

# Evaluation of Materials Used in Cleanrooms with ESD Sensitive Hardware

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Measurements were done on nearly 80 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<sup>2</sup> and static dissipative properties.

## Introduction

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.

Static dissipative materials are desirable for ESD control since they drain charges at a controlled rate. Moreover, an ESD protective material will attract less particulate contamination to its surface than an insulative material since the dissipative material does not accumulate charges on its surface.

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 March 1999, the United States Air Force commenced a study of cleanliness and ESD protective properties of materials study through its USAF/RLML S3AE Initiative. TRW Space and Electronics spearheaded the study and tested nearly

80 products for electrical properties and nonvolatile residue (NVR).

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.

The purpose of this paper is to objectively report the results and trends of the study. The data should not be construed as recommendations 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. Material Tests

### I.a. Types of Materials Tested

Over the past several years, materials and processes engineers at TRW have been repeatedly asked to provide recommendations and/or evaluations of materials that could be used to safely process hardware sensitive to both ESD and contamination.

These materials included 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. Test 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 exuded 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 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 solution was then filtered. The filter was evaporated to constant weight, and the residue remaining on the filter was weighed.

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. A common standard in Class 10,000 cleanrooms is that materials have NVR values less than 1 mg/ft<sup>2</sup>.

“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 fibers/surface area.

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, and measuring the concentration of particles and fibers in the air with a particle counter.

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 particle shedding tests were completed for materials made of cloth 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

**Table 1. Tests Methods for Material Evaluation**

Test	Method/Reference	Category of Material						
		Floors	Bags/ Sheeting	Gloves	Finger Cots	Swabs	Wipes	Garments
<b>Electrical</b>								
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		✓					
<b>Cleanliness</b>								
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						✓	✓
<b>Other</b>								
Environmental/ Durability test	Properties tested after high temp & humidity or 50 washes (garments)	✓						✓
Solvent Resistance	Properties tested after exposure to solvents	✓					✓	

10<sup>5</sup> and 10<sup>12</sup> 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, was set up in a humidity chamber controlled with a HygroDynamics humidity meter. A MILLI-TO 2 Dr. Thiedig resistance meter was also used with ETS model 803B and 850 probes to make resistance measurements.

For sleeve-to-sleeve resistance measurements on garments, a 3M 701 Megohmmeter was used. Static decay data were measured with an ETS 406C meter. For the field attenuation measurements on shielding bags, a Monroe Electronics Model 268 Charged Plate Analyzer and a Simco SS-2X field meter were used. 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. For those materials, nonstandard test methods were used to complete the evaluation. 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 approved industrial laundering facilities.

## II. Test Results

Tables 2-10 give the test 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 for the material or there was insufficient sample for test.

## III. Discussion of Results

For many types of materials, no product had both static dissipative properties and NVR less than 1 mg/ft<sup>2</sup>, 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<sup>2</sup> and low outgassing will be available.

### III.b. Swabs

Two general types of swabs were tested: common 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 5 shows that most of the polyester or foam swabs had much lower NVR than the cotton ones. Therefore the “ESD swabs” are better suited for contact with contamination sensitive items than the cotton ones. 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<sup>2</sup> when tested with IPA use (higher with acetone).

### III.c. Wipers

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

**Table 2. ESD & Cleanliness Testing of Floor Materials**

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

**Table 3. ESD and Contamination (NVR) Testing on Gloves**

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

<b>Table 4. ESD and Contamination Testing of Finger Cots</b>					
<b>Sample</b>	<b>Static Decay Time (seconds) 15% humidity</b>	<b>End to End Resistance (<math>\Omega</math>) 50% humidity</b>	<b>Finger to Body Resistance (<math>\Omega</math>) 50% humidity</b>	<b>Triboelectric Charge Generation (V) 50% humidity</b>	<b>Contamination Nonvolatile Residue (NVR, mg/COT)</b>
LC56 white latex	> 5	$1 \times 10^{13}$	$2 \times 10^7$	485	0.59
QRP 7C700 pink latex	> 5	$3 \times 10^{10}$	$2 \times 10^7$	47	0.53
North Safety Products black	0.01	$9 \times 10^8$	$2 \times 10^6$	8	0.34
Clean ESD 480 white Regular non powered	>5	$1 \times 10^8$	$2 \times 10^7$	923	0.55
Clean ESD 490 white Antistatic super clean	>5	$5 \times 10^9$	$2 \times 10^7$	74	0.44
Clean ESD 492 pink Antistatic super clean	>5	$1 \times 10^{10}$	$1 \times 10^9$	36	0.55
Clean ESD 494 black Static dissipative super clean	0.01	$6 \times 10^9$	$2 \times 10^6$	7	0.74

**Table 5. ESD and Cleanliness Testing of Swabs**

<b>Sample</b>	<b>Swab Material</b>	<b>Bulk Resistivity of Handle (<math>\Omega</math>-cm) 50% humidity</b>	<b>Tribocharge on Conductor (V) 50% humidity</b>	<b>Tribocharge on Insulator (V) 50% humidity</b>	<b>Contamination Nonvolatile Residue (mg/swab)</b>
Texwipe TX740E	Foam	$1.0 \times 10^8$	9	46	0.01
Texwipe TX742E	Foam	$2.3 \times 10^8$	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	$1.4 \times 10^8$	8	10	0
Texwipe TX753E	Foam	$1.8 \times 10^8$	5	20	0.01
Texwipe TX754		N/a	N/a	N/a	0
Texwipe TX757E	Foam	$1.9 \times 10^8$	8	45	0.01
Texwipe TX758E	Polyester	$1.4 \times 10^8$	12	40	0
Texwipe TX759E	Polyester	$2.0 \times 10^8$	9	49	0
Texwipe TX765E	Polyester	$1.6 \times 10^8$	5	26	0.02
Texwipe TX769E pick	None (pick)	$1.7 \times 10^8$	7	10	0.02
Coventry SA-41050	Foam	$8.2 \times 10^8$	9	10	0.51
Coventry SA-31050	Polyester	$5.0 \times 10^8$	11	26	0.05
Puritan—wooden handle	Cotton	$2.1 \times 10^9$	17	45	0.27

**Table 6. ESD and Contamination Testing on Wipes**

<b>Sample</b>	<b>Surface Resistivity (<math>\Omega</math>/sq) 50% humidity</b>	<b>Surface Resistivity (<math>\Omega</math>/sq) 15% humidity</b>	<b>Saturated with IPA--Surface Resistivity (<math>\Omega</math>/sq) 50% humidity</b>	<b>Volume Resistivity (<math>\Omega</math> cm) 50% humidity</b>	<b>Static Decay Time (seconds) 15% humidity</b>	<b>Triboelectric Charge Generation (V)</b>	<b>Finger to Body Resistance (<math>\Omega</math>)</b>	<b>Nonvolatile Residue (mg/ft<sup>2</sup>)</b>	<b>Airborne Particulate (part /ft<sup>2</sup>)</b>	<b>Tape Lift Particulate (fibers/ft<sup>2</sup>)</b>
Texwipe TX 1109	$1 \times 10^{13}$	$> 10^{14}$	N/a	$1 \times 10^{13}$	N/a (discharge $> 0$ V)	69	$2 \times 10^6$	28.4	$3 \times 10^5$	N/a
Texwipe TX 4025	$1 \times 10^9$	$> 10^{14}$	$3 \times 10^7$	$3 \times 10^7$	0.01	12	$1 \times 10^6$	3.27	N/a	1168
Kimberly Clark Precision Wipes	$7 \times 10^{12}$	$> 10^{14}$	$6 \times 10^{11}$	$5 \times 10^{12}$	N/a (discharge $> 0$ V)	57	$1 \times 10^6$	1.95	$4 \times 10^5$	N/a
Milliken Anticon Black Gold II	$1 \times 10^{14}$	$> 10^{14}$	$2 \times 10^7$	$6 \times 10^{13}$	$> 5$	850	$7 \times 10^7$	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 ( $\Omega$ /sq)	Surface Resistivity 15% humidity ( $\Omega$ /sq)	Volume Resistivity 50% humidity ( $\Omega$ ·cm)	Contamination Nonvolatile Residue (mg/ft <sup>2</sup> )
	To 500V	To 100V				
Cleanfilm Inc Antistatic Nylon	> 5 s	>5 s	$2 \times 10^{12}$	$> 10^{16}$	$1 \times 10^{12}$	0.02
Cleanfilm Nylon Tubing	> 5 s	>5 s	$2 \times 10^{13}$	$> 10^{16}$	$7 \times 10^{13}$	0.05
Cleanfilm Bear Poly Tubing	> 5 s	>5 s	$3 \times 10^{13}$	$> 10^{16}$	$> 10^{16}$	0.26
Cleanfilm ULO Poly Tubing	> 5 s	>5 s	$4 \times 10^{13}$	$> 10^{16}$	$> 10^{16}$	0.02
Cleanfilm Aclar 33C sheet	> 5 s	>5 s	$2 \times 10^{14}$	$> 10^{16}$	$> 10^{16}$	0.02
Cleanfilm Antistatic Bear Poly	4.0 s	9.0 s	$3 \times 10^{11}$	$2 \times 10^{13}$	$3 \times 10^{13}$	0.26
RCAS 2400 nylon	> 5 s	>5 s	$3 \times 10^{13}$	$> 10^{16}$	$4 \times 10^{12}$	0.34
RCAS 1206P ("pink poly")	0.24 s	1.8 s	$4 \times 10^{10}$	$3 \times 10^{11}$	$4 \times 10^{12}$	3.3
Richmond MDPE	> 5 s	>5 s	$> 10^{16}$	$> 10^{16}$	$6 \times 10^{16}$	0.03
Richmond A-124	> 5 s	>5 s	$3 \times 10^{12}$	$> 10^{16}$	$3 \times 10^{13}$	0.04
Static Intercept sheet	0.01 s	0.01 s	$2 \times 10^5$	$< 10^9$	$4 \times 10^{12}$	0.23
Benstat blue poly	0.03 s	0.18 s	$6.9 \times 10^9$	$8.4 \times 10^{10}$	$8 \times 10^{12}$	N/a
SECO amine free clear bubble wrap	0.7 s	4.0 s	$8 \times 10^{10}$	$1 \times 10^{12}$	$3.2 \times 10^{15}$	0.64

**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
	To 500V	To 100V	( $\Omega$ /sq)	( $\Omega$ /sq)	(V)	(mg/ft <sup>2</sup> )
RCAS 4150	0.01 s	0.04 s	$2 \times 10^{10}$ inner & outer	$8 \times 10^{11}$	30	0.49
RCAS 4200	0.01 s	0.01 s	$5.0 \times 10^8$ inner & outer	$2.1 \times 10^8$	20	1.9
Richmond Drypack 3750 bag	0.01 s	0.01 s	$1 \times 10^8$ inner & outer	$1 \times 10^9$	20	13.24
Richmond Drypack 9000 bag	0.01 s	0.01 s	$1.9 \times 10^6$ inner & outer	$7.5 \times 10^7$	20	2.73
NMD FR#48PA1-NY	0.01 s	0.03 s	$3.4 \times 10^{11}$ outer layer $4.0 \times 10^{12}$ inner layer	$2.2 \times 10^{13}$ outer layer $5.1 \times 10^{13}$ inner layer	20	0.27
NMD FR#48PA1-NNY	0.01 s	0.03 s	$2.6 \times 10^{10}$ outer layer $7.1 \times 10^{12}$ inner layer	$1.6 \times 10^{12}$ outer layer $3.8 \times 10^{14}$ inner layer	80	0.16
NMD FR#100PA1-N	0.01 s	0.01 s	$2.1 \times 10^{10}$ outer layer $2.7 \times 10^{12}$ inner layer	$3.0 \times 10^{13}$ outer layer $5.1 \times 10^{13}$ inner layer	20	0.02
NMD FR#190PA1-NN	0.01 s	0.02 s	$1.1 \times 10^{11}$ outer layer $9.4 \times 10^{12}$ inner layer	$2.1 \times 10^{13}$ outer layer $1.2 \times 10^{15}$ inner layer	260	0.35
Caltex CP Stat 100 metallized sheet/bag	0.01 s	0.01 s	$1.7 \times 10^9$ inner & outer	$5.8 \times 10^{11}$	20	
Cleanfilm Shielding sheet	0.01 s	0.03 s	$1.3 \times 10^{14}$ outer layer $> 10^{16}$ inner layer	$2.0 \times 10^{15}$ outer layer $> 10^{16}$ inner layer	70	0.18

**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	$4 \times 10^5$	$3 \times 10^6$	$3 \times 10^9$	$>10^{11}$	$>10^{11}$
NSP coat	$9 \times 10^4 - 2 \times 10^5$	$9 \times 10^4$	$2 \times 10^5 - 6 \times 10^7$	$2 \times 10^9 - 4 \times 10^9$	$1 \times 10^{10}$
Prudential AB 5800 cleanroom	$2 \times 10^7$	$7 \times 10^7 - 1 \times 10^{10}$	$9 \times 10^7 - 3 \times 10^8$	$1 \times 10^{10} - 6 \times 10^{10}$	$3 \times 10^{10}$
Red Kap Static Control Tech Coat	$8 \times 10^6$	$2 \times 10^6$	$1 \times 10^{11}$	$>10^{11}$	$>10^{11}$
Red Kap ESDiffuse Tech Coat	$9 \times 10^4$	$1 \times 10^5$	$2 \times 10^5$	$7 \times 10^5$	$3 \times 10^5$
Red Kap Cleanroom	$1 \times 10^8$	$1 \times 10^8$	$1 \times 10^8$	$3 \times 10^{10}$	$1 \times 10^{10}$
Tech Wear OFX-100	$2 \times 10^5$	$8 \times 10^5 - 5 \times 10^6$	$8 \times 10^5 - 1 \times 10^6$	$1 \times 10^7 - 2 \times 10^7$	$1 \times 10^6$
TW Clean cleanroom	$1 \times 10^5$	$2 \times 10^5$	$3 \times 10^5$	$2 \times 10^6$	$6 \times 10^5$
Tyvek frock (disposable)	$2 \times 10^7$	(not washed)	$8 \times 10^7$	(not washed)	$4 \times 10^9$ (not washed)

**Table 10. Particle Shedding Measurements on Garments**

Garment	Material	Tape Pull Test (fibers & particles)	Airborne Particulate per ASTM F51-68 (fibers & particles)	
		After 50 Washes	After 25 Washes	After 50 Washes
Angelica coat	80% polyester/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

### III.d. Gloves

One of the most pressing needs was to find a glove that was clean and ESD protective, yet it proved quite difficult to find. The 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 lint eliminated them from consideration as a cleanroom material.

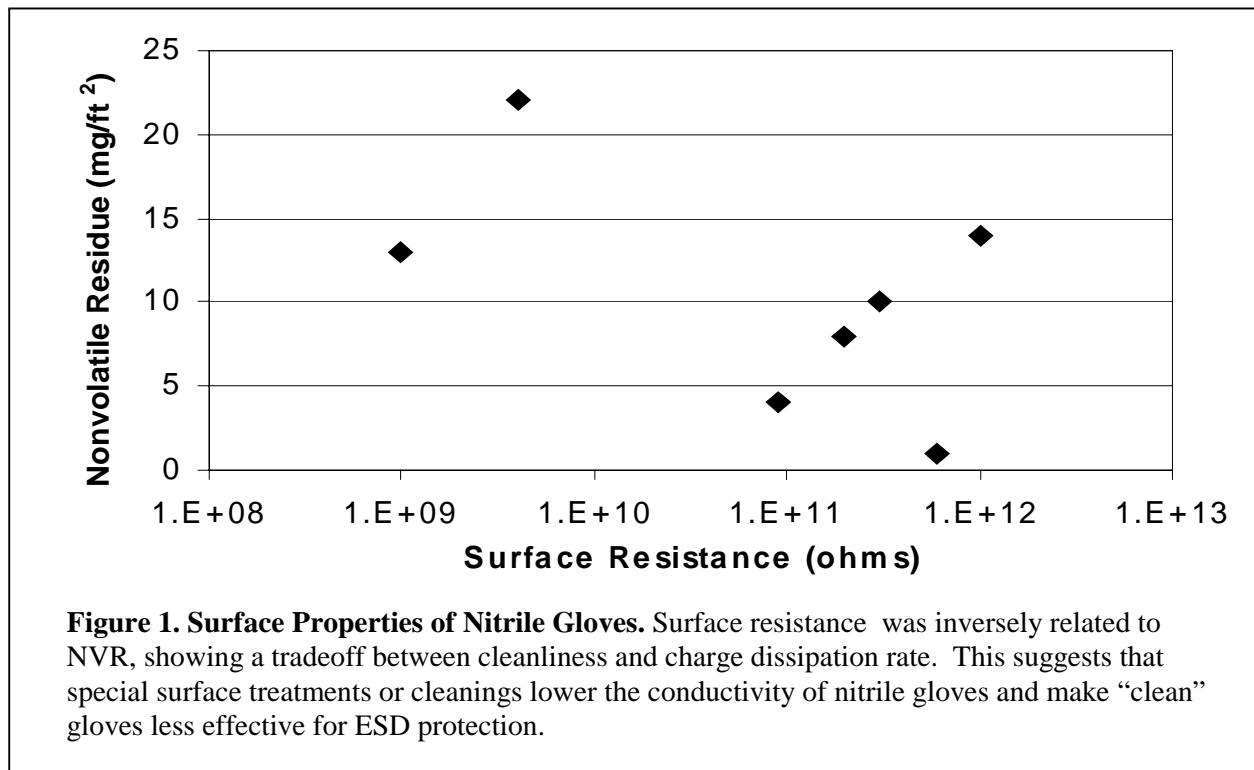
A clear trend was evident from the glove data: for a given type of material, as NVR increased, surface resistance decreased. Figure 1 shows the trend for 7 different types of nitrile gloves. After the manufacturing process, surface treatments are often needed to remove contaminants on the surface, typically 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 an abundance of adsorbed water.

Therefore, by cleaning the glove, the manufacturer (perhaps unknowingly) removed an element of the ESD protection.

For example, consider two types of nitrile gloves, called A and B (actual products). 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. Nonvolatile ionic contamination from the surface, which will enhance the surface conductivity more than equivalent amounts of nonpolar compounds, 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<sup>2</sup>, 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 transferred 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 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 be treated to get static dissipation. In some applications, materials treated with topical antistats are undesirable since they have limited shelf life and may lose effectiveness due to wiping or evaporation.

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 above 10<sup>12</sup> 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

- Determined data on NVR and electrical properties for new products.
- Determined NVR data for key products that had been previously tested and approved as ESD protective materials.
- Established a list of suppliers of selected products that are cleaner and have better ESD protective properties than previously-used materials.
- Established recommended products that will lead to safer handling of flight hardware and reduction in ESD and contamination incidents from use of improper materials.
- Established new and improved test methods for evaluating products for ESD and contamination.

The following conclusions are based on the test results.

- Few products available on the market today can meet the criteria for ESD protection and NVR less than 1 mg/ft<sup>2</sup>.
- In many cases, materials do not meet all criteria and best available materials must be used.
- Periodic evaluation of products is necessary: tests performed on the same product manufactured at different times shows variations in product quality.
- In some product areas, there is a need for improved materials technology.

## **V. Acknowledgments**

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## **VI. References**

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