties, but NVR values were high compared with the best floor tiles. Based on these results, from a contamination control standpoint, permanently-installed floor tiles are superior to floor mats. It appears that industrial capabilities are approaching the point where static dissipative vinyl floors with NVR less than 1 mg/ft^2 and low outgassing will be available.

III.b. Swabs

Two general types of swabs were tested: general-purpose wooden-handled ones, and plastic-handled ones designed specifically for cleanliness and ESD protection. The swabs had a variety of head materials, including foam, polyester and cotton. When rubbed against metallic or insulative materials, all of the swab heads charged to less than 50 V. The swab handle materials all had acceptable resistivity.

Table 2. ESD & Cleanliness Testing of Floor Materials										
Sample	**Static Decay Time from 5000 V**		**Surface Resistivity 50% humidity (Ω/sq)**	**Surface Resistivity 15% humidity (Ω/sq)**	**Resistance to Ground (Ω)**	**Volume Resistivity ($\Omega \cdot$cm)**	**Solvent Resist. (sfc. res. after IPA & acetone)**	**85/85 Test (sfc. res. after 100 hours at 85% humidity & 85°C)**	**Contamination Nonvolatile Residue (mg/ft^2)**
	To 500V	**To 100V**							
VPI Conductile Con 2 Floor Tile	0.01 s	0.01 s	$1.8x10^8$	$1x10^9$	$6x10^7$	$7x10^{10}$	Pass	Pass	19.5
VPI Conductile LE	0.01 s	0.01 s	$9.4x10^8$	$1x 10^6$	$1x10^9$	$6x10^{10}$	N/a	N/a	3.47
VPI Conductile XLE	0.01 s	0.01 s	$1x10^9$	$1x10^6$	$1x10^9$	$2x10^9$	N/a	N/a	1.31
Flexco Dissipative Floor Tile	0.01 s	0.01 s	$2.3x10^6$	$2.1x10^8$	$2x10^6$	$2x10^{10}$	Pass	Pass	13.7
Forbo Colorex 5201 Floor Tile	0.01 s	0.01 s	$8x10^8$	$1x10^9$	$5x10^6$	10^{10}	Pass	Pass	29.8
Dätwyler 6090 Unifloor Mat	0.01 s	0.01 s	$1x10^8$	$1x10^9$	$3x10^6$	$3x10^8$	Pass	Pass but color faded	1.79
Westek Decade 5300 Mat	0.01 s	0.01 s	$1.9x10^6$	$7.5x10^7$	$1.2x10^6$	$<10^5$	Pass	Pass	26.4
Tek Stil 6015 Conductive Unifloor Mat	0.01 s	0.01 s	$7.5x10^8$	$1x10^9$	$3x10^6$	$6x10^7$	Pass	Pass	N/a
Tek Stil 7294 Static Dissipative Unifloor Mat	0.01 s	0.02 s	$5.1x10^8$	$1x10^9$	$3x10^6$	$6x10^7$	N/a	Pass	12.3
Ergomat Gray Polyethylene	0.03 s	0.1 s	$2x10^{10}$	$9x10^{10}$	$1x10^8$	$4x10^9$	N/a	Fail—crumbled	21.6
Clean ESD Blue Polyethylene Mat	0.01 s	0.08 s	$2x10^9$	$2x10^9$	$7x10^7$	$8x10^9$	N/a	Pass	53.8
Norament 928 al S grano (as installed)	N/a	N/a	N/a	N/a	$2x10^8$	N/a	N/a	Pass	N/a
Noraplan mega al rubber (as installed)	N/a	N/a	N/a	N/a	$1x10^8$	N/a	N/a	Pass	N/a
3M 8414 Dissipative Blue	0.01 s	0.01 s	$6x10^7$	$1x10^8$	$1x10^9$	N/a	N/a	N/a	N/a
Clean Zone Static Dissipative Mat (blue side)	0.02 s	0.18 s	$4x10^9$	$4x10^9$	$1x10^9$	$2x10^{10}$	N/a	N/a	68.3

Table 3. ESD and Contamination (NVR) Testing on Gloves									
Sample	**Surface Resistivity 50% RH (Ω/sq)**	**Surface Resistivity 15% RH (Ω/sq)**	**Volume Resistivity 50% RH (Ω cm)**	**Static Decay Time 15% RH (seconds)**	**Palm to Finger Resistance (Ω)**	**Finger to Body Resistance (Ω)**	**Palm to Body Resistance (Ω)**	**Triboelectric Charge Generation (V)**	**Contamination--Nonvolatile Residue (mg/ ft^2)**
MAPA Rollpruf 716 Latex	$1 X 10^{10}$	$6 X 10^{14}$	$2 X 10^{14}$	> 10	$1 X 10^{10}$	$1 X 10^{10}$	$8 X 10^{9}$	701	3.16
Oak Technical clear vinyl	$7 X 10^{13}$	N/a	$1 X 10^{12}$	0.4	$2 X 10^{11}$	$7 X 10^{6}$	$5 X 10^{6}$	90	> 300
AQL NXT 100 white nitrile	$1 X 10^{10}$	$2 X 10^{13}$	$1 X 10^{11}$	5.8	$1 X 10^{8}$	$2 X 10^{7}$	$7 X 10^{6}$	25	13.2
Chem Soft white nitrile	$6 X 10^{12}$	$2 X 10^{13}$	$2 X 10^{12}$	2.6	$5 X 10^{11}$	$1 X 10^{8}$	$2 X 10^{7}$	136	1.02
Allied High Tech blue nitrile	$9 X 10^{11}$	$2 X 10^{13}$	$1 X 10^{11}$	> 5	$1 X 10^{8}$	$2 X 10^{7}$	$4 X 10^{6}$	44	3.9
QRP blue nitrile HR 12PM	$2 X 10^{12}$	> 10^{14}	$7 X 10^{12}$	3.3	N/a	N/a	N/a	N/a	7.6
Polygenex 3210 ESD white cloth	$5 X 10^{13}$	> 10^{14}	$2 X 10^{10}$	0.01	> 10^{12}	$5 X 10^{6}$	$2 X 10^{7}$	18	N/a
Tech Styles white cloth	$2 X 10^{6}$	< 10^{7}	< 10^{7}	0.01	$1 X 10^{7}$	$1 X 10^{6}$	$2 X 10^{6}$	17	N/a
Duraclean clean polyurethane	$7 X 10^{11}$	$8 X 10^{12}$	$1 X 10^{12}$	0.3	$2 X 10^{10}$	$6 X 10^{6}$	$2 X 10^{6}$	78	4.9
Safeskin Hypoclean Critical copolymer	$5 X 10^{12}$	$3 X 10^{13}$	$1 X 10^{10}$	0.2	$4 X 10^{10}$	$2 X 10^{6}$	$3 X 10^{6}$	87	1565
Safeskin Hypoclean nitrile	$3 X 10^{12}$	$2 X 10^{13}$	$1 X 10^{11}$	3.0	$1 X 10^{12}$	$7 X 10^{6}$	$2 X 10^{7}$	160	9.6
Safeskin Hypoclean latex	$2 X 10^{13}$	> 10^{14}	$3 X 10^{14}$	> 10	$8 X 10^{10}$	$3 X 10^{11}$	$2 X 10^{12}$	338	N/a
CLEAN-DEX blue nitrile C9905PFL	$1 X 10^{13}$	$4 X 10^{13}$	$3 X 10^{12}$	5.2	$7 X 10^{10}$	$6 X 10^{6}$	$2 X 10^{7}$	60	14.1
N-DEX blue nitrile 60005PFL	$4 X 10^{10}$	$2 X 10^{13}$	$5 X 10^{11}$	5.9	$2 X 10^{10}$	$4 X 10^{6}$	$2 X 10^{7}$	80	22.1
Phoenix Medical 1603 clear vinyl	$1 X 10^{13}$	$2 X 10^{13}$	$7 X 10^{11}$	0.6	$3 X 10^{11}$	$7 X 10^{6}$	$7 X 10^{6}$	178	776
Phoenix Medical 1703 pink vinyl	$1 X 10^{13}$	$1 X 10^{13}$	$4 X 10^{11}$	0.2	$8 X 10^{10}$	$6 X 10^{6}$	$4 X 10^{6}$	134	1225

Table 4. ESD and Contamination Testing of Finger Cots

Sample	Static Decay Time (seconds) 15% humidity	End to End Resistance (Ω) 50% humidity	Finger to Body Resistance (Ω) 50% humidity	Triboelectric Charge Generation (V) 50% humidity	Contamination Nonvolatile Residue (NVR, mg/COT)
LC56 white latex	> 5	1×10^{13}	2×10^{7}	485	0.59
QRP 7C700 pink latex	> 5	3×10^{10}	2×10^{7}	47	0.53
North Safety Products black	0.01	9×10^{8}	2×10^{6}	8	0.34
Clean ESD 480 white Regular non powered	>5	1×10^{8}	2×10^{7}	923	0.55
Clean ESD 490 white Antistatic super clean	>5	5×10^{9}	2×10^{7}	74	0.44
Clean ESD 492 pink Antistatic super clean	>5	1×10^{10}	1×10^{9}	36	0.55
Clean ESD 494 black Static dissipative super clean	0.01	6×10^{9}	2×10^{6}	7	0.74

Table 5. ESD and Cleanliness Testing of Swabs					
Sample	**Swab Material**	**Bulk Resistivity of Handle (Ω·cm) 50% humidity**	**Tribocharge on Conductor (V) 50% humidity**	**Tribocharge on Insulator (V) 50% humidity**	**Contamination Nonvolatile Residue (mg/swab)**
Texwipe TX740E	Foam	1.0×10^8	9	46	0.01
Texwipe TX742E	Foam	2.3×10^8	7	14	0.01
Texwipe TX768E		N/a	N/a	N/a	0
Texwipe TX750E		N/a	N/a	N/a	0
Texwipe TX751E	Foam	1.4×10^8	8	10	0
Texwipe TX753E	Foam	1.8×10^8	5	20	0.01
Texwipe TX754		N/a	N/a	N/a	0
Texwipe TX757E	Foam	1.9×10^8	8	45	0.01
Texwipe TX758E	Polyester	1.4×10^8	12	40	0
Texwipe TX759E	Polyester	2.0×10^8	9	49	0
Texwipe TX765E	Polyester	1.6×10^8	5	26	0.02
Texwipe TX769E pick	None (pick)	1.7×10^8	7	10	0.02
Coventry SA-41050	Foam	8.2×10^8	9	10	0.51
Coventry SA-31050	Polyester	5.0×10^8	11	26	0.05
Puritan—wooden handle	Cotton	2.1×10^9	17	45	0.27

Table 6. ESD and Contamination Testing on Wipers										
Sample	**Surface Resistivity (Ω/sq) 50% humidity**	**Surface Resistivity (Ω/sq) 15% humidity**	**Saturated with IPA--Surface Resistivity (Ω/sq) 50% humidity**	**Volume Resistivity (Ω cm) 50% humidity**	**Static Decay Time (seconds) 15% humidity**	**Triboelectric Charge Generation (V)**	**Finger to Body Resistance (Ω)**	**Nonvolatile Residue (mg/ft^2)**	**Airborne Particulate ($part/ft^2$)**	**Tape Lift Particulate ($fibers/ft^2$)**
Texwipe TX 1109	$1x10^{13}$	$> 10^{14}$	N/a	$1x10^{13}$	N/a (discharge > 0 V)	69	$2x10^6$	28.4	$3x10^5$	N/a
Texwipe TX 4025	$1x10^9$	$> 10^{14}$	$3x10^7$	$3x10^7$	0.01	12	$1x10^6$	3.27	N/a	1168
Kimberly Clark Precision Wipes	$7x10^{12}$	$> 10^{14}$	$6x10^{11}$	$5x10^{12}$	N/a (discharge > 0 V)	57	$1x10^6$	1.95	$4x10^5$	N/a
Milliken Anticon Black Gold II	$1x10^{14}$	$> 10^{14}$	$2x10^7$	$6x10^{13}$	> 5	850	$7x10^7$	N/a	N/a	854

Table 7. ESD & Cleanliness Testing of Nonmetallized Sheeting/Bagging Materials							
Sample	**Static Decay Time from 5000 V**		**Surface Resistivity 50% humidity (Ω/sq)**	**Surface Resistivity 15% humidity (Ω/sq)**	**Volume Resistivity 50% humidity (Ω·cm)**	**Contamination Nonvolatile Residue (mg/ft^2)**	**Approx. Cost (per ft^2)**
	To 500V	**To 100V**					
Cleanfilm Inc Antistatic Nylon	> 5 s	>5 s	$2x10^{12}$	$> 10^{16}$	$1x10^{12}$	0.02	0.32
Cleanfilm Nylon Tubing	> 5 s	>5 s	$2x10^{13}$	$> 10^{16}$	$7x10^{13}$	0.05	0.09
Cleanfilm Bear Poly Tubing	> 5 s	>5 s	$3x10^{13}$	$> 10^{16}$	$>10^{16}$	0.26	0.08
Cleanfilm ULO Poly Tubing	> 5 s	>5 s	$4x10^{13}$	$> 10^{16}$	$>10^{16}$	0.02	N/a
Cleanfilm Aclar 33C sheet	> 5 s	>5 s	$2x10^{14}$	$> 10^{16}$	$>10^{16}$	0.02	1.33
Cleanfilm Antistatic Bear Poly	4.0 s	9.0 s	$3x10^{11}$	$2x10^{13}$	$3x10^{13}$	0.26	N/a
RCAS 2400 nylon	> 5 s	>5 s	$3x10^{13}$	$> 10^{16}$	$4x10^{12}$	0.34	N/a
RCAS 1206P (“pink poly”)	0.24 s	1.8 s	$4x10^{10}$	$3x10^{11}$	$4x10^{12}$	3.3	0.15
Richmond MDPE	> 5 s	>5 s	$>10^{16}$	$> 10^{16}$	$6x10^{16}$	0.03	N/a
Richmond A-124	> 5 s	>5 s	$3x10^{12}$	$> 10^{16}$	$3x10^{13}$	0.04	N/a
Static Intercept sheet	0.01 s	0.01 s	$2x10^{5}$	$< 10^{9}$	$4x10^{12}$	0.23	0.14
Benstat blue poly	0.03 s	0.18 s	$6.9x10^{9}$	$8.4x10^{10}$	$8x10^{12}$	N/a	N/a
SECO amine free clear bubble wrap	0.7 s	4.0 s	$8x10^{10}$	$1x10^{12}$	$3.2x10^{15}$	0.64	0.09
LF&P opaque polyethylene 8900C	1.7 s	3.2 s	$3x10^{10}$	$2x10^{12}$	N/a	< 1.0	0.12

Table 8. ESD & Cleanliness Testing of Metallized Sheeting/Bagging Materials							
Sample	**Static Decay Time from 5000 V**		**Surface Resistivity 50% humidity**	**Surface Resistivity 15% humidity**	**Field Attenuation (measured 2" from 5000 V source)**	**Contamination Nonvolatile Residue**	**Approx. Cost**
	To 500V	**To 100V**	**(Ω/sq)**	**(Ω/sq)**	**(V)**	**(mg/ft^2)**	**(per/ft^2)**
RCAS 4150	0.01 s	0.04 s	$2x10^{10}$ inner & outer	$8x10^{11}$	30	0.49	0.17
RCAS 4200	0.01 s	0.01 s	$5.0x10^{8}$ inner & outer	$2.1x10^{8}$	20	1.9	0.17
Richmond Drypack 3750 bag	0.01 s	0.01 s	$1x10^{8}$ inner & outer	$1x10^{9}$	20	13.24	N/a
Richmond Drypack 9000 bag	0.01 s	0.01 s	$1.9x10^{6}$ inner & outer	$7.5x10^{7}$	20	2.73	N/a
NMD FR#48PA1-NY	0.01 s	0.03 s	$3.4x10^{11}$ outer layer $4.0x10^{12}$ inner layer	$2.2x10^{13}$ outer layer $5.1x10^{13}$ inner layer	20	0.27	N/a
NMD FR#48PA1-NNY	0.01 s	0.03 s	$2.6x10^{10}$ outer layer $7.1x10^{12}$ inner layer	$1.6x10^{12}$ outer layer $3.8x10^{14}$ inner layer	80	0.16	N/a
NMD FR#100PA1-N	0.01 s	0.01 s	$2.1x10^{10}$ outer layer $2.7x10^{12}$ inner layer	$3.0x10^{13}$ outer layer $5.1x10^{13}$ inner layer	20	0.02	0.33
NMD FR#190PA1-NN	0.01 s	0.02 s	$1.1x10^{11}$ outer layer $9.4x10^{12}$ inner layer	$2.1x10^{13}$ outer layer $1.2x10^{15}$ inner layer	260	0.35	0.54
Caltex CP Stat 100 metallized sheet/bag	0.01 s	0.01 s	$1.7x10^{9}$ inner & outer	$5.8x10^{11}$	20		0.17
Cleanfilm Shielding sheet	0.01 s	0.03 s	$1.3x10^{14}$ outer layer $> 10^{16}$ inner layer	$2.0x10^{15}$ outer layer $> 10^{16}$ inner layer	70	0.18	N/a

Table 9. Electrical Resistance Measurements on Garments					
Garment	**Point-to-point resistance (ohms)**		**Sleeve-to-sleeve resistance (ohms)**		**Sleeve-to-sleeve resistance (ohms) at 15% humidity after 50 washes**
	Before Washing	**After 50 Washes**	**Before Washing**	**After 50 Washes**	
Angelica coat	$4x10^{5}$	$3x10^{6}$	$3x10^{9}$	$>10^{11}$	$>10^{11}$
NSP coat	$9x10^{4}$-$2x10^{5}$	$9x10^{4}$	$2x10^{5}$-$6x10^{7}$	$2x10^{9}$-$4x10^{9}$	$1x10^{10}$
Prudential AB 5800 cleanroom	$2x10^{7}$	$7x10^{7}$-$1x10^{10}$	$9x10^{7}$-$3x10^{8}$	$1x10^{10}$-$6x10^{10}$	$3x10^{10}$
Red Kap Static Control Tech Coat	$8x10^{6}$	$2x10^{6}$	$1x10^{11}$	$>10^{11}$	$>10^{11}$
Red Kap ESDiffuse Tech Coat	$9x10^{4}$	$1x10^{5}$	$2x10^{5}$	$7x10^{5}$	$3x10^{5}$
Red Kap Cleanroom	$1x10^{8}$	$1x10^{8}$	$1x10^{8}$	$3x10^{10}$	$1x10^{10}$
Tech Wear OFX-100	$2x10^{5}$	$8x10^{5}$-$5x10^{6}$	$8x10^{5}$-$1x10^{6}$	$1x10^{7}$-$2x10^{7}$	$1x10^{6}$
TW Clean cleanroom	$1x10^{5}$	$2x10^{5}$	$3x10^{5}$	$2x10^{6}$	$6x10^{5}$
Tyvek frock (disposable)	$2x10^{7}$	(not washed)	$8x10^{7}$	(not washed)	$4x10^{9}$ (not washed)

Table 10. Particle Shedding Measurements on Garments				
Garment	**Material**	**Tape Pull Test (fibers & particles)/ft^2**	**Airborne Particulate per ASTM F51-68 (fibers & particles)/ft^2**	
		After 50 Washes	**After 25 Washes**	**After 50 Washes**
Angelica coat	80% polester/20% cotton	5500	1200	1080
NSP coat	62% polyester/32% cotton/6% Naptex	5500	1160	1480
Prudential AB 5800 cleanroom frock	Polyester	250-900	N/a	N/a
Red Kap Static Control Tech Coat	98% polyester/2% carbon-nylon	1584	400	480
Red Kap ESDiffuse Tech Coat	87% polyester/13% carbon-nylon	998	560	400
Red Kap Cleanroom frock	100% polyester	216	480	280
Tech Wear OFX-100 coat	Polyester/nylon/ carbon	1600-1700	800	280
TW Clean cleanroom frock	98% polyester/2% carbon	288	N/a	400
Tyvek frock (disposable)	Tyvek	Material tore (not washed)	N/a	N/a

Table 5 shows that most of the polyester or foam swabs had much lower NVR than cotton. Therefore the "ESD swabs" are better suited for contact with contamination sensitive items than cotton swabs. Since the surface area of each swab (including handles) was near 1 square inch, the corrected NVR values ranged from 0 to 1.2 mg/ft^2 when tested with IPA (higher with acetone).

III.c. Wipes

Only a small sample of commercially-available wipes was tested. Two general categories of wipes were tested, those made of less expensive cellulose material, and more expensive woven wipes. Although the surface resistivity of low-cost disposable wipers was high, triboelectric charge generation and finger to body resistance was low. A wipe specifically made for contact with ESD sensitive hardware gave much better electrical properties but the NVR and particle shedding results were inconclusive.

III.d. Gloves

One of the most pressing needs was to find a glove that was clean and ESD protective, but it proved quite difficult to find. The test results showed that most low-residue gloves are highly insulative. Of the types of gloves tested in this study, nitrile showed the best combination of cleanliness and static dissipation, compared with vinyl or latex.

ESD protective properties of vinyl gloves were better than latex ones, but not as good as nitrile. However, vinyl gloves should be avoided in cleanrooms due to their very high NVR values. Cloth gloves showed promise as ESD protective materials, but their propensity to shed eliminated them from consideration as a cleanroom material.

A clear trend was evident from the glove data: for a given type of material, as NVR increased, surface resistance decreased. Figure 2 shows the trend for 7 different types of nitrile gloves. After the manufacturing process, surface treatments are often needed to remove contaminants on the surface, typically salts, minerals and oils.

However, these contaminants make the glove material more electrically conductive by increasing ion mobility on the surface, especially at higher humidities where there is more water available for adsorption. Therefore, by cleaning the glove, the manufacturer (perhaps unknowingly) removes a significant element of the ESD protection.

For example, consider two types of commercially-available nitrile gloves, anonymously called A and B. According to the manufacturer, these gloves are made with the same material and processing steps except that A gloves are cleaned to more stringent levels than B ones. Tests showed that the B gloves had a 30% higher amount of NVR on their surface, and much lower surface resistance, than the A gloves.

The correlation between NVR and surface conductivity should be even stronger if a more polar solvent, such as water, was used as the NVR test solvent rather than IPA. In that case, more nonvolatile ionic contamination from the surface would be captured in the polar solvent.

The ideal "ESD clean" glove would have a chemically-bound additive incorporated in its base polymer. Such a material could have a very clean surface and maintain permanent static dissipation. Chemically-bound additives have been successfully incorporated into hard plastics products, to form so-called "inherently dissipative" materials; perhaps in the near future, the same technology will be applied to pliable polymers.

III.e. Finger Cots

As shown in Table 4, seven types of finger cots were tested and showed NVR values between 0.3 and 0.7 mg/cot. Since the cots had about 10 square inches of surface area, that translates to 5-10 mg/ft^2, considerably higher than the NVR values of the cleanest gloves.

In this study, black dissipative finger cots showed superior electrical properties and the lowest NVR. However, a concern with black-colored materials is conductive particle shedding. Black materials usually are filled with conductive carbon particles which, if tranferred to hardware, can cause both electrical and contamination problems.

This concern was investigated by wiping the finger cot across a white sheet of paper. The

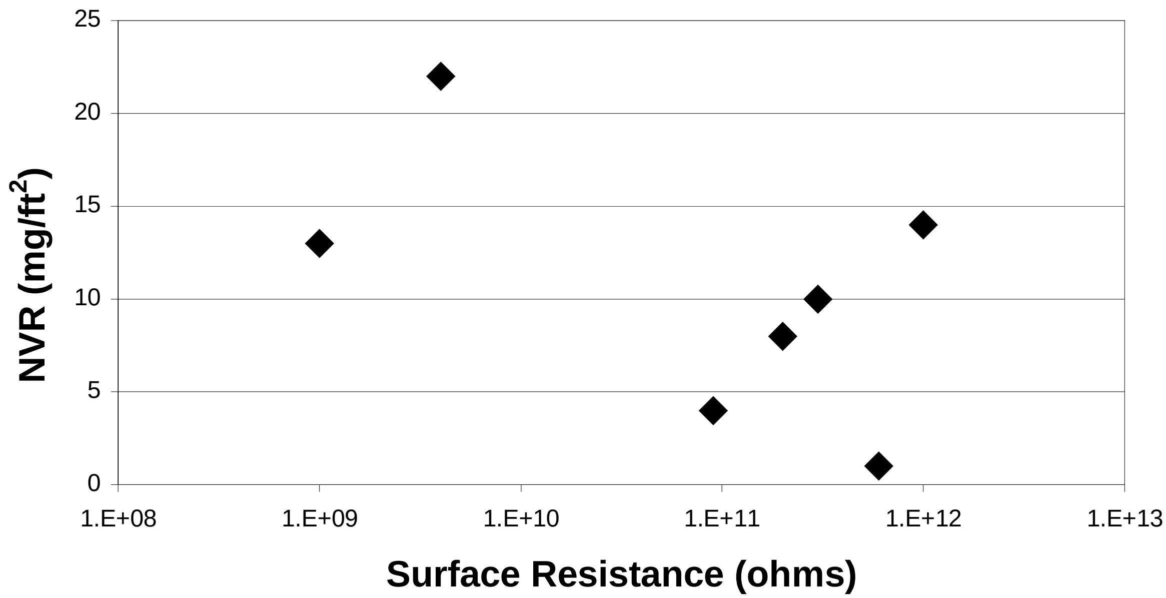

Figure 2. Surface Properties of Nitrile Gloves. Surface resistance was inversely related to NVR, showing a tradeoff between cleanliness and charge dissipation rate. This suggests that special surface treatments or cleanings lower the conductivity of nitrile gloves and make “clean” gloves less effective for ESD protection.

black finger cots consistently left black particles on the paper.

The black finger cots provided excellent ESD protection and should be worn while handling hardware that is extremely sensitive to ESD, but only if contamination is not a primary concern. For handling critical surfaces, such as mirrors or optics, the cleaner nitrile gloves carry less risk for contamination.

All of the finger cots appeared to be made of latex. A possible improvement would be finger cots made of non carbon-loaded nitrile that would exhibit better electrical properties than latex, without the risk for conductive particle shedding. In limited searches over the past year, the authors did not find any nitrile finger cots available on the market.

III.f. Sheeting/Bagging Materials

Tables 7 and 8 give the results on sheeting and bagging materials. Evaluation of packaging materials began with a comparison of heat sealable nylon sheeting. Nylon films were very clean, but like gloves, typically must treated to get static dissipation. In some applications, materials treated with topical antistats are undesirable due to concerns about contamination and limited service life.

Users of ESD packaging materials are cautioned not to get a false sense of security from the term “antistatic.” This qualitative term should not be equated with “ESD protective” or “dissipative.” The ESD Association defines an “antistatic” material as one that “inhibits tribocharging,” but tests showed that “antistatic” materials typically had surface resistivities well above 10^{12} ohms/square.

However, in a cleanroom, if there is a choice between antistatic and untreated materials having comparable NVR values, the antistatic material should be chosen. Since it will inhibit tribocharging, the antistatic material accumulates a lower charge density on its surface. Particles are attracted to charged surfaces; thus, regular nylon sheeting will attract higher particulate concentrations, since it carries more charge, than antistatic nylon sheeting.

III.g. Garments

Tests were done with coats, frocks and smocks, but not on suits or boots. For cleanrooms, garments made of polyester, with a conductive fiber network, showed the best combination of cleanliness and electrical continuity across the garment.

For non cleanroom areas, a variety of other garment materials provide excellent ESD protection, and showed little degradation of their electrical properties after 50 washes. Disposable garments are an option in areas where the garments are routinely damaged and must be discarded after a few uses.

IV. Summary and Conclusions

- Data on NVR and electrical properties were determined for products in several key categories.
- NVR data was determined for products that had been previously tested and approved as ESD protective materials.
- New and more insightful test methods were used to evaluate products for ESD and contamination.

The following conclusions are based on the test results.

- Few products available on the market today are both static dissipative and have NVR less than 1 mg/ft^2.
- For many products, there is a tradeoff between NVR and surface resistivity.
- Periodic evaluation of products is necessary: tests performed on the same product manufactured at different times shows variations in product quality.
- In most product areas, there is a need for improved materials technology.

V. Acknowledgments

The authors thank the United States Air Force for financial support, and M. Atwood who performed most of the NVR measurements and provided valuable input to this study.

VI. References

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