SOAR-1

State-of-the-Art Report

ESD PROTECTIVE MATERIALS AND EQUIPMENT: A CRITICAL REVIEW

Spring 1982

Reliability Analysis Center
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A DoD Information Analysis Center

State-of-the-Art Report

ESD PROTECTIVE MATERIAL AND EQUIPMENT: A CRITICAL REVIEW

Spring 1982

Prepared by:

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Under Contract to:

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Griffiss AFB, NY 13441

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This document addresses those factors effecting the choice of optimum, cost effective materials and equipment to prevent electrostatic discharge (ESD) damage to sensitive electronic components and equipment. The approach is that of reviewing applicable data and discussing the relevant trade-off options. Section 1 addresses Wrist Straps; Section 2, Protective Work Surfaces; Section 3, Protective Packaging; Section 4, Air Ionizers; Section 5, Electrostatic Detectors, Voltmeters and Monitors; Section 6, Conductive →

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Floors, Floor Mats and Footwear; Section 7, Garments and Clothing; Section 8, Topical Antistats; Section 9, Material and Equipment Test and Inspection Procedures; Section 10 is a listing of the applicable references

PREFACE

The purpose of this report is to broaden the reader's awareness and understanding of those factors effecting the choice of optimum, cost effective materials and equipment to prevent electrostatic discharge (ESD) damage to sensitive electronic components and equipments. The information compiled within this document should provide a valuable resource for those individuals who are responsible for the selection, specification, qualification, and purchase of materials and equipments to be used within their facility to prevent ESD damage to sensitive components. A further purpose of this document is to assist the user in implementing the requirements of DOD-STD-1686, Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices) by discussing the relevant protective materials trade-off options.

This document is prepared as part of the Reliability Analysis Center's (RAC) continued responsibility to provide new information relating to the reliability of electronic devices. Major portions of the data contained herein were collected under the sponsorship of the Program Assurance Division, Office of the Chief Engineer, National Aeronautics and Space Administration and of the Naval Sea Systems Command, Department of the Navy.

The author wishes to express his appreciation for the contributions of the RAC staff and numerous Government and industry personnel. This report could not have been accomplished without the cooperation and support of the many individuals within government and industry who performed the tests and took the time and effort to document their results.

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INTRODUCTION

The recent explosive growth of the ESD protective products market has introduced a vast array of products to the potential buyer. Unfortunately, the multitude of voices in the market place has tended to make the choice of an optimum product more rather than less difficult. Some of the companies tend to oversell and/or misrepresent their products. Other manufacturers fairly represent their products but they have serious quality control problems. Still other vendors have poorly trained sales representatives who have too limited a viewpoint. They can see only their own product and are not really trying to solve their customer's problem, i.e., they tend to rely on pat solutions rather than thorough understanding of the phenomenon.

The following quotations from selected papers presented at the third annual (1981) EOS/ESD Symposium serve to illustrate these difficulties: "Materials and equipment seemingly very similar are actually quite different in the ESD protection they offer" (Gary Head, Lear Siegler, Grand Rapids, MI)[55]; "Significant differences in ESD...characteristics are apparent among the products tested" (Hansgregory Hartmann, Hewlett-Packard Co., Sunnyvale, CA)[53]; "The magnitude of charge developed is related to the potential on the lead frame in order to provide a frame of reference for selecting (DIP STICK) tubes that have safe triboelectric properties" (Burt Unger, Bell Telephone Labs, Murray Hill, NJ)[22]; "Inconsistent quality of antistatic materials necessitates constant vigilance by the manufacturers and end users of ESD (Sensitive) components to insure...satisfactory performance", "There are variations in quality from lot to lot of each manufacturer and larger variations between manufacturers" (Alvin Topolski, E.J. du Pont de Nemours & Co., Wurtland, KY).[54]

The problem is further complicated by the lack of material standards and agreement on optimum tests and test methods. Only two material standards exist which directly define material electrostatic requirements.

They are MIL-B-81705 B covering electrostatic-free packaging materials and PPP-C-1842A (with Amendment 3) covering electrostatic-free cushioned packaging materials. A third standard MIL-P-81997A (with Amendment 1) covering reclosable cushioned pouches indirectly establishes the requirement by requiring that the items be fabricated from materials conforming to MIL-B-81705 and/or PPP-C-1842. None of the other products and materials are as yet addressed by applicable standards.

Therefore, "Caveat Emptor," let the buyer beware, is especially germane to the purchase of ESD protective materials. For maximum quality assurance, substantial purchases should only be made after a thorough review of the market, a formal product qualification program and lot sample testing to assure consistent quality. The intent, then, of this document is to aid the buyer in making an intelligent choice by discussing the pros and cons, strengths and weaknesses and potential failure mechanisms of the various different generic materials presently available for ESD protection.

The information and data contained in this document are not to be construed as an endorsement or prohibition of any specific product.

It should be recognized that the use of ESD Protective Materials and Equipment are only one element, albeit an important element, of an ESD Control Program. A formal comprehensive training program for all personnel who specify, procure, design, manufacture, assemble, process, inspect, test, package, repair, rework and install ESD sensitive items is an equally important companion task.

Another important element of an adequate ESD Control Program is the identification of ESD sensitive parts utilizing V_{ZAP} testing. A future document in this series will address this topic.

SECTION 1

WRIST STRAPS

SECTION 1: WRIST STRAPS

Wrist straps are the first line of defense in the battle against electrostatic discharge. The purpose of the wrist strap is to provide a permanent path to ground for the individual operator in order to prevent unsafe static charge levels from being generated during ordinary work-related movements. The wrist strap provides prompt and effective removal of these charges from conductive items. All ESD prevention programs should utilize wrist straps even if no other precautions are available.

There are four generic types of wrist straps presently in use. These are:

(1) Bead chain with a wire lead.
(2) Bulk conductive plastic or polyester fabric, both cuff and lead.
(3) Conductive plastic or polyester fabric cuff with a wire lead.
(4) "Speidel band" with a wire lead.

Each of these different types have their own advantages and disadvantages. From a reliability viewpoint, however, all of these wrist straps contain six vulnerable elements as illustrated in Figure 1. These elements are:

(1) Cuff - It provides electrical contact with the wearer's skin.
(2) Lead - It provides continuity between the cuff and the ground point.
(3) Series Resistor - Intended to protect the wearer from electrical shock should he/she accidentally come into contact with a potentially lethal voltage.
(4) Connection between the cuff and the lead.
(5) Connection between the lead and the resistor.
(6) Connection between the resistor and the ground point.

It is possible in the design of some wrist straps to combine two or more of these elements into a single element; however, to properly evaluate a wrist strap all six elements must be addressed. Table 1 is an example of the strengths and weaknesses of each of the generic types of wrist straps. Table 2 is a listing of some of the different wrist straps presently available from some of the various suppliers.

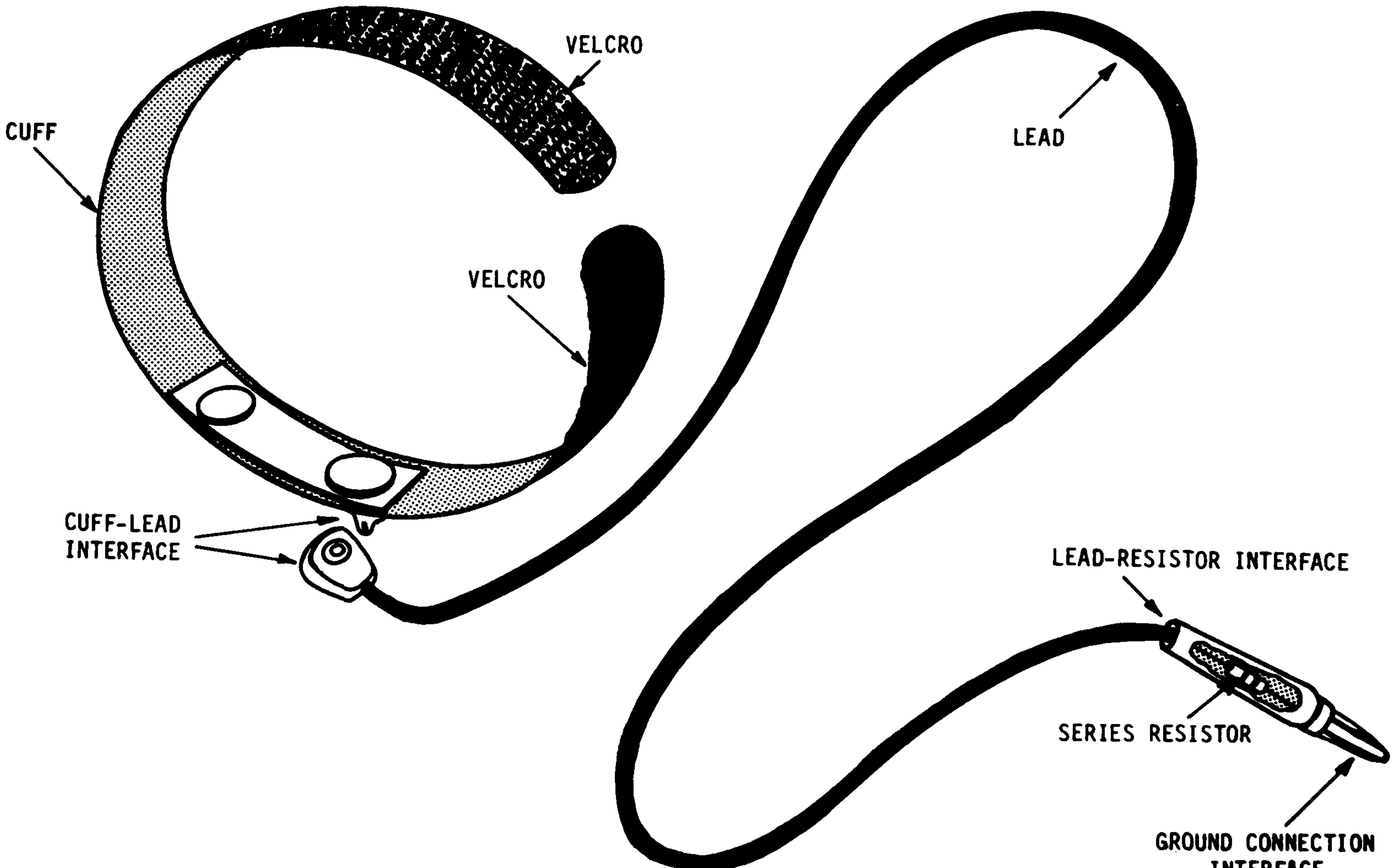


FIGURE 1: A TYPICAL WRIST STRAP

TABLE 1: WRIST STRAP CONSIDERATIONS

Wrist Strap Type	Cuff	Cuff-Lead Interface	Lead	Lead-Resistor Interface	Resistor	Ground Connection Interface
Bead Chain with Wire Lead	Poor skin contact too loose	One piece; disconnection is usually not possible	Flexibility and durability depend on wire gauge and no. of strands	Adequate strain relief is required	Discrete Value*	Adequate strain relief is required. Disconnect force varies
Conductive Plastic Cuff with Wire Lead	Subject to deterioration	Snap connection disconnect force varies				
"Speidel" Band with Wire Lead	Best skin contact					
Bulk Conductive Cuff and Lead	Subject to deterioration	either/or	Combined into a single element. May be subject to deterioration.			

*Resistance sufficient to limit current to 5MA under worst case voltage (Ref. paragraph 7.2.6.1 of DOD-HDBK-263)

TABLE 2; WRIST STRAPS

Generic Type	Name or Model*	Supplier	Safety Resistor (Ω)	Approx. Price*	Documented Test Results	Reference Number
Bead chain cuff with wire lead	3010889	Control Static	270K,1M		HSP 9-80	1
	EN5610-4BC	Semtronics	1M	$5.50		
	W-0742	Wescorp	1M	6.16		
Conductive plastic with wire lead	2064	3M	1M	11.25	MH 3-80	3
	30111&2	Control Static	270K, 1M			
	Wristat	W.G. Legge	250K			
	Simco-Stat	Simco	1M	7.45		
	EN5603&4	Semtronics	1M	8.80		
	Wristrap Grd	ALX	1M			
	Std or Deluxe	Biggam	250K			
	BA-5050/2	NRD	1M	10.50		
"Speidel" band with wire lead	30113	Control Static	1M	16.85		
Conductive polyester cuff and ribbon	CP401	Charleswater		5.00		
	30106	Control Static				
	EN5602-4	Semtronics		5.50	MH 3-80	3
	W-074021	Wescorp		6.16		

* Basic model only

Bead Chain

One investigator found the bead chain type of wrist strap to have the poorest operator acceptance,[1] while another investigator[20] has found it to have the highest operator acceptance. A possible solution to this type of dilemma is to qualify and stock a couple of different wrist strap models and allow the individual operator to take his/her choice. This would, of course, require compatibility of connectors with the various work stations. The bead chain type of wrist strap tends to be difficult to put on and to take off. It has a tendency to hang on too loosely, slide up over the operator's sleeve and thus lose skin contact. Also, it is either not adjustable or cannot be properly adjusted using one hand. They have also been reported[2] to have become nonconductive due to contamination and/or corrosion from body oils.

Bulk Conductive Plastic or Polyester Fabric (Cuff and Lead)

These are typically a carbon-impregnated plastic and may be of either a one piece or a two piece construction. Some of this type utilize a conductive plastic cuff or a conductive plastic cuff liner to establish electrical contact with the user's skin. If a conductive plastic cuff liner is used, to assure optimum skin contact it should extend over a minimum of 180° when the cuff is adjusted to its largest size. These conductive plastics have a tendency to deteriorate with use[3]. The human body oils can contaminate the conductive plastic surface causing a significant increase in contact resistance and hence rendering them ineffective. Unfortunately this appears to be a permanent change. Cleaning with various solvents does not restore the surface conductivity[3]. Therefore, cuffs utilizing conductive plastics for electrical contact with the skin should be replaced periodically. One user[4] has recommended a three-month replacement schedule.

Other wrist straps utilize a metal button to establish electrical contact with the operator's skin. These do not tend to deteriorate in the same manner; however, it is imperative that they always be worn in such a manner that the button is making intimate contact with the skin.

Depending upon the specific construction details this may require the strap to be worn somewhat tighter than might otherwise be required. Another investigator[59] has found that under very low humidity conditions many operators developed a layer of dead skin on their wrists which effectively created an open circuit between the operator and the metal button of the ground strap. Effective corrective action for this deficiency consisted of the addition of a 2-inch long by 0.5 inch wide Ni Ag alloy metal strip connected by a pop rivet to the snap on the wrist band.

Both the metal button contact and the conductive plastic surface contact cuff normally utilize a Velcro strip attachment and thus are relatively easy to put on, take off and adjust properly. Some models, however, utilize a wider cuff and a loop arrangement in addition to the Velcro. These were found to be the easiest to put on, take off, and adjust properly. The Velcro itself, however, can cause some personnel dissatisfaction[1] if it is exposed in such a way that it tends to snag on clothing or on the electronic components themselves. Additional problems have been reported in the past[2,3,5] concerning deterioration of the bulk conductive plastic due to perspiration causing the plastic to crack, resulting in significantly increased resistance and/or open circuits.

<u>Conductive Plastic or Conductive Polyester Fabric Cuff with a Wire Lead</u>

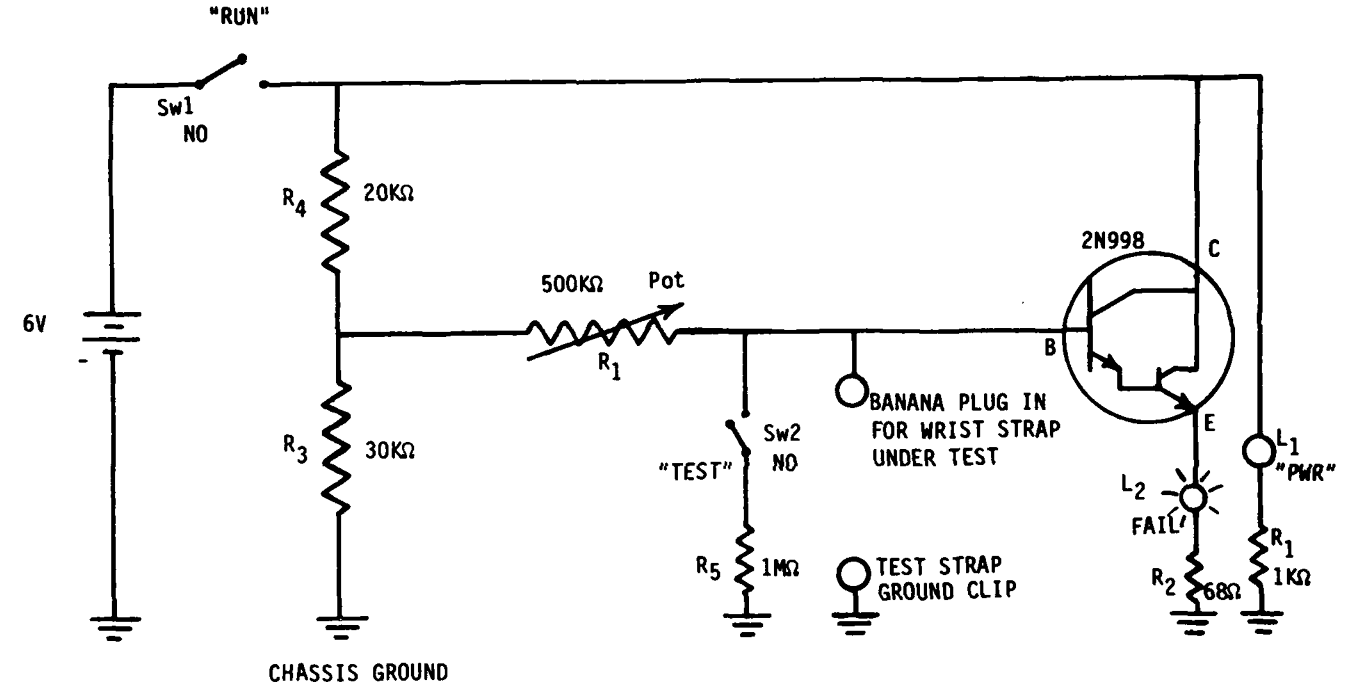
These may be of either a one piece or a two piece construction. Considering operator safety, such as emergency evacuation, etc., the two piece construction with a metal snap connecting the two pieces is the preferred type of construction. However, some users[1,5] have reported a tendency of the metal snap to become noticeably looser with use. The previous comments regarding the limited life of the conductive plastic cuff are equally true of this configuration also. In addition the flexibility of the wire, including wire gauge and number of strands, and the necessary strain relief incorporated at either end of the wire is very important. A recent GIDEP Alert[21] documents a series of wrist strap failures at the resistor-ground point interface. The basic problem with the wire lead is that individual strands will break without any indication until the final strand breaks and then continuity is suddenly lost. The most reliable leads were found to be those utilizing a "tinsel cord" construction.[20] It is imperative that all wrist straps be electrically tested periodically. This should be done daily when in use using a multimeter or a wrist strap test circuit such as is shown in Figure 2.[1]

"Speidel band" with Wire Lead

The "Speidel band" type of wrist strap provides the best and the most dependable contact with the user's skin. It has a high degree of operator preference[1] and also offers the longest life. It shares the same risks relative to metal snap connection and wire lead as the previous type. In addition, unless the exterior of the band is also insulated, neither this type nor the bead chain type should be used when troubleshooting or repairing live electrical equipment (even low voltages). This is to prevent serious burns from high currents should circuits be accidentally bridged.

Additional General Considerations

All wrist straps regardless of type should incorporate a series resistor between the operator and ground to limit the current to a safe value should the operator accidentally come into contact with a high voltage. Although the construction is less common, some investigators prefer the added safety inherent in placing the resistor in the immediate vicinity of the cuff rather than at the ground connection. This configuration will still provide the operator with adequate protection should the lead insulation become frayed, allowing the wire itself to accidentally contact ground. With the more common construction this would effectively short out the safety series resistor. The series resistor normally should be between 250K ohms and 1Meg ohm. However, it may be necessary for the specific handling of some extremely sensitive parts such as Gallium Arsenide diodes to reduce the series resistor to 100K ohms.[2] Operator safety can be further enhanced by the use of a Ground Fault Circuit Interrupter (GFCl) as required by the British Standard Institution specification BS 5783:1979.



1 - 2N998 Darlington Transistor
2 - SPDT Pushbutton Switches Normally Open
1 - 6V Battery
1 - Banana Plug, female Chassis Mount
1 - 500KΩ Potentiometer, R1
1 - Yellow LED; L1 "PWR"
1 - Red LED; L2 "FAIL"
1 - 68Ω, Resistor, R2
1 - 30K , Resistor, R3
1 - 20K , Resistor, R4
1 - 1M , Resistor, R5
1 - 1K , Resistor, R6
1 - Alligator Clip

OPERATION:

1 Press "RUN". Both LED's should light up.
2 While holding "RUN" down, press "TEST". Only Yellow "PWR" should be lit.
3 Plug bench end of wrist strap into banana plug, clip alligator clip on cuff.
4 Press "RUN". Only "PWR" LED should light.
5 If "FAIL" LED lights up, replace wrist strap.

SECTION 2

PROTECTIVE WORK SURFACES

SECTION 2: PROTECTIVE WORK SURFACES

The purpose of an ESD protective work surface or bench is to drain static charges out of an operator's general working area before they can damage ESD sensitive items. This implies that the work surface be at least partially conductive and that it is grounded. An ungrounded insulator will retain a charge indefinitely rather than bleed it off. Furthermore, the work surface material should tend to generate a minimum of electrostatic charges. (Triboelectric charging is covered in more detail in Section 3.).

After wrist straps, protective work surfaces are the most important defense against ESD damage. There are a considerable number of different generic types of ESD protective work surfaces presently available with new ones coming onto the market continually. In selecting the most effective work surface for a given application, a number of factors in addition to cost must be considered. These factors include:

a) electrical conductivity
b) life, durability or wear resistance
c) chemical compatibility
d) surface hardness
e) operator comfort
f) grounding method

Each of these important characteristics will be discussed in detail. Table 3 is a listing of some of the different protective work surfaces available together with their strengths and weaknesses.

Electrical Conductivity

Work surfaces may be separated into three categories as determined by the resistivity of the material. DOD-STD-1686 defines the three levels of conductivity as:

Conductive =	resistivity less than 10^5 ohms per square
Static Dissipative =	resistivity between 10^5 ohms per square and 10^9 ohms per square
Antistatic =	resistivity between 10^9 ohms per square and 10^{14} ohms per square

TABLE 3: PROTECTIVE WORK SURFACES

Generic Type	Name or Model	Supplier	Typical Resistance (Ω/sq.)	Typical Decay Time ① (Voltage)	Typical Decay Time ① (Sec's)	Wear Resistance	Chemical Resistance (Solvents)	Caution Notes	Surface Characteristics	Documented Test Results	Reference Numbers
CONDUCTIVE Resistivity < 10^5 Ω/sq											
Aluminum					10^{-9}	Good	Good		Hard, Cold	CSDL 9-79	7
Stainless Steel					10^{-9}	Good	Good		Hard, Cold	CSS	
Wire Mesh/Plastic Laminate	Omega VII	American Top	$2x10^2$	5000	0.001	Unknown	Trichlomethane		Hard	SCC	60
Conductive Vinyl Tile	Conductile	Vinyl Plastics		5000	0.03 ②	Good	Good		Resilient	CSDL	46
Carbon-Loaded Polyolefin or Polyethylene Sheet (Black Opaque)	Velostat Neutro-Stat Weststat Enstat	3M Simco Wescorp Semtronics	$3x10^4$	5000	0.005	Carbon particles may be scuffed off	Poor solvent resistance	③	Resilient ↓	VPI 1-80 CSDL	30 46
Carbon-Loaded Fiberglass	Plasticon	Plastic	$1x10^4$		0.4	Good	Good		Hard		
STATIC DISSIPATIVE Resistivity ≈ 10^5 to 10^9 Ω/sq											
Conductive Vinyl Laminate	Simco Stat 8210 Enstat CP602	Simco 3M Pervel Semtronics Charleswater	$1x10^8$ $1x10^8$ $1x10^7$ $1x10^9$	 5000 5000	0.45 0.06 0.05				Soft ↓ Hard	ETS 8-80	26
Amino Resin Laminate	Micastat	Charleswater	$1x10^9$	5000	0.03 ②	Good	Good				
ANTISTATIC Resistivity > 10^9 to 10^{14} Ω/sq.											
High Density Ligno-Cellulosic	Benalux	Reed Plastics	$1.5x10^{11}$		1.2 to	Good		Humidity Dependent	Semi-Hard	CSDL 9-79	7
Hardboard Sheet Insulation	Benalux	Masonite			1.8 ②				" "		
Melamine Formaldehyde (General Purpose Melamine Laminate)	Textolite Nevamar Formica	GE	$3x10^{11}$	5000	1.3 to 48 3 to 5	Good	Good	Humidity Dependent	Hard " "	HAC 1-78 CSDL 9-79 HDSD 3-80	2 46 47
Antistatic Polyethylene (Pink Poly-Transparent)	RCAS 1200	Richmond Wescorp Biggam	$4x10^{12}$	5000	23	Subject to abrasive damage	Trichloethylene MFK, Silicone	Humidity Dependent	Resilient " "	CSDL 9-79	7
Blue Polyethylene	2P101	Bengal	$2.9x10^9$		14.6			215°C max. ⑤	"	LGCS 5-79 CSDL	48 46
Antistatic Nylon (Orange-transparent)	RCAS 2400	Richmond	10^{13}			Subject to abrasive damage		Highly Humidity Dependent ④	"	KSC 4072	8

① Decay to 37% fo Original Voltage Value
② Decay to 0 volts
③ Corrosive in the presence of aluminum and High RH
④ Requires an RH of 50% or Greater
⑤ Antistatic properties may be lost if exposed to higher temperatures

Protective work surfaces are available in each of the different levels of conductivity; however, it would appear that an ideal work surface would fall into the mid-range of resistivity, i.e., static dissipative. Under low relative humidity conditions antistatic materials may take excessively long to dissipate a static charge. Consider the case of a large highly charged conductive tote box placed on an antistatic table top in a 30% or lower relative humidity environment. Under these conditions one investigator[11] has found a significant static potential remaining on the tote box for long periods of time. This could allow an operator wearing a wrist strap to inadvertently damage sensitive components by accidentally discharging the tote box through these components while placing a printed circuit card into the tote box. In contrast, under other circumstances a highly conductive material may allow a static charge to be dissipated too quickly. Take the case that another investigator has studied,[22] that of an integrated circuit becoming charged while sliding through a plastic antistat-treated shipping tube and the IC subsequently falling onto a highly conductive protective table top. The resultant low resistance discharge of the device occurs in nanoseconds with peak currents in excess of 10 amperes, thus damaging or destroying the device without the operator even having touched it.

It is also of utmost importance that the resistivity of the work surface not change appreciably with changes in temperature, humidity or life. Tests or experience have shown[2,6,7,8] that work surfaces which are hydrophilic or which depend upon a sweat layer of ambient moisture for conductance may exhibit increased resistivity and would be poor choices in very low humidity climates. Antistatic nylon, for example, is very humidity sensitive,[8] requiring a humidity level of 50% or greater to assure adequate conductivity and to preclude significant charge development and retention.

Life, Durability or Wear Resistance

Some of the softer materials have been reported to tear, shred or slough off particles during normal use as a result of wear or abrasion.[4,6,9]

Carbon-loaded polyolefins are usually unacceptable in clean room applications as they tend to deposit black carbonaceous dust when they are abraded.[9]

A potential wearout mechanism could exist with the antistat-impregnated plastic materials due to the eventual depletion of the antistat.

Chemical Compatibility

An ideal work surface should not be attacked, softened or otherwise degraded by cleaners, solvents and other common chemicals which could be expected to come into contact with a work surface. Some work surfaces are attacked by common solvents or cleaners.[9] One work surface tested by the Reliability Analysis Center[42] was found to be attacked by a common cleaner, trichloromethane. Also, antistatic polyethylene (pink poly) can have its properties adversely affected by silicones, trichlorethylene, MEK and other similar propertied liquids. Also, the work surface should not react chemically with other common materials. For example, it has been shown[10] that carbon filled plastics in conjunction with aluminum and salt water can cause an EMF of as much as +3 volts, resulting in extensive corrosion.

Surface Hardness

The surface hardness should be such that it offers some degree of resilient protection for those parts which are inadvertently dropped onto the work surface. Conductive vinyl laminates do provide such cushioning. There is, of course, a necessary tradeoff between surface hardness and durability or wear resistance.

Operator Comfort

The ideal work surface should provide a pleasing surface for the operator to work on. For example, a plain metal work surface is normally cold to the touch. An operator may tend to place some insulative material between himself and the bench to avoid its cold feel, thus defeating the purpose of the protective work surface.

Also some materials tend to curl up rather than to lie flat on the work bench.[4]

Grounding Method

The physical construction of the protective work surface will frequently dictate the method by which it is grounded. Some of the softer mat or pad-like materials use a grommet to make connection to ground. Some instances of inadequate connection between the grommet and the mat or pad have been reported.

As with the wrist straps, a current limiting resistor is required for operator safety for the low resistivity work surface materials (less than 10^5 ohm per square); it is optional for the higher resistivity work surface materials.

SECTION 3

PROTECTIVE PACKAGING

SECTION 3: PROTECTIVE PACKAGING

To be completely effective, electrostatic protective packaging requires the application of three separate and distinct principles. These three principles are: a) equipotential bonding, b) the prevention of charge generation caused by triboelectric contact and separation, and c) protection from strong electrostatic fields by Faraday cage shielding.

Equipotential Bonding

Bonding is the process of connecting two or more conductive objects together by means of a conductor. There is practically no potential difference between two metallic objects that are connected by a bond wire because the current through a bond wire is generally quite small. However, the situation may be different with an object that is connected to ground. "Grounding (earthing)" is the process of connecting one or more objects to the ground and is a specific form of bonding. An object that is connected to ground may, under heavy current flow, develop a high potential difference with respect to ground ($E = I \times R$).

Thus, when all the terminals of an electronic device are bonded together (but not grounded) it is virtually immune to ESD. However, a bonded device that is charged might be subject to damage if suddenly grounded.

ESD sensitive devices are equipotentially bonded by inserting the devices into conductive foam or a similar substance. Equipotential bonding of modules and printed circuit cards containing ESD sensitive parts is accomplished by the use of shorting plugs or conductive shunts on printed circuit edge connectors to assure that during shipping and handling all of the circuitry on the card is maintained at the same potential.

Triboelectric Charging

When any two materials are placed in intimate contact and then separated a triboelectric charge is generated. The magnitude of this charge is a function of the relative separation between the two materials in the triboelectric series (Table 4). The triboelectric series also establishes which material will become positively charged and which material will become negatively charged. Another way of visualizing static electrification via a triboelectric series chart is that it is a listing of materials by their relative electron densities. As long as there is a difference in electron density, charges will be transferred at each encounter. Triboelectric charging can be reduced in three ways. The first method is by the proper selection of packing materials, i.e., those materials which are not too widely separated on the triboelectric series from the external material of the item to be protected. The second method is by the use of packing materials with sufficient conductivity to allow any such charges to be quickly bled away and dissipated before they can build up to damaging levels. The third method is by the introduction of a lubricant or other surface contamination between the materials to reduce the intimacy of their contact; antistats in particular when deposited on the surface of a material act in such a way as to prevent charge generation.

Faraday Cage Shielding

Charges placed on an insulated hollow conductive object reside entirely on its outer surface. Because of this no charge is apparent inside the conductive object. Michael Faraday carried out experiments to prove this. He built a large metal-covered box which he mounted on insulating supports and charged with a powerful electrostatic generator. Faraday wrote of his experiment: "I went into the cube and lived in it, and, using lighted candles, electrometers, and other tests of electrical states, I could not find the least influence upon them...though all the time the outside of the cube was very powerfully charged, and large sparks and brushes were darting off from every part of its outer surface."

TABLE 4: SAMPLE TRIBOELECTRIC SERIES

Positive +	Air
	Human Hands
	Asbestos
	Rabbit Fur
	Glass
	Mica
	Human Hair
	Nylon
	Wool
	Fur
	Lead
	Silk
	Aluminum
	Paper
	Cotton
	Steel
	Wood
	Amber
	Sealing Wax
	Hard Rubber
	Nickel, Copper
	Brass, Silver
	Gold, Platinum
	Sulfur
	Acetate Rayon
	Polyester
	Polyethylene
	Polypropylene
	PVC (Vinyl)
	KEL F
	Silicon
Negative -	Teflon

It is this behavior that enables conductive bags to protect ESD sensitive devices from external charges and electrostatic fields. More important, it illustrates the need to have devices enclosed in a conductive enclosure to be protected.

Higher Assembly Considerations

Each of these three principles must be applied in all stages of shipping and handling from the receiving of the ESD sensitive devices through the completion of the finished product containing these devices. Assembly of an ESD sensitive device into a higher level assembly does not render it insensitive. Because of their greater electrical capacitance, printed circuit boards (PCB) can store much more charge than the device itself.

In some cases, then, the device is more vulnerable to ESD damage when it is installed on a PCB than the device would be itself. In addition, the circuit paths themselves on the PCB can act as antennae and intensify the potential to which the device is subjected when the PCB is exposed to an electrostatic field. Thus, the same or comparable precautions must be taken with higher level assemblies. For example, PCBs containing ESD sensitive parts must be handled as ESD sensitive assemblies, and finished products containing ESD sensitive parts should be shipped with shorting plugs attached to protect the sensitive circuits therein.

Each of these three principles--equipotential bonding, prevention of triboelectric charging and Faraday cage shielding--apply individually and they cannot be interchanged one for another. Unfortunately, however, no single package scheme incorporates all three principles. Therefore, the proper ESD packaging will usually be a two or three step process in order to incorporate all three principles.

PROTECTIVE BAGS

There are a number of different types of antistat protective bags on the market; however, at present the majority utilize three generic approaches. These approaches are a) bulk conductive plastics, b) antistat impregnated plastics, c) metallic films coupled with other materials.

Different manufacturers utilize these three approaches in a variety of ways. Some products provide only protection against triboelectric charging, others provide only protection against external electrostatic fields, and some products provide protection against both triboelectric charging and external electrostatic fields.

To provide adequate protection, however, sensitive items must be actually inserted into the bag and not simply laid on top of the bag. For those bags which provide only triboelectric charging protection, it will be necessary to "double bag" with a second type of bag to provide electrostatic field protection.

It should be noted that neither of the two types of bags constructed from MIL-B-81705 materials provides completely adequate ESD protection by itself. The Type I bag provides excellent electrostatic field protection but it does not protect against triboelectric charging. In contrast, the Type II bag does provide protection against triboelectric charging but it provides no protection against electrostatic fields. What is needed is a Type III bag incorporating the best features of both the Type I and the Type II bags. A revision to the specification to correct this deficiency has been proposed.

Other types of bags also on the market include aluminum foil/paper laminates, carbon-filled TYVEK cloth, and various carbon and paper combinations. None of the bags, however, provide true equipotential bonding. A separate shunt bar or shorting connector is recommended when a printed circuit card or a module is inserted into the antistatic bag. Table 5 provides a listing of some of the better-known ESD protective bags with a summary of their capabilities.

Antistat Impregnated Plastic Bags

Antistat impregnated plastics, typically "pink poly" or "blue poly," depend upon a "sweat layer" of moisture derived from the atmosphere to provide the necessary conductivity. Thus, they tend to

TABLE 5: PROTECTIVE BAGS

Generic Type	Name or Model	Supplier	Inside Resistivity ohms/sq.	Triboelectric Protection	Faraday Cage	Approx. Price (6" x 10")	Documented Test Results	Reference Number
Opaque aluminum foil film laminate (MIL-B-81705 TYPE I)	MIL-B-81705 I	Champion Packaging	10^{16}	No	Excellent			
	MIL-B-81705 I	Ludlow		No	Excellent			
Antistat Treated Polyethylene (Pink or Blue Poly) (MIL-B-81705 TYPE II)	RCAS 1200	Richmond	10^{11}	Yes	None	9¢	Ray 10-79	16
	Benstat 2P101	Bengal	3×10^{9}	↓	↓	9¢		
	RCAS 1200	Controlled Static	10^{11}	↓	↓			
	Autobag Static Stopper	Automated Packaging Systems	10^{12}	↓	↓			
	T-100 Antistatic	Techni-Bag		↓	↓	9¢		
	Pink Poly Bags	Colvin Packaging		↓	↓			
	RCAS 1200	Lydall		↓	↓			
	Aircap Antistatic Bubble Bags	Sealed Air Corp		↓	↓			
Antistat Treated Polyethylene Cushioned Reusable (Zip Lock) (MIL-P-81997)	Cushioned Zip Lock	Controlled Static		Yes	None			
	Cushioned Static Protective	Lydall		Yes	None			
Conductive-carbon impregnated polyolefins	Series 2000	3M	3×10^{4}	Yes	Fair	33¢		
	Padded conductive bag	Jiffy Packaging		↓	↓			
	EN4000	Semtronics	7×10^{3}	↓	↓	23¢		
	A4692	Simco		↓	↓	25¢		
	Conductive Bags	Static Inc.		↓	↓			
	W-6100	Wescorp	2×10^{4}	↓	↓	29¢		
Conductive Nylon	CP302	Charleswater	3×10^{4}	Yes	Fair	28¢		
Multi-layer conductive outside with antistatic inter layer-metallized polyester/anti-static polyethylene composite	2100	3M	10^{13}	Yes	Good	39¢	Ray 10-79	16
	CP303	Charleswater	10^{12}	↓	↓	29¢		
	Static-Barrier	Simco	10^{11}	↓	↓	37¢		
Antistatic treated Tyvek, aluminum foil, antistatic RCAS-1200	RCAS 3600	Richmond	10^{12}	Yes	Excellent	24¢		

lose their effectiveness at very low relative humidities. At least one investigator[20] has found that "blue poly" tends to be somewhat less humidity sensitive than the "pink poly," possibly due to the "blue poly's" normally higher conductivity. One investigator[61] has found many of the antistatic impregnated plastics to exhibit significant changes in surface resistivity with prolonged exposure to air. A number of different product samples exhibited increases of two or three orders of magnitude after one year of exposed shelf storage compared with identical lot control samples which were not so exposed. The antistat impregnated plastics provide triboelectric charging protection but do not provide protection against external electrostatic fields.

Bulk Conductive Plastic Bags

Bulk conductive plastic bags typically are black and are carbon filled to obtain the necessary conductivity. All of them provide protection against triboelectric charging; however, the degree of protection against external electrostatic fields is less clearly defined. The degree of protection is a function of the surface conductivity, and not all manufacturer's bags have the same conductivity. The greater the conductivity the greater will be the degree of electrostatic field protection.[45] One additional drawback of this type of bag, a tendency to smudge, generally restricts their use in clean rooms.

Metallic Film Laminate Bags

The metallic film bags are typical of a sandwich construction composed of various separate layers bonded together. The inside surface is usually an antistat impregnated plastic and another one of the layers is a thin metallic coating of nickel or aluminum. These bags are designed to provide protection against both triboelectric charging and external electrostatic fields.

With bags utilizing a thin metallic film it is important that the bag is not creased in such a way that the metallic film is cracked. This is especially important at the bottom edge of the bag because the conduction from one side of the bag to the other side of the bag can be lost and hence the Faraday cage effect may be greatly reduced[20] or rendered ineffective. The normally used methods of heat sealing along the sides of the bag do not provide electrical contact; thus the conductivity of the bottom of the bag is vital to its retaining an effective Faraday cage.

Other Protective Bag Properties

Additional considerations in the selection of an optimum choice of protective bags may include factors such as:

a) degree of transparency
b) permeability to water vapor
c) abrasion resistance
d) heat seal strength
e) puncture resistance

One investigator has reported on his studies of these considerations.[52] The results of his tests are illustrated in Tables 6, 7, 8, 9 and 10.

Transparency results are given in Table 6. The nickel-coated bag was noticeably darker than some other samples. The aluminum-coated material has significantly better transparency. Packaged items are very clearly seen through blue or pink poly, especially the latter, whose 87% transparency approaches that of 93% found for a 6-mil film of ordinary low-density polyethylene. In the latter case, most of the 7% loss is due to reflection.

Water vapor permeabilities, under the conditions of MIL-STD-202E, Method 106, are given in Table 7. The materials are ranked in their

TABLE 6: BAG TRANSPARENCY

MATERIAL	TRANSPARENCY (%)	RATING
PINK POLY	87	EXCELLENT
BLUE POLY	79	GOOD
NICKEL-COATED	35	POOR
ALUMINUM-COATED	60	FAIR
BLACK	0	NONE
TYPE I	0	NONE
"3600"	0	NONE

TABLE 7: BAG WATER VAPOR PERMEABILITY

MATERIAL	g./100 IN.^{2}/24 HR	RATING
PINK POLY	0.6	FAIR
BLUE POLY	1.5	FAIR
NICKEL-COATED	1.1	FAIR
ALUMINUM-COATED	2.3	FAIR
BLACK	2.9, 6.2	POOR
TYPE I	$<$0.003	EXCELLENT
"3600"	$<$ 0.002	EXCELLENT

TABLE 8: BAG ABRASION RESISTANCE

MATERIAL	CYCLES TO FAILURE	RATING
NICKEL-COATED	$>$10, $<$50	FAIR
ALUMINUM-COATED	$\sim$100	FAIR
TYPE I	$\sim$1000	EXCELLENT
"3600"	$\sim$1000	EXCELLENT

TABLE 9: BAG HEAT SEAL STRENGTH

MATERIAL	HEAT SEAL STRENGTH (LB/IN. OF WIDTH)	RATING
PINK POLY	10.3	EXCELLENT
BLUE POLY	7.3	EXCELLENT
NICKEL-COATED	0.4-9.2	POOR-EXCELLENT
ALUMINUM-COATED	14.9	EXCELLENT
BLACK	8.4, 9.3	EXCELLENT
TYPE I	6.0	GOOD
"3600"	4.5	GOOD

TABLE 10: BAG PUNCTURE RESISTANCE

MATERIAL	FAILURE (LB.)	RATING
PINK POLY	1.5	FAIR
BLUE POLY	1.9	FAIR
NICKEL-COATED	2.6	GOOD
ALUMINUM-COATED	3.2	GOOD
BLACK	1.8, 1.5	FAIR
TYPE I	4.7	EXCELLENT
"3600"	4.2	EXCELLENT
PINK POLY + TYPE I	5.8	EXCELLENT

expected order. Both foil bags (Type 1 and "3600" are excellent moisture barriers; the requirement of MIL-B-81075 for Type I is 0.02 g./100 sq. in. /24 hr. at 100°F and 90% relative humidity.

Abrasion resistance results are given in Table 8. There is an order of magnitude difference between the performance of the metal-coated bags and the foil-containing bags because the latter have their foil "buried" under a layer of spun-bonded polyethylene. By 100 cycles, the metal-coated bags had lost their metallization. At 1000 cycles, the aluminum foil in Type 1 and the "3600" had been exposed and was partially eroded. Under normal handling conditions, abrasion is not expected to be a problem with any of these bags.

Heat seal strength values are listed in Table 9. All the results, except for 0.4 lb. for one lot of the nickel-coated bags, seem high enough in practice. Two nickel-coated bags were tested. The one with a heat seal of uniform appearance gave the low result (0.4 lb.). The other bag, with a heat seal of crimped configuration, has an excellent value (9.2 lb.). In general, the quality of heat seals varies with machine settings, e.g., temperature. No attempt was made to estimate the relative ease of heat-sealability of the bag materials, all of which use polyethylene of varying thickness as the sealable layer.

Puncture resistance results are given in Table 10. A pointed probe was used to represent a solder point on a printed circuit board. The stress for failure is listed, but strain may also be a factor. The metal-coated Type 1 and "3600" material showed "elongations" (probe displacement as stress rose to the point of puncture) of 0.1-0.2 in. vs. above 0.3 in. for the polyethylene or black (carbon-loaded polyethylene) films. Thus the latter have more ability to stretch and accomodate a tight-fitting item which might, albeit with more applied force, rupture the stronger but less extensible polyester or aluminum foil laminates. All the materials may be adequately puncture-resistant in practice. Note that a combination of "pink poly" and Type 1 gave the highest puncture force, as would be expected. This combination represents a double-bagging system, i.e., a Type 2 bag inside of a Type 1 bag.

Antistatic Cushioned Packaging Material

Antistatic cushioned packaging material is typically fabricated from antistat-impregnated plastic. It may be either a bubble pack construction or an expanded polyethylene or polypropylene. A typical use of this product would be to wrap a printed circuit board or module in prior to insertion into a MIL-B-81705 Type 1 bag for thorough protection during storage, shipping and handling. This combination would provide physical protection as well as triboelectric generation protection and external electrostatic field protection.

Two separate studies have established that the effectiveness of the antistat impregnated materials used in both the bubble pack and foam may be highly dependent upon the relative humidity (RH). The first of these studies[53] measured the surface resistivity and the static decay properties of eight different materials at both 55% RH and 15% RH. The material surface resistivity was found to increase for a given product by anywhere from 2x to 1000x at the lower RH. The associated static decay times (to 10% of initial value) for a given product were found to increase by up to a factor of 20 or more at the lower RH. In fact, some of the products were unable to meet the generally accepted value (established by MIL-B-81705B) of a static decay time (to 0 volts) of 2.0 seconds or less at the lower RH. The results of these tests are illustrated in Figures 3 and 4.

The second study[54] measured and compared surface resistivity and static decay time of three different materials at four different values of relative humidity. Material surface resistivity was found to increase by up to a factor of 55 between 80% RH and 13% RH. Static decay time (to 10% of initial value) was found to increase by a factor of up to 20 or more between 83% RH and 13% RH. The results of these tests are illustrated in Figures 5 and 6.

The inconsistent quality of some of these products was also documented in the first of the studies as illustrated in Figure 7. The

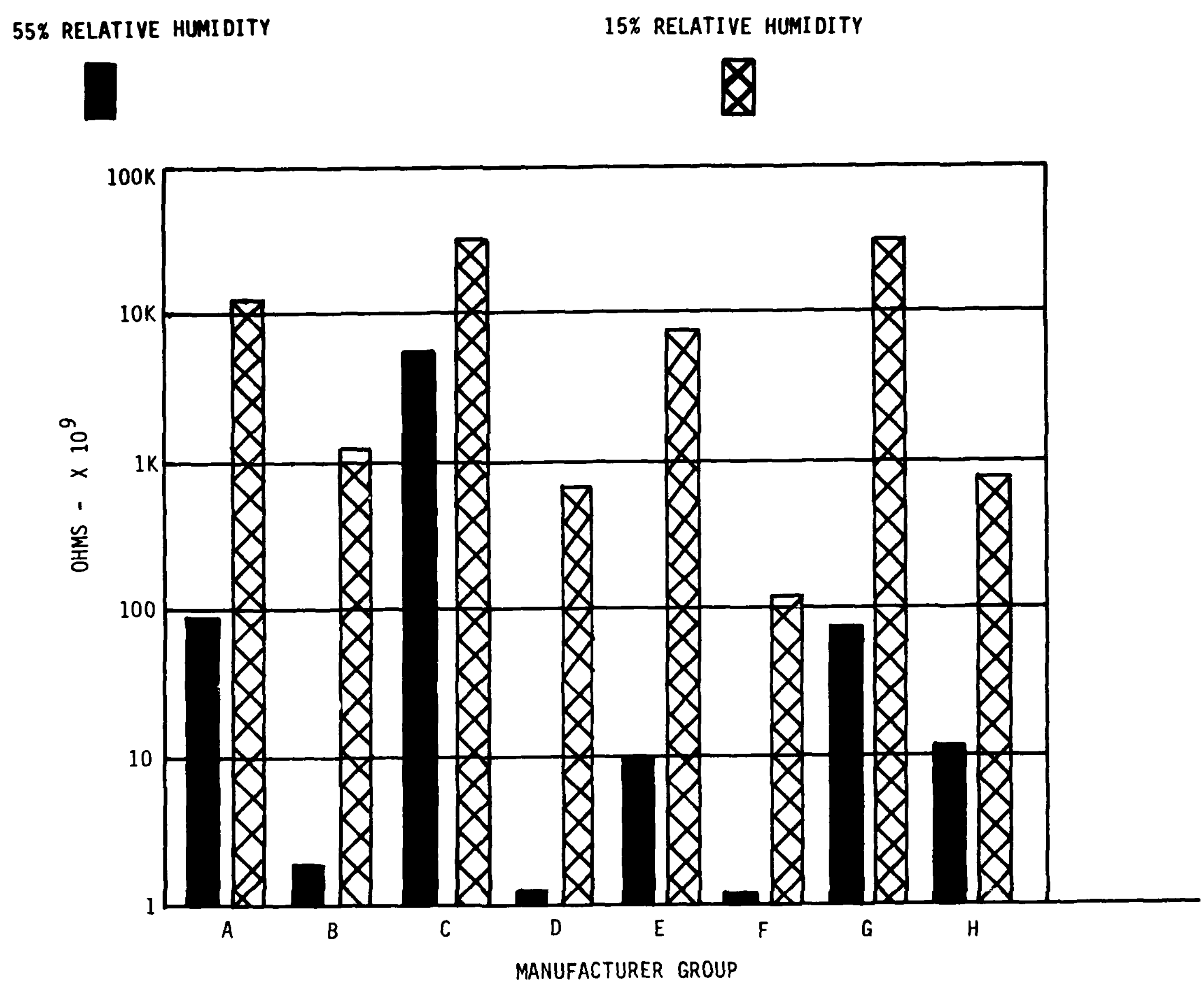


FIGURE 3: SURFACE RESISTIVITY AT 55% RH AND AT 15% RH

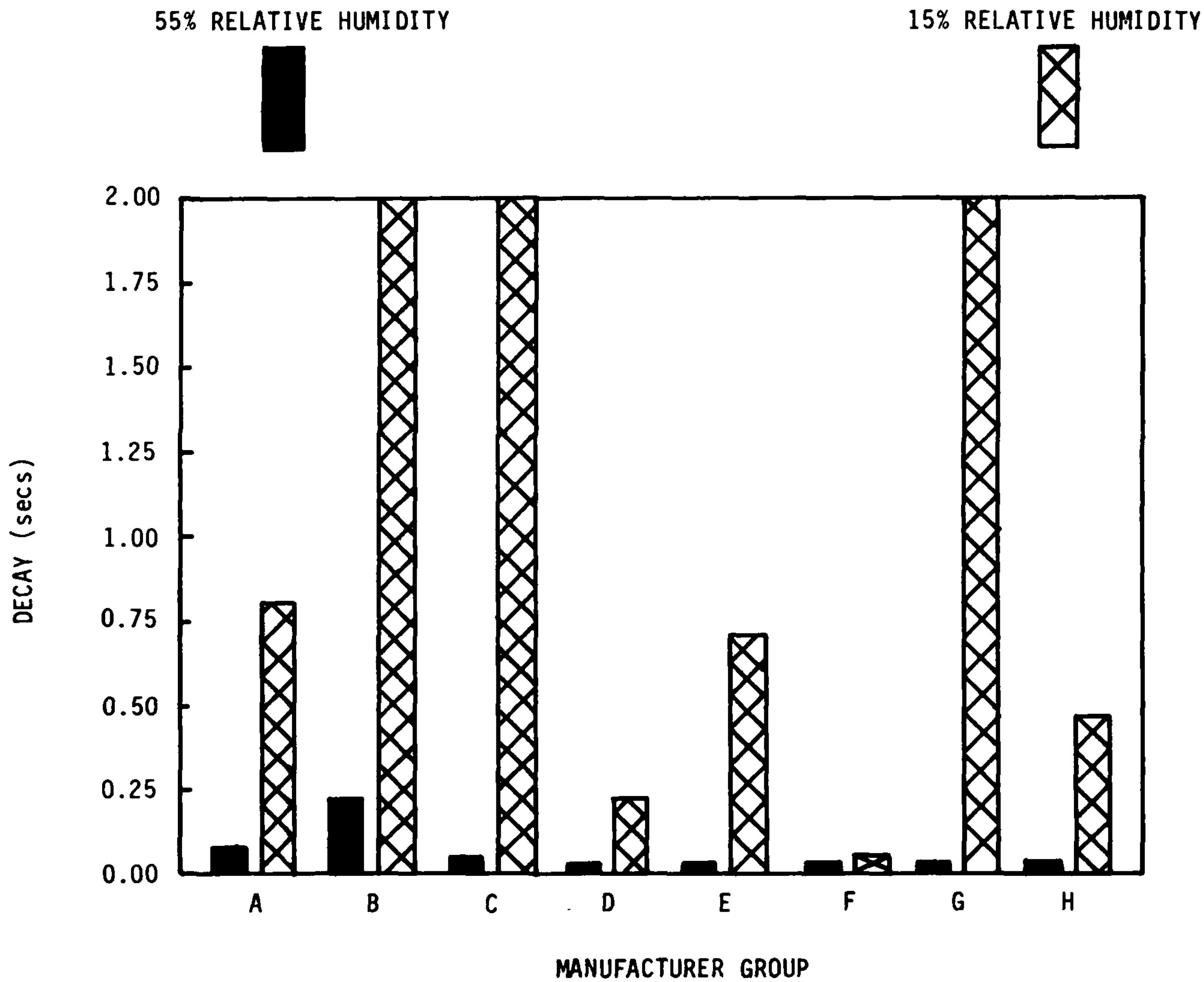


FIGURE 4: STATIC DECAY TIMES AT 55% RH AND AT 15% RH

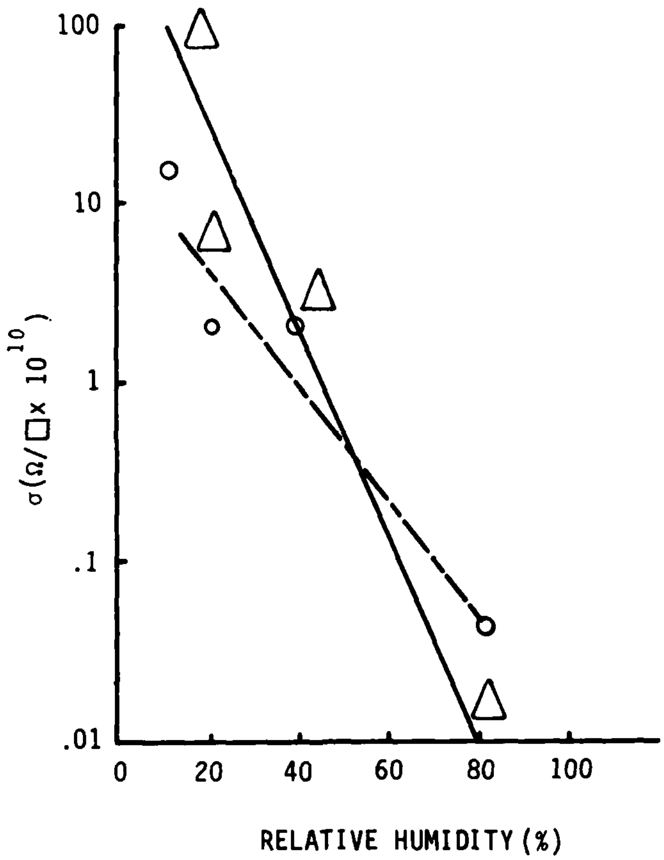


FIGURE 5: SURFACE RESISTIVITY CHANGE VS. RH

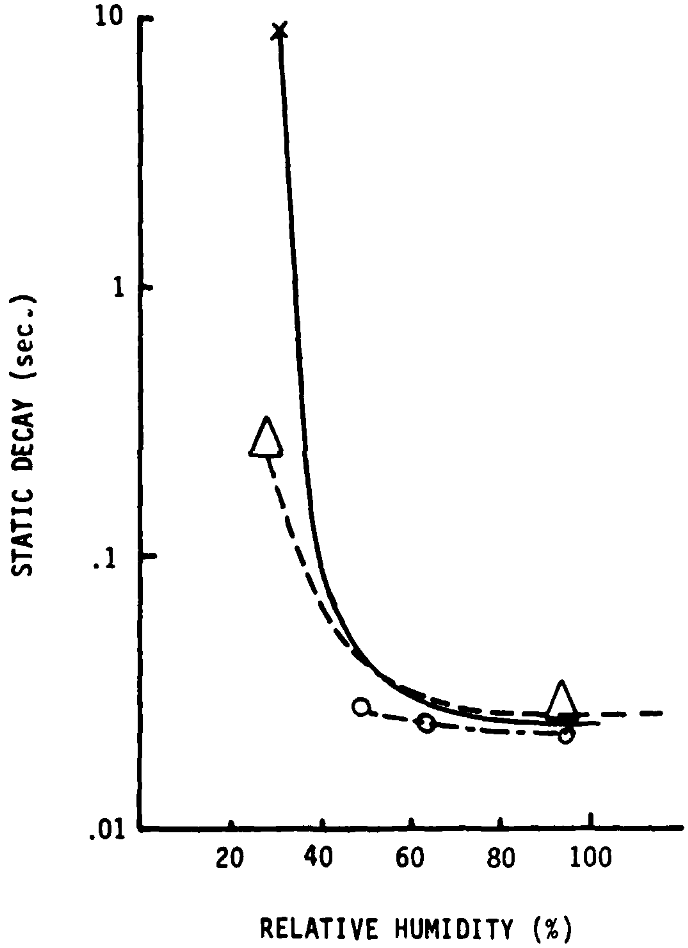


FIGURE 6 : STATIC DECAY TIME CHANGE VS. RH

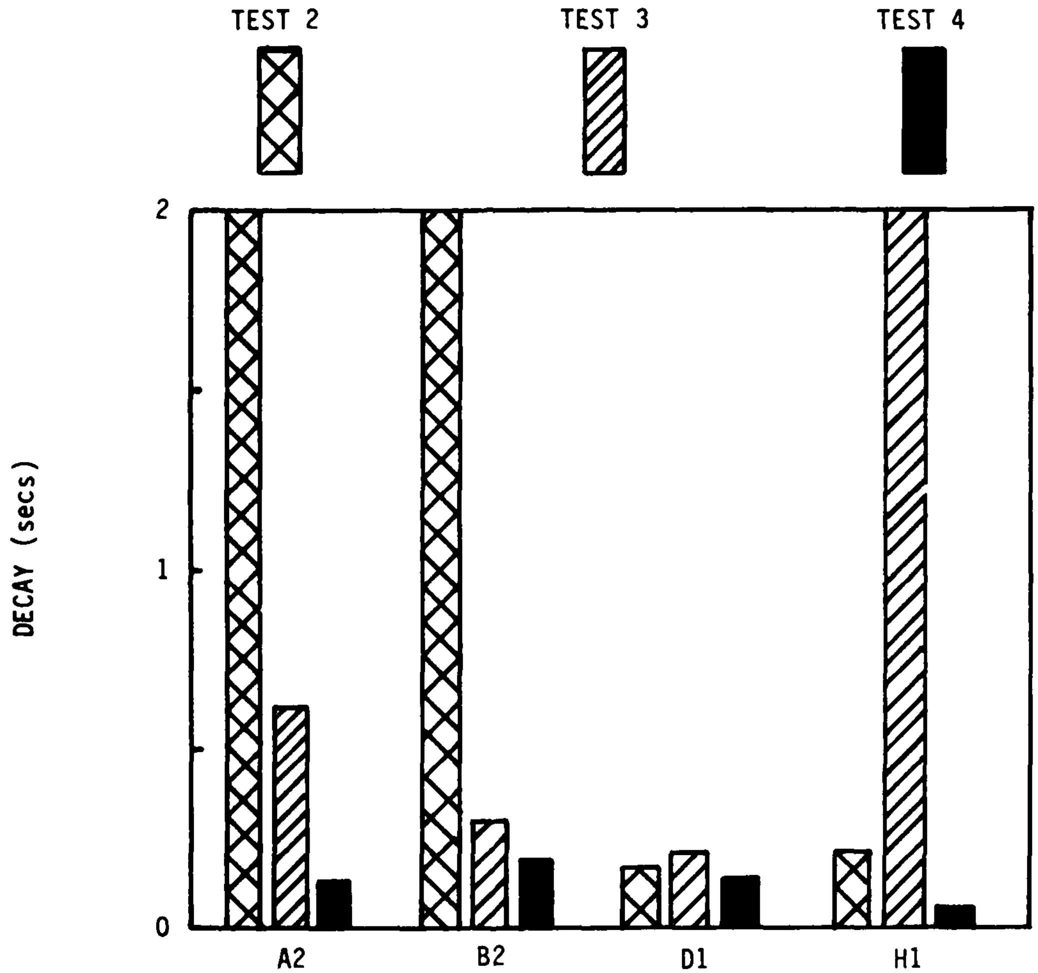


FIGURE 7: STATIC DECAY TIME VARIABILITY BY LOT

static decay time (to 10% of initial value) of three separate samples of each product was measured and compared. Significant lot to lot variations can be noted between each of the three samples for three of the products while the consistency of the fourth product's three samples shows that consistent product quality is possible.

In another case the inconsistent quality of some ESD products is illustrated by a formal demonstration test performed by another investigator.[20] In this case the manufacturer submitted three samples of an antistatic bubble wrap for qualification. The three samples were supposedly identical, differing only in the size of the bubbles. Samples 1 and 2 passed the test with no problems. Sample 3 failed completely. It exhibited no antistatic protective properties whatsoever. A different sample of antistatic bubble wrap submitted by a different vendor, although pink in color, was also found to be totally an insulator.

Researchers have found that antistat-treated materials utilized in antistat-impregnated materials outgas substances that tend to cloud precision optic surfaces.[16] The detergent action of the antistat chemicals can also damage precision bearings and their lubricants.[17] Caution is advised against the use of antistat-treated materials around such precision items.

Conductive Foam

There are at present two different carbon-filled conductive foam densities. Low density foam provides optimum cushioning for physical protection. High density conductive foam is used to provide equipotential bonding while holding IC and other discrete device leads securely without bending. Severe corrosion of IC leads has been reported in the past[18] due to chloride and sulfide ions in high density conductive foam in the presence of moisture. This problem may be caused by the addition of fire retardants to the foam[19] or by an improper foaming process that does not allow sufficient time to cook off the sulfides.[20] Many manufacturers have reformulated their high density foams to eliminate the corrosive chlorides and sulfides. Additional problems detected[20] during formal qualification testing of various carbon filled conductive foams include instances of a glue-like material adhering to the leads of devices inserted into the foam and some instances where the foams themselves have seriously degraded, i.e., literally fall apart after extended high humidity exposure. Some of the high density foams have also been noted to break up readily and shed particles in normal use; thus their use is generally prohibited in clean rooms.[5]

Table 11 contains a listing of antistatic cushioned packaging materials and conductive foams with their suppliers.

Conductive Shunts

The terminals of all ESD sensitive items, including higher level assemblies, should be shunted together during handling, storage and assembly. The shunts described in this section are those normally used on printed circuit boards. To act as an adequate shunt, the resistance of the shunting material should be orders of magnitude less than the minimum impedance between any two pins of the ESD sensitive item; thus conductive or static dissipative rather than antistatic materials should be used for shunts. The types of circuit board shunts presently on the market are typically a semi-rigid carbon-filled bulk conductive plastic or rubber. They are available from various sources as shown in Table 12.

DIP Tubes and IC Carriers

Most dual-in-line integrated circuits are shipped from the manufacturer in tubes referred to as magazines, chutes or DIP sticks.

TABLE 11: CUSHIONING MATERIALS

Generic Type	Name or Model	Supplier	Resistivity Ω/sq.	Non-Corrosive (see text)
Conductive Foam	Soft Foam	Foam Fab	10^4	Yes
(Low Density		Lydall	2K-5K	
Carbon Filled)	Low Density	Pervel	10^4	Yes
		Republic Pack.	<100K	
	2900 & 2905	3M	$1x10^5$	Yes
	Low Density CP105	CHarleswater	$3x10^4$	Yes
	Low Density	Controlled Static		Yes
	EN1000	Semtronics		
	A4695	Simco	$5x10^3$	
	ST1001-06	Static, Inc.		
	W-100	Wescorp	$7x10^3$	
	2448	Techni-Bag		
Antistatic Foam	Microfoam	DuPont	10^{11}	N/A
(Antistat Impregnated)		Republic Pack.	10^5	N/A
		Sentinel Foam	$5x10^{10}$	N/A
	SFC-18 & 104	Techni-Bag		N/A
	Benstat Foam	Bengal	$3x10^9$	N/A
Antistatic Bubble Wrap	Air Cap	Sealed Air		N/A
(Antistat Impregnated)	Antistatic Bubbles	Techni-Bag		N/A
	Antistatic Cancel	ADE		N/A

TABLE 12: CONDUCTIVE SHUNTS

Generic Type	Name or Model	Supplier	Resistivity	Non-Corrosive (see text)
Conductive Foam (High Density, Carbon Filled)	Crisp Foam	Foam Fab	10^4 Ω/sq.	Yes
		Lydall	2K-5KΩ	
	High Density	Pervel	10^4Ω/sq.	Yes
	Semi-rigid	Republic Pack.	<100KΩ/sq.	
	2910 & 2915	3M	1.7×10^4 Ωcm	Yes
	High Density CP105	Charleswater	3×10^3 Ωcm	Yes
	High Density	Controlled Static		Yes
	EN2100	Semtronics	3KΩ	Yes
	A4694	Simco	5×10^3	
	ST2101-06	Static Inc.		
	W-1100	Wescorp		
	1824	Techni-Bag		
Antistatic Foam (Antistat Impregnated)	Shunt Foam	Controlled Static		N/A
		Richmond		
PCB Shunt Bars/Boardshorts (Carbon Filled)	5220X	3M	.5mΩ/36"	
	CP403	Charleswater		
	60200 & 02	Controlled Static		
	EN5700	Semtronics		
	A4698	Simco		
	ST5701-05	Static Inc.		
	W-6743	Wescorp		

Flat-pack integrated circuits are usually placed in plastic IC carriers which may or may not be subsequently placed into similar shipping tubes. Typical DIP tubes and IC carriers are illustrated in Figure 8. Three generic types of shipping tubes, intended to provide ESD protection, are in general use. These are:

1) metallic tubes, usually aluminum either formed or extruded
2) carbon-loaded bulk conductive plastics
3) antistatic plastics

Unfortunately none of these three types provides completely adequate ESD protection for a variety of reasons.

One deficiency which they all share is the fact that they do not provide true equipotential bonding. Due to normal manufacturing tolerances all of the device pins are not at all times in contact with the conductive surfaces. Furthermore, triboelectric charges can be generated as the ICs slide through the tube.

Triboelectric charge generation is a function of the two or more different materials which come into intimate contact. The difference between these materials on the triboelectric series (see Table 4) will determine the amount of charging which takes place. Therefore, a single choice of tube material may not be best for all types of integrated circuit packages. The optimum tube material choice would depend upon whether the IC package used ceramic, metal ceramic, or a specific type of plastic encapsulation. Aluminum tubes (without an anodic coating) provide minimum triboelectric charge generation for all types of IC packages. For an additional discussion of this consideration see Reference 22.

Table 13 provides a sample listing of some of the DIP tubes and IC carriers presently available with some of the suppliers.

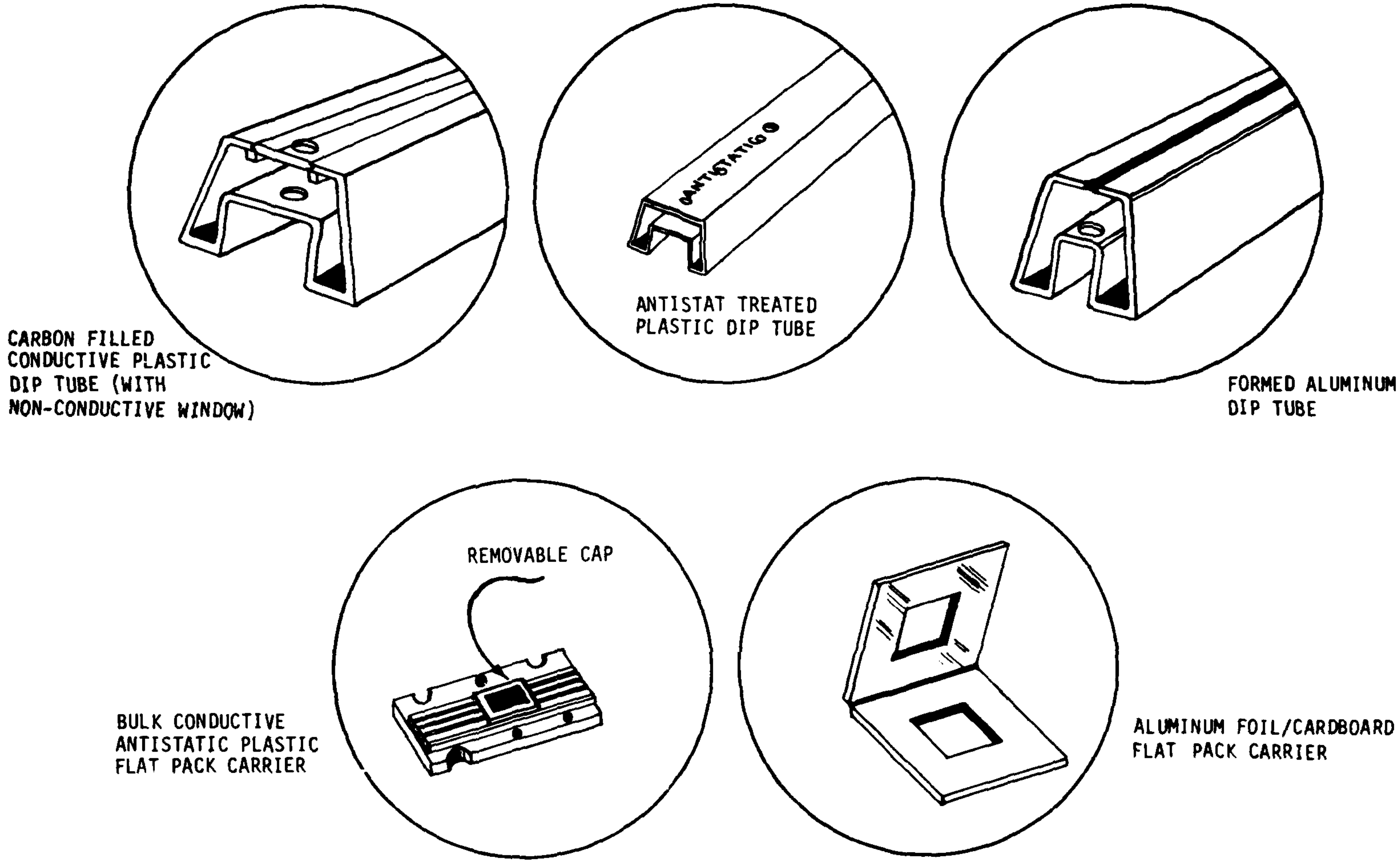


FIGURE 8: TYPICAL DIP TUBES AND IC CARRIERS

TABLE 13: DIP TUBES AND IC CARRIERS

Generic Type	Make or Model	Supplier	Resistivity Ω/sq.	Approx. Price per 1000	Viewing Slot	Faraday Cage	TRIBOELECTRIC CHARGE GENERATION Plastic IC	Ceramic/ Metallic	Cerdip IC
Formed Aluminum	W-0601,51	Wescorp		54¢-74¢		Excellent	Minimum	Minimum	Minimum
Conductive Plastic (Carbon Filled)							Variable with Manufacturer		
	5550,51	3M	200Ω/cm		Yes	Fair ↓			
	W-0625,75	Wescorp		36¢-46¢					
	SLYD-PAK	Thielex	300Ω/cm		Yes				
	EN6000S	Semtronics	300Ω/cm		Yes				
Antistatic Plastic	BDT 3,4,6.	Bengal	$1.8x10^9$		Transparent	None	Low	Low	Low
Antistat Treated Plastic							High(New)	Low(New)	Low(New)
	Stati-kote	Thielex			Transparent	None ↓	All increase with use →		
	.3,.4,.6.	Gibson-Egar	$1.5x10^9$						
	W-0605,55	Wescorp		26¢-36¢					
Flat-Pack IC Carriers (Aluminum Foil/ Cardboard)	Flat-Pack Carrier	L. Gordon		<10¢	Yes	Good	Not Applicable		

Metallic Tubes

While aluminum tubes (without an anodic coating) do provide minimum triboelectric charge generation for all types of IC packages, because of their low conductivity they also allow any existing charges to be readily transferred to the tube and evenly distributed over the entire tube. These charges are then transferred to the devices as they leave the tube. For this reason it is manditory that personnel handling aluminum IC tubes always wear a wrist strap to prevent the ICs from becoming inadvertently charged via this mechanism. Anodic coatings are insulators; thus anodic coated aluminum tubes provide no ESD protection and should not be used.

Some of the other problems associated with aluminum tubes are their higher weight, their tendency to form nonconductive aluminum oxides in the pin contact areas, and their tendency to dent and to become bent and nicked. They do, however, due to their high conductivity, provide excellent Faraday cage shielding from external electrostatic fields. Some aluminum tubes also contain viewing slots to allow proper identification of the parts without necessitating their removal.

Bulk Conductive Plastic Tubes

Bulk conductive plastics depend upon carbon loading to provide their conductivity; thus they are black in color and are opaque, although some contain viewing slots or clear plastic windows. The amount of carbon loading and hence the associated conductivity varies with supplier. Triboelectric charge generation varies significantly between manufacturers and with device type. (Clear plastic windows, if used, can also generate significant charges.) High conductivity in itself is not a valid criterion for low triboelectric charge generation. The relatively high conductivity of the carbon-filled tubes also allows for effective charge transfer to the devices as they leave the tube. This mandates the use of wrist straps by personnel handling them to prevent the inadvertent charging of ICs therein.

The effectiveness of the Faraday cage shielding of the bulk conductive plastics is directly related to their conductivity. The greater the conductivity the more effective will be the shielding from external electrostatic fields. None of the carbon-filled plastic tubes, however, offers as effective shielding as do the aluminum tubes.

Antistatic Treated Plastic Tubes and Carriers

There are two different generic types of antistatic plastic tubes and carriers: those incorporating antistatic additives in the plastic (for example, Benstat), and those which simply have a topical antistat applied to their surface. While sharing some characteristics they also exhibit significant differences. One investigator[22] has found that Benstat tubes after proper aging did not generate significant triboelectric charges with any of the different types of IC packages. The antistat-treated plastics, however, did tend to generate such charges with plastic encapsulated devices when new and also generated significant triboelectric charges with all types of IC packages as they were used more and the antistat coating became worn away. The antistat-treated plastics are the cheapest and the most common, but they provide the least effective ESD protection. The antistat-treated plastics lose their protective properties with repeated use. Some large volume users, however, monitor the charge decay rate and retreat the tubes as necessary. Neither the antistat modified plastic tubes or the antistat-treated plastic tubes provide shielding from external electrostatic fields.

Other IC Carriers

One unique IC carrier that does provide very effective electrostatic protection is of an aluminum-cardboard sandwich construction. Unfortunately, its usage is only applicable to flat-pack ICs.

Tote Boxes, Bins and Trays

ESD protective tote boxes, bins and trays, including printed circuit board (PCB) carriers, are also an important element in the ESD packaging scheme. The nonconductive plastic tote boxes, bins and trays frequently used in manufacturing areas, due to their large electrical capacitance, may be significant sources of electrostatic charges. Furthermore, since the plastic is nonconductive, removal of these charges is more difficult. The replacement of nonconductive tote boxes, bins and trays with ESD protective equivalents is highly recommended. The ESD protective tote boxes, bins and trays should be conductive enough so that a nearby charged body cannot induce a significant voltage across the item but not so conductive that a spark discharge will occur.

Three or more generic types of ESD protective tote boxes, bins and trays are presently available commercially. These include:

a) injection molded or formed bulk conductive plastic
b) topical antistat-treated plastic
c) carbon-coated cardboard

Other types of tote boxes, bins and trays observed in use include aluminum foil lined cardboard boxes and nonconductive tote trays utilizing static dissipative, antistatic or conductive liners or hammock-like cell inserts or modified with aluminum separators riveted inside of them.

Of these various models available one would be considered not acceptable for repeated use. That is a topical antistat-treated hard plastic tray. Since the tray is a hard plastic, the topical antistat is not absorbed and thus provides only marginal effectiveness.[20] It should be recognized that all antistat-treated plastics will lose their effectiveness during normal handling and use and thus require periodic retreatment.

An ESD protective tote box, bin or tray with a conductive cover may be considered to be an acceptable substitute for an antistatic bag, provided, of course, that equipotential shunts are used. However, if the tote box, bin or tray is used without a conductive cover, then the Faraday cage effect is lost and shielded bags are also required. The greater the conductivity of the enclosure the greater will be the attenuation of external electrostatic fields. The antistat impregnated plastics do not provide sufficient conductivity to provide an effective Faraday cage shield.

Table 14 is an example of some of the tote boxes, bins and trays presently available with their principle suppliers.

TABLE 14: TOTE BOXES, BINS AND TRAYS

Generic Type	Name or Model	Supplier	Resistivity Ω/sq.
Antistatic Tote Boxes, Bins and Trays (Antistat Impregnated)		Colvin Pack.	
	Divider Box	Lewis Systems	10^{12} Ω max
	Plastibox	"	
	Benstat	Bengal	3×10^{10}
	40111 40500	Controlled Static	
	CP801	Charleswater	
	A4697	Simco	
		Parsons	
Conductive Nylon Tote Box Liners	CP3026	Charleswater	30×10^{3}
Conductive Tote Boxes, Bins and Trays (Carbon Filled)	4400 Series	3M	200Ω-cm
	4016 & 4017	3M	
	EN6500	Semtronics	
	EN6400	"	
	CP801	Charleswater	3×10^{4}
		Stanley Vidmar	
	A4690	Simco	
	W-5024	Wescorp	
	Plasticor	Shell Containers	10^{5}
Antistatic Component Carriers (Antistat Coated)	E-Stab-Rel	Life Line	
Cardboard Containers (Various Constructions)			
Cardboard with static free circuit board holders	Flat Box	Central Container	
		Lydall	
Cardboard coated with conductive material	Corstat	Conductive Containers	10^{4}
Cardboard with conductive foam inside	Convoy	Foamfab	10^{4}
	Sandwich Pack	Shell Containers	
Cardboard coated with conductive material with conductive foam insert	Conduct-o-carton	Republic Packaging	
Conductive container with conductive circuit board holders	Plasticor	Shell Containers	10^{5}

SECTION 4

AIR IONIZERS

SECTION 4: AIR IONIZERS

Wrist straps and protective work surfaces are effective in eliminating electrostatic charges on conductive items. Wrist straps and protective work surfaces are not, however, effective in eliminating electrostatic charges on nonconductive items such as clothing and nonconductive tote trays. Air ionizers can neutralize static charges on nonconductive items by supplying them with a constant stream of both positive and negative air ions. The charged object attracts the oppositely charged ions, thereby neutralizing itself in situ. The unused ions or those having the same sign as the charged surface are repelled and eventually recombined with other ions or are themselves neutralized by contact with grounded conductive surfaces.

Ionized air blowers may be thought of as a second line of defense in the battle against electrostatic discharge, i.e., they provide additional charge neutralization for those items not effectively neutralized by the wrist straps and the protective work surfaces. Ionizers should never be used in an attempt to eliminate either wrist straps or protective work surfaces. Air from ionizers should contain nearly equal amounts of positive and negative ions to dissipate both the negative and positive charges produced when static electricity is generated. An imbalance of positive or negative ions can result in residual voltage over the ionized area.

There are at present three different generic types of general work area air ionizers currently on the market. There are also various compressed air and spot ionizers. The three general work area generic types are a) the nuclear (radioactive) source with a blower, b) the corona discharge with a blower, c) the corona discharge without a blower.

One investigator has studied the effectiveness of some of the more common blower types of ionizers including several of the laminar flow units and has published his results.[13] Another investigator[49] has studied the effects of different styles of blowers and has concluded that this can have a significant effect upon the distribution of the ion flow over the work surface and hence the effectiveness of the ionizer. His data indicates that a squirrel cage blower yields significantly more even ion distribution patterns than does a fan style blower. A third investigator has tested a newer nonblown ionizer intended to neutralize static charges throughout the entire room.[28].

A major difference between the nuclear activated units and the corona discharge units is economic rather than technical. That is, the nuclear units, or at least the active element portion of the instrument, is available on a yearly lease basis only. Due to the nature of its radioactive source it is not available for purchase. Table 15 is a listing of some of the different models of air ionizers available from some of the suppliers.

Significant design differences do exist between the various corona discharge ionizers. Some of them use a D.C. high voltage, others use a 60 Hertz high voltage and still others utilize a modified wave form, high frequency/high voltage. There are also significant differences in the high voltage levels used.

A potential hazard associated with some models of corona discharge air ionizers is the generation of excessive amounts of ozone. OSHA standards[57] set a maximum ozone level of 0.1 PPM for 8 hour exposure. Some sensitive people can detect ozone by smell at levels as low as 0.015 PPM. Ozone levels of 0.01 and 0.02 PPM will cause cracking of rubber that is under stress.[49]

In a recent ESD survey conducted for NASA one manufacturer was identified who had to discontinue the use of corona discharge air ionizers because of ozone damage to rubber "O" rings used in his equipment.[14]

TABLE 15: AIR IONIZERS

Generic Type	Name or Model	Supplier	Air Delivery (CFM)	Discharge Time 15KV to 100V @ 3ft(secs) (1)	Ozone Level (PPM)	Isotope P 210 °Qty (Millicuries)	Operating Voltage Level (KV)	Approx. Price $	Documented Test Results	Reference Number
Nuclear	909	3M	50	28	N/A	40	N/A	250/yr	HAC 5-79	13
Blowers & Portable Fans	P-2061	NRD			↓	40	N/A	180/yr		
	905	3M	157			40	N/A	310/yr		
	911	3M		(9)	↓	20	N/A	(10)		
Corona Discharge	Aerostat APS	Simco						593		
Blowers & Portable Fans	" -APMA	Simco	94	11	Medium	N/A		304	HAC 5-79	13
	" - "	"				↓		265	CSDL 4-80	27
	WD-100	Wescorp	100		0.012				EAL 12-77	12
	"	"		Not possible					HAC 5-79	13
	Dynastat 120-2	Static, Inc.	100	Not possible	Medium				HAC 5-79	13
	" 320	Static, Inc.	320							
	1044	Calvin Packaging								
	SEB-32-100	Taak, Inc.	100					260		
	SEB-32-55	Taak, Inc.	55					260		
	60410	Controlled Static			0.008		(8)			
	100	Scientific Ent.	100	25	Low		3-4 (7)		HAC 5-79	13
	"	"	100						CSDL 4-80	27
	575	"	575	19 (2)	Low		3-4 (7)		HAC 5-79	13
	WD-300	Wescorp	300			↓		440		
Corona Discharge Grid	Ion Flow	Static, Inc.	100	132		N/A				
	Envirostat	Simco	100	146			7			
	X-Static Air	Wescorp	100	Not possible				275		
		Scientific Ent.	100	104		↓			HAC 10-79	13
	Ener-jet	Consan Pacific/	N/A	12 (3)		N/A	±15 (8)		JPL 4-81	28
	↓	Controlled Static ↓		14 (4)						
				17 (5)						
				19 (6)						
	Ion Control Sys.	Environmental Integrity Sys.	N/A				60 (8)			
	Envirostat	Simco	N/A			↓	7			
Corona Discharge Grounded Work Station	Microautostat	Clean Rm Products				N/A				
		Static, Inc.				"				

(1) HAC Test Results
(2) @ 6ft
(3) @ 2ft JPL Test
(4) @ 4ft JPL Test
(5) @ 7ft JPL Test
(6) @ 11ft JPL Test
(7) High Frequency Unit
(8) DC Unit
(9) Has provisions for slightly warm air
(10) Radioactive element only is leased

An ozone level of 1.0 PPM is readily detectable as a very noxious odor. High levels of ozone were measured during recent testing of a foreign-made corona discharge-type air ionizer.[15] However, on the basis of presently available data[12,13], it appears that none of the corona discharge ionizers identified in this report represent a health hazard. Nuclear source ionizers by their nature do not generate ozone.

Extreme caution should be exercised when utilizing any air ionizer in the vicinity of high voltage equipment since inadvertent high voltage breakdown may result from the ionized air.

Table 16 is a listing of some of the different models of compressed air ionizers and static eliminators available from some of the suppliers.

TABLE 16: COMPRESSED AIR IONIZERS AND STATIC ELIMINATORS

Generic Type	Name or Model	Supplier	Isotope P_o 210 Qty (Millicuries)	Operating Voltage Level (KV)	Approx. Price $
Nuclear Air Nozzle/Gun	902,6,7,8	3M	10 to 40	N/A	115/yr
	Nuclecel	NRD			
Corona Discharge Air Nozzle/Gun	Ionizing Air Gun	Controlled Static	N/A		
	Antistatic Air Gun	Chapman		5	
	WD-190	Wescorp			250
	190, HPX-3	Static, Inc.			254
	Various Models	Simco			
	Super Sonic Micro-Mini	Scientific Ent.			
Nuclear Spot or Bar	204,6,10,15	3M	5 to 40	N/A	
	Nucle-spot	NRD		N/A	
Corona Discharge Bar	SM Bar	Chapman	N/A	5	
	W-406-L	Wescorp			
	ME, SS	Simco			
	11, 12	Static, Inc.			
	Air Bar	Taak, Inc.			

SECTION 5

ELECTROSTATIC DETECTORS, VOLTMETERS AND MONITORS

SECTION 5: ELECTROSTATIC DETECTORS, VOLTMETERS AND MONITORS

Electrostatic detectors are used to determine the presence or absence of electrostatic charges in the work area. They may be used to determine the polarity and the relative magnitude of the charge. They are not, however, designed to make accurate measurements of electrostatic charges or to measure the decay rate of electrostatic charges. These types of measurements require the use of the more elaborate laboratory-grade electrostatic voltmeters. A third class of instruments, electrostatic monitors, are used for the continuous automatic surveillance of excessive electrostatic potentials in the work area. They are used to record the event, notify the operator and/or actuate ancillary equipments such as air ionizers.

Electrostatic Detectors

There are two primary generic types of electrostatic detectors presently on the market. These are a) the pure electro (induction) type and b) the combination electro/nuclear source type. Because of the extremely low level of radioactive material involved, the electro/nuclear type of detector may be purchased outright in contrast to the nuclear ionized air blowers, which can only be leased.

Both the electro type and the electro/nuclear type operate similarly to a simple box camera. They detect any electrostatic field due to a static charge within their field of view. They both suffer essentially the same deficiencies. They are unable to distinguish between different static charged areas or objects within this field of view. Also, there is an inverse relationship between the sensed level and the distance to the object. Their accuracy then is dependent upon three factors: a) angular field of view, b) distance from the instrument to the object and c) calibration. The solid angle field of view is fixed by the design of the instrument or, on some models, can be changed by the use of different aperture stops. The instrument will respond to any electrostatic charge within its field of view. This may easily include items other than the object to be measured and thus result in a significant source of error. Electrostatic detectors are calibrated to read a specific voltage at a specific distance from the object. Any error in the actual distance from the object is reflected as an error in the voltage reading.

The calibration of the detector itself is open to question, since seldom is there a requirement for, or the facilities for, periodic recalibration of the detector. Nevertheless, recognizing these limitations, survey-type electrostatic detectors do play an important role in the battle against ESD. Table 17 is a sampling of some of the electrostatic detectors currently on the market with some of their more germane features.

Precision Electrostatic Voltmeters

A detailed study of laboratory-type instruments is beyond the scope of this report; however, since such instruments may be required at times for more in-depth ESD studies, we have included in Table 18 a brief listing of a few of the better known laboratory-type instruments with some of their major features.

A basic limitation of electrostatic meters is their response time. Most meters are incapable of responding to pulses with fast rise time and short pulse widths. For measurements of pulses with very fast rise and decay times, a high-speed storage oscilloscope can be used for static charges that are generated and dissipated in shorter times than the response time of a meter.

Electrostatic Monitors

Electrostatic monitors cover a very broad range of equipments. They range from a simple instrument, analogous to a thermostat, designed to actuate when an electrostatic field reaches a preset level and turn

TABLE 17: ELECTROSTATIC DETECTORS

Generic Type	Name or Model	Supplier	Sensitivity: Max. Full Scale	Sensitivity: Measurement Distance	Sensitivity: Min. Full Scale	Sensitivity: Measurement Distance	Number of Ranges	Approx. Price ($)
Nuclear Hand Held Meter	1127E	Sweeney	200KV	12 in.	0.5KV	2 in.	9	750
	703	3M	200KV	12 in.	0.5KV	2 in.	9	455
Non-Nuclear Hand Held Meter	230B	Monroe	1.5KV				3	695 (1)
	W-1230	Wescorp	150KV	12 in.	500V	1 in.	3	700
	51A	Trek						
	5010	NRD	10KV/Meter		1KV/Meter		2	275
	CS-66	Custom Scientific					3	
Digital Non-Nuclear Hand Held	2B	Scientific Ent.	99.9KV	3.9 in.			(3)	595
Non-Nuclear Portable Meter	SS-2	Simco	200KV	1 in. (2)	0.5KV	2 in.	2	458 (1)
Nuclear Pocket Locator	1134	Sweeney	10KV	12 in.	5KV	6 in.	1	295
Non-Nuclear Pocket Locator	224C	Semtronics	30KV	12 in.	5KV	3 in.	3	280
	"	Tech						
	"	Wescorp						
	LC-1	Simco	50KV	5.5 in.	2.5KV	2 in.	2	198
	Elect. Microscan	Scientific Ent.	10KV	4 in.			(4)	
	Ind. Microscan	" "	100KV				(4)	
	DCA-1200-1	Anderson	10KV	12 in.	5KV	6 in.	2	255
	200	Wescorp	30KV	12 in.	5KV	4 in.	2	237
	ACL-300	Analytical Chem.	30KV	4 in.	0.5KV	0.5 in.	2	260

(1) Remote Ouput Available
(2) With Remote Prob
(3) Microprocessor Auto Ranging LED Display
(4) Microprocessor Auto Ranging

TABLE 18: PRECISION ELECTROSTATIC VOLTMETERS

Generic Type	Name or Model	Supplier	Max. Full Scale	Min. Full Scale	Number of Ranges	Approx. Price	Remarks
Non-contacting Sensor	W100B	Electro-tech	5KV	100V	2		Output for a recorder
	Isoprobe 1015						
	168-1	Monroe	5KV	1V	2	3750	
	168-3	Monroe	"	"	"	3995	Digital Meter
	340	Trek	10KV	100V	3/5	4150	
	340HV	Trek	19,999V	199.9V	3	5535	Digital Meter

on an alarm or to turn an air ionizer on and off to a complex precision multifunction, multistation monitoring system. The selection of a precision area static level/alarm monitoring system is indeed a major decision and beyond the scope of this report. Features one should consider in making such a selection would include: sensitivity range of response of sensor heads; the number of heads that can be used with the base station; the maximum distance a sensor head can be mounted from the base unit; the alarm level; the recording capabilities; self-calibration features: the distance a sensor head can be mounted from static generating source and retain monitoring level accuracy; available secondary functions, i.e., auxiliary machine control, computer connection capability; and the response time and system accuracy. Table 19 is a sample of some of the better-known monitors presently available with some of their major features.

TABLE 19: ELECTROSTATIC MONITORS

Generic Type	Name or Model	Supplier	Max. Full Scale	Measurement Distance	Min. Trip Level	Measurement Distance	Number of Ranges	Approx. Price	
Nuclear Monitor	1149	Sweeney	5KV	3 in.	1KV	3 in.	1	2030	①
	702	3M	5KV					3750	
Non-Nuclear Monitor	Sentry I, II	Scientific Ent	3.4KV	14 in.	25V	2 in.	3	280	
	Sentry IV	Scientific Ent	20KV	20 ft.	25V	2 in.	2		
	602	Electro-Tech	10KV	1 in.	5KV	1 in.	2		②
	350	ACL	5KV		15V				

① Remote Output Available

② 3-Channel with Chart Recorder

SECTION 6

CONDUCTIVE FLOORS, FLOOR MATS AND FOOTWEAR

SECTION 6: CONDUCTIVE FLOORS, FLOOR MATS AND FOOTWEAR

Conductive floors, floor mats and footwear are a rather specialized form of ESD protection. Although they may not be required in every instance, they do fulfill a definite role in the arsenal of ESD protective weapons. Their primary role is in those areas where, for whatever the reason, it is not possible to employ all of the previous ESD protective tools. For example, wrist straps may not be used near moving conveyor belts and in wave solder operations. In this type of application conductive floors or floor mats and conductive footwear should be utilized.

Conductive floors or floor mats alone without conductive footwear are of limited use in providing ESD protection. The conductivity of normal footwear varies greatly depending upon materials and construction. High density leather soled shoes may well provide adequate conductivity with the floor;[23] however, manmade shoe materials seldom provide adequate conductivity. Therefore, it is essential that heel straps or similar means be used to provide conductivity between the operator and the conductive floor or floor mat.

Chairs and stools used in conjunction with conductive floors should also be conductive, both the legs which make contact with the floor and the seat surface itself, to assure that the operator remains properly grounded even with his or her feet off the floor.

For operator safety, as with the protective work surfaces and wrist straps, conductive floors and floor mats should, where possible, be grounded through a current limiting resistor of between 250K ohms and 1 megohm.

Table 20 is a listing of some of the wide variety of different conductive flooring, floor mats and conductive footwear products presently commercially available.

TABLE 20: CONDUCTIVE FLOOR SURFACES, MATS AND FOOTWEAR

Generic Type	Name or Model	Supplier	Typical Resistance Ω/sq	STATIC DECAY RATE Volts	STATIC DECAY RATE Time (secs)	Safety Resistor Required	Documented Test Results	Reference Number
FLOOR MATS								
Carbon-filled plastic or rubber (Conductive)	Velostat	3M				Yes		
	CP501 Statfree	Charleswater	3×10^4			↓		
	70700	Controlled Static				↓		
	EN3000	Semtronics				↓		
	ST3007-08	Static Inc.	10^3			↓		
	W-5052-54	Wescorp	5×10^3			↓		
	W-5800	Wescorp				↓		
Conductive Vinyl Laminate (Static Dissipative)	8200	3M	10^9	5000	0.06	Yes		
	Enstat	Semtronics	10^6			↓		
	Simco-stat	Simco	10^6		0.45	↓		
		Pervel	10^7	5000	0.45	↓		
TILE								
Conductive Vinyl Flooring	Conductile	VPI	25K-1MΩ	5000	.02		VPI 80	30
Vinyl bonded to aluminum floor plate		Floating Floors	<1MΩ					
PAINT								
Conductive Floor Coatings	Elimstat	W. Legge	5×10^3				NWC 9-75	29
	Conducote	W. Legge	5×10^5				NWC 9-75	29
	Con-Deck	Wescorp						
FOOTWEAR								
Heel Strap	CP711	Charleswater						
Heel Protector	Solestat	W. Legge						
Heel Protectors	W-2040	Wescorp						
Neutro-stat boots	A4700	Simco						
Heel Grounders	A4706	Simco						
Heel Protectors	EN8001	Semtronics						
Shoe grounding strap-conductive	2045	3M						
CARPETING*								
Nylon containing conductive monofilament	Compu-carpet	United Tech. Prod.						
Nylon containing conductive copper threads	Shock Absorber	Minicomputer Ass.						
Nylon interwoven with conductive filaments	TX523-8	Texwipe						
Nylon containing conductive monofilament	No Shock	Techni-Bag						

*See limitations noted in the text

Terrazzo floors, which have been successfully used for many years in hospitals and munitions plants to prevent explosions due to ESD, were not included in this listing due to their relatively high cost.

Carpeting

Although they may be useful in reducing "glitches" in a computer environment, most "conductive" carpetings currently on the market are not adequate for the protection of ESD-sensitive electronic parts. They were designed primarily for personnel comfort rather than equipment protection, i.e., to reduce the electrostatic charges below the limit of human feeling. Thus they can still leave residual charge levels of thousands of volts, more than sufficient to destroy most sensitive parts. Furthermore, the applicable specification AATCC Test Method 134-1975 establishes the test method only; it does not establish any acceptable or limiting value of either static voltage levels or static decay rates.

SECTION 7

GARMENTS/CLOTHING

SECTION 7: GARMENTS/CLOTHING

Usually specific garments or clothing are not specified for ESD control; however, some exceptions do exist. Shop or lab coats and smocks are probably the most important example. Where these types of garments are required to be worn it is essential that ESD protection be considered.

Five different generic types of cloth are presently used in these garments. They are:

a) Cotton
b) Polyester
c) Cotton/Polyester blend
d) TYVEK (Spunbonded Olefin)
e) Cotton/Polyester blend with additional stainless steel threads

Virgin cotton is almost in the center of the triboelectric series and generally has sufficient conductivity to prevent static charge buildup; however, it is seldom used. Wash-and-wear or Perma-Press and fire retardant treatments may either enhance or degrade the conductivity from its virgin state. Another significant drawback to cotton is its tendency to generate lint. This prohibits its use in most clean room applications.

Polyester tends to build up and hold large static charges. Washing this material causes even larger charge buildups.[40] Therefore, the commonly used dacron/polyester and polyester/cotton blends require the use of an antistat treatment to provide ESD protection. Such antistat treatment must be performed each time the garment is laundered. This can be very effective in ESD control; however, quality control is the most vital consideration. A number of users of these garments have reported instances in which such laundered garments were received on occasions without the specified antistat treatment. TYVEK garments are similar in that they also require an antistat treatment; however, they are normally designated as a disposable rather than a reusable garment.

Various polyester/cotton blend cloths with 1% or 0.5% stainless steel threads are currently on the market. Their effectiveness in preventing static charge buildup, potentially very good, does vary with construction. Some investigators also question the use of the metal thread antistatic smocks in a clean room environment due to the possibility of introducing additional metallic contamination should the metal fibers become loose due to wear or abrasion.

Table 21 contains a listing of some of the different types of garments presently available.

TABLE 21: GARMENTS AND CLOTHING

Generic Type	Name or Model	Supplier	Typical Resistance (Ω/sq)	Temperature °F	Relative Humidity %	Typical Decay Time (V)	Typical Decay Time (Sec)	Charge remaining after 10 secs. of buffing with a Motordriven Teflon coated wheel (see Reference 8). 0.35	0.5 Sec	1.0 Sec	1.5 Sec	Documented Test Results	Reference Number
Virgin Cotton			$3x10^{10}$	70	50	5KV	0.25					FRL 2-80	32
(Not "perma-press" treated)			$4x10^{11}$	70	30	5KV	2.23						
			$8x10^{11}$	70	20	5KV	5.35						
				Not measured				9400V	7167V	1633V	433V	KSC 10-72	34
(Fire retardant treated)				73	45			<100V	<100V	<100V	<100V	KSC 3-79	41
Dacron Polyester (New) *			$2x10^{12}$	70	50	5KV	132					FRL 8-79	31
" " (After cleaning) *			$2x10^{12}$	70	50	5KV	732					FRL 8-79	31
			$2x10^{12}$									RI 12-80	36
" " (Antistatic Treated)			$2x10^{10}$	70	50	5KV	0.1					FRL 8-79	31
			$2x10^{9}$	70	50	5KV	0.20					FRL 2-80	32
			$3x10^{10}$	70	30	5KV	0.21						
			$4x10^{10}$	70	20	5KV	0.27						
" " (Antistatic Treated after 1 day's wear)			$4x10^{9}$	70	50	5KV	0.20						
			$5x10^{10}$	70	30	5KV	0.28						
			$7x10^{10}$	70	20	5KV	0.47						
Dacron Polyester (New) *				72	47			191V ①	191V ②	183V ③	161V ④	KSC 11-77	40
" " (After 4 washings) *				72	47			16,700V ①	12,550V ②	5,500V ③	1,200V ④	KSC 11-77	40
Polyester/Conductive Nylon (New)	ASQ-100	Angelica	$1.6x10^{6}$		50		0.1					ANG 9-81	51
" " (After 50 washings)			$1.0x10^{11}$		50		0.2					ANG 9-81	51
65% Polyester 34% Cotton 1% Stainless Steel	Neutro-stat	Wescorp Simco	$2.3x10^{10}$									RI 12-80	36
Nomex SS (1% Stainless Steel)	No-Mo-Stat	Southern Mills		82	37	5KV	0.1	1200V	980V	660V	Not meas.	KSC 2-75	37
												USA 11-80	35
Polyester/Cotton 0.5% Stainless Steel	Riegelstat	Riegel Textile										USA 11-80	35
"	"	" "		75	50			1020V	884V	826V	793V	KSC 10-72	33
" " (After 10 washings)	"	" "	$2x10^{10}$	70	50							FRL 3-70	50
" " (After 25 washings)	"	" "	$8.4x10^{10}$	70	50							FRL 3-70	50
" " (After 75 wash-	"	" "	$8.4x10^{10}$	70	50							FRL 3-70	50
Antistatic Vinyl Film with Black Conductive Printed Pattern	CP1101	Charleswater	$1x10^{5}$										

* Not Antistatic for comparison purposes only.

① After 1 sec. ② After 1 min.
③ After 5 min. ④ After 15 mins.

SECTION 8

TOPICAL ANTISTATS

SECTION 8: TOPICAL ANTISTATS

Topical antistats may also be a powerful weapon in the battle against ESD. They function in two different ways. First, they reduce the materials' coefficient of friction by increasing surface lubricity. This tends to reduce the maximum potential charge that can be generated in a frictional or triboelectric situation.

Second, they increase surface conductivity, thus allowing any charges to be bled off and dissipated more rapidly. However, some topical antistats function by absorbing moisture from the ambient air and forming a conductive vapor layer on the material's surface. These types become less effective below 35% to 40% relative humidity.

Topical antistats are generally liquids consisting of two basic components:

a) Carrier - the vehicle that transports the antistat mechanism. It acts as a solvent and can be water, alcohol or other solvents.

b) Antistat - the primary material which when deposited on the substrate performs some static control or charge prevention function.

The carrier allows control of the amount and application of the antistat.

Topical antistats are typically used in applications such as:

a) Cleaning of work surfaces and floors

b) Surface treatment of items which are not ameanable to other ESD control techniques, such as the exposed common plastic surfaces of CRT displays, computer terminals and other equipment found in the work area.

In selecting the most effective antistat for a given application a number of factors, in addition to cost, must be considered. These factors include:

a) Performance compatibility with your materials
b) Contamination factors
c) Longevity and wear characteristics
d) Decay performance and controllability
e) Ease of application

For a detailed discussion of these and other necessary considerations see Reference 25.

Table 22 is a listing of some of the more common topical antistats with their suppliers.

Antistats should be used with caution in the vicinity of critical high impedance circuits. Circuit malfunctions could result from shunting action of antistats on printed circuit boards.

TABLE 22: ANTISTATIC SPRAYS AND CLEANERS

Generic Type	Name or Model	Supplier	Typical Resistivity Ω/sq	Documented Test Results	Reference Number
Antistatic Spray	Staticide	ACL		USN 2-81	38
	"	"		ITT 8-80	39
	#79	Merix	25-100M		
	#79-0L	Merix			
	Zero Change	Tech-Spray			
	CPS101 Nostat	Charleswater	10^7 Ωcm		
	Resque	Controlled Static			
	Resque	Richmond			
	Neutro-Stat	Simco			
	Antistat	Texwipe			
	Stop-Stat	Techni-Bug			
	Statico	W. Legge			
		TAKK			
	W-062	Wescorp			
Antistatic Freeze Spray (Spray Can)		Tech-Spray	10^{10}		
CRT Screen & Terminal Cleaner (Spray Can)		Tech-Spray			
Work Surface Cleaner	70500	Controlled Static			
Record Spray (Spray Can)		Tech-Spray			

SECTION 9

MATERIAL AND EQUIPMENT TEST AND INSPECTION PROCEDURES

SECTION 9: MATERIAL AND EQUIPMENT TEST AND INSPECTION PROCEDURES

Material and equipment that are to be incorporated as ESD controls should be tested and evaluted per applicable test standards or documented evaluation procedures to qualify them and to assure that they have the characteristics that are desired. Once the material or equipment has been incorporated as a control, it should be periodically inspected to determine if the material or equipment has degraded. Test methods developed internally or obtained from other sources should be employed to assure that the material or equipment has retained its effectiveness. The test methods should be sufficiently well-documented to insure consistent results.

Table 23 is a listing of some of the more common ESD-related test standards.

The EIA is preparing an interim standard for Antistatic Packaging materials. At present, the draft version applies only to IC plastic shipping tubes.

Tests and Test Methods

Three distinct material figures of merit are relevant to electrostatic discharge. They are: 1) volume or surface resistivity measurements, 2) static decay time measurements, and 3) charge generation due to triboelectric charging. These three parameters, while not totally unrelated, do not exhibit consistent quantifiable relationships. Of the three parameters, surface or volume resistivity is the most commonly used and is probably the best defined. It does not, however, adequately characterize all materials. All three figures of merit must be considered for their unique contribution before the optimum tests or test methods are selected for material evaluation and/or qualification.

TABLE 23: ESD TEST STANDARDS

FED-STD-101B	Preservation, Packaging and Packaging Materials, Test Procedures: Test Method 4046 Electrostatic Properties of Materials
FED-STD-406	Test Method 4041 Electrical Resistance (Insulation, Volume, Surface)
AATCC 134-1975	Test Method for the Electrostatic Propensity of Carpets
AATCC 76	Test Method for the Determination of the Electrical Resistivity of Fabrics
ANSI Z41.3	Conductive Safety-Toe Footwear: Section 5, Conductivity
ASTM D257-78	D-C Resistance or Conductance of Insulating Materials
ASTM D991-75	Test Method for Rubber Property-Volume Resistivity of Electrically Conductive and Antistatic Material
ASTM D2679-73	Test Method for Electrostatic Charge
ASTM D3509-76	Test Method for Electrostatic Field Strength Due to Surface Charges
ASTM F150-72	Standard Test Method for Electrical Resistance of Conductive Resilient Flooring
EIA P.N. 1525 (Draft)	Antistatic Packaging Materials, Draft EIA Interim STD
ANSI/ASTM D2865-71 (76)	Calibration of Standards and Equipment for Electrical Insulating Materials Testing

Surface Resistivity and Volume Resistivity

Surface resistivity (ρ_s) is measured in ohms per square, and volume or bulk resistivity (ρ_v) is measured in ohm-centimeters. The measurement technique is defined by the American Society for Testing and Materials ASTM D257-78. This test method has been adopted by the Department of Defense to replace an earlier document Federal Test Method Standard 406 Method 4041. Both documents specify the use of a 500 VDC test voltage and an electrification time of 60 seconds before recording the resistance value. The test methods define various fixture configurations along with the associated calculations required for true readings.

A simplified low cost procedure and test fixture for surface resistivity measurements, albeit somewhat more limited in range and accuracy, is documented in Reference 55. A major source of errors associated with less sufficiated surface resistivity measurements is due to "fringing effects." This is particularly true if the material sample is significantly larger than the dimensions of the fixture used.

The use of a concentric circular fixture such as the one described in the ASTM test method or an improved version developed by the Naval Avionics Center, Indianapolis, IN,[44] overcomes the "fringing effect" problems. In addition the Navy fixture gives a direct reading in ohms per square (x10) without additional calculations and reduces the stringent flatness requirements associated with earlier designs of concentric circular probes. An example of a commercial instrument suitable for accurate surface resistivity and volume resistivity measurements would be the Hewlett Packard model 4329A High Resistance Meter together with model 16008A Resistivity Cell. An additional calculation, however, is required to convert the reading to ohms per square.

For the purpose of ESD protective materials qualification, surface resistivity or volume resistivity measurements should be performed at the lowest relative humidity anticipated in the usage environment.

Hygroscopic antistat material will show significant variations in surface resistivity with relative humidity, particularly at low values of relative humidity (refer to Figures 3 and 5).

Static Decay Tests

Static decay measurements are defined by Federal Test Method Standard 101 Method 4046. This procedure specifies contact charging the material alternately to + and - 5000 volts DC and measuring the decay time to 0 volts under a 73°F, 15% (MAX) RH environment. Because of the difficulties associated with measuring decay to zero volts, i.e., accurate calibration, poor reproducibility, touchy zero adjustments, etc., investigators frequently use cutoff points other than 0 volts to assure consistent results. Illustrating the diversity of techniques used by various investigators, test results referenced in this report have used decay to 50%, 37%, 25%, 10%, 2% and 1% of original charge voltage in addition to the specified decay to 0 volts. Decay to 10% is the most frequently used option, however, and probably represents a reasonable compromise, all things considered. For additional tradeoff considerations relative to decay to 0 volts vs. decay to 10% see Reference 54.

An example of a commercial instrument suitable for accurate static decay measurements in accordance with Federal Test Method Standard 101B Method 4046 would be Electro-Tech Systems model 406B Static Decay Meter. Another commercial instrument suitable for accurate static decay measurements, although using a somewhat different principle than that described in Federal Test Method Standard 101B Method 4046, is the Monroe Electronics/Princeton Electrodynamics model 276A Static Charge Analyzer.

For the purpose of ESD protective materials qualifications, static decay tests should be performed at the lowest relative humidity anticipated in the usage environment. Hygroscopic antistatic materials will show significant variations in decay time with relative humidity, particularly at low values of relative humidity (refer to Figure 4 and 6).

Specifying of the test temperature is also recommended since a recent study[58] of electrostatic decay times of several common materials has shown a substantial temperature dependence of these materials in addition to the commonly accepted relative humidity dependence.

Triboelectric Test

No single generally recognized triboelectric test procedure presently exists; however, a preliminary draft standard test method together with the associated triboelectric test apparatus[8,56] is presently being con-sidered by ASTM. NASA's Material Testing Branch at Kennedy Space Center developed this evaluation procedure to test the effectiveness of ESD protective materials as a function of relative humidity at ambient temperature, utilizing an improved triboelectric test apparatus. This apparatus and procedure are capable of giving highly repeatable results. A major portion of the triboelectric charge and discharge data contained in this report was generated utilizing this test apparatus.

SECTION 10

REFERENCES

SECTION 10: REFERENCES

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35. GIDEP General Document Summary Sheet E240-1370, "Electrostatic Propensity of Garments Made of Nomex with One Percent Metal Fibers Compared with Flameproof Cotton," US Army R & D Command, Dover, NJ, Nov. 1980.

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APPENDIX A

TEST DOCUMENTATION

Appendix A

Test Documentation

A literature search, an initial survey, and subsequent follow-up visits and meetings with the user community identified a number of pertinent documents dealing with the testing and use of ESD protective materials and products. Table A-I is a bibliographic listing of the major test reports other than GIDEP reports presently available for study. Table A-II is a listing of the GIDEP documents.

TABLE A-I: ESD PROTECTIVE MATERIALS/PRODUCTS TEST REPORTS

Subject/Title	Date	Company/Agency	Author
Evaluation of the Chemical Resistance of a Conductive Table Top	August 3, 1981	Reliability Analysis Center Griffiss AFB, NY	G. Kraeger
Antistatic Agents, Lubricants and Precision Bearings	May 11, 1981	Naval Research Laboratory Washington, DC	M.K. Bernett H. Ravner
Test Report on New Equipment and Techniques for Controlling/Minimizing Electrostatic Charge Build Up	April 1981	Jet Propulsion Laboratory Pasadena, CA	W.R. Woods
Topical Antistat "STATICIDE" In Dry-Nitrogen Atmosphere	February 12, 1981	Naval Avionics Center Indianapolis, IN	B.I. Rupe
Evaluation of Westat Antistat Lab Coat, Part Number W-2502, Wescorp	December 4, 1980	Rockwell International Anaheim, CA	J.M. Kolyer
Evaluation of In-Package Performance of Antistatic Materials	November 1980	U.S. Army Material Developments Readiness Command Tobyhanna, PA	R. McGill
An Evaluation of Wrist Strap Parameters	September 1980	Honeywell St. Petersburg, FL	J.E. Sohl
MICASTAT Static Decay Tests	August 26, 1980	Electo-Tech Systems Glenside, PA	S. Weitz
Reliability Alert: 3M Type 2064 Wrist Strap	August 22, 1980	Honeywell Minneapolis, MN	C.L. Baron
Qualification Test for Use and Application of Anti-static Liquid to Study the Effects of the Antistatic Liquid on the Solderability, Functionability and/or Corrosion of Components and Printed Circuit Boards	August 8, 1980	ITT Courier Tempe, AZ	J.L. Scovern
Testing of Scientific Enterprises Smart 100 Air Ionizer System and Comparison with Simco APMA	April 30, 1980	Charles Stark Draper Laboratory Cambridge, MA	C.H. Briggs, Jr.
Determination of Electrostatic Properties of Materials; Clean Room Garments	February 19, 1980 August 23, 1979	FRL Dedham, MA	R.E. Erlandson S.C. Stern
CONDUCTILE Static Decay Rates	January 23, 1980	VPI Sheboygan, WI	
Air Ionizing Grids - A Comparative Analysis	October 19, 1979	Hughes Aircraft Los Angeles, CA	J.G. Biddle
Review of Antistatic Protective Packaging Materials	October 1979	Raytheon Sudbury, MA	T.E. Baker J.R. Recesso
Electrostatic Conductivity Characteristics of Workbench-Top Surface Materials	September 24, 1979	Charles Stark Draper Laboratory Cambridge, MA	C.H. Briggs, Jr.

TABLE A-I: ESD PROTECTIVE MATERIALS/PRODUCTS TEST REPORTS (Cont'd)

Subject/Title	Date	Company/Agency	Author
A Report on Small Air Ionizers and Air Ionizer Grids	May 28, 1979	Hughes Aircraft Los Angeles, CA	J.G. Biddle
Evaluation of Bengal 2P-101 Antistatic Polyethylene	May 25, 1979	Litton Woodland Hills, CA	R. Taylor
"CONDUCTILE" Static Conductive Vinyl Flooring by VPI	March 30, 1979		P.P. Olin
Evaluation of Electrostatic and Flammability Characteristics of Flame Retardant Coveralls (Thiokol)	March 7, 1979	NASA Kennedy Space Center, FL	J.E. Minster
Ozone Generation of Wescorp WD-100 Destaticizing Blower	December 16, 1977	Environmental Analysis Laboratory Richmond, CA	M.W. Nathans
Materials Evaluation, Electrostatic Charge Dissipation Properties, Polyester Coveralls	November 1, 1977	NASA Kennedy Space Center, FL	J.T. Copeland
Testing of Legstats	November 17, 1976	Associated Testing Laboratory Wayne, NJ	G.J. Murphy
Alert: Safety and Handling Plans at Cape Canaveral	April 19, 1976	Aerojet Solid Propulsion Sacramento, CA	R.B. Smalley, Jr.
Testing of (2) Wrist Straps	December 3, 1975	Associated Testing Laboratory Wayne, NJ	G.J. Murphy
Precautions to be Considered in Using Antistatic Plastics	October 23, 1975	Jet Propulsion Laboratory Pasadena, CA	W.R. Woods
Evaluation of Transparent Antistatic Polyethylene (RCAS-1200) for Packaging Parts and Devices	March 1975	Rockwell International Anaheim, CA	J.M. Kolyer
Evaluation of the Electrostatic Charge Dissipation Properties of Antistatic Nylon Sheet Material, RCAS 2400, as a Function of Relative Humidity at Ambient Temperatures, Utilizing an Improved Triboelectric Test Apparatus	April 24, 1972	NASA Kennedy Space Center, FL	C.L. Springfield
Static Decay Time Tests of General Materials Treated with Staticide		Analytical Chemical Laboratories Elk Grove Village, IL	S.A. Halperin
Use of Melamine Work Surfaces for ESD Potential Bleed-off	September 22, 1978	Charles Stark Draper Laboratory Cambridge, MA	A. Warsher
Melamine Laminate and RCAS-1200 Work Surface Materials, Evaluation Study	January 16, 1978	Hughes Aircraft Company Culver City, CA	W.D. Johnson R.R. Weekly

TABLE A-II: GIDEP SEARCH ON ELECTROSTATIC DISCHARGE

GIDEP Access Number	Date	Title/Subject
E240-1370	11/80	Electrostatic Propensity of Garments made with one percent Metal Fibers compared with Flameproof Cotton
E231-2093	5/80	Failure Experience Directly Attributable to Electrostatic Discharge Damage Encountered in Receiving, Shipping, Inspection, Assembly, and Field Usage
E203-1442	2/80	Electrostatic Discharge Protection of Sensitive Electronics
E167-1340	6/79	Handling of Electrostatic Sensitive Electronic Items
E204-0954	12/78	Exploratory Developement of Conductive (Antistatic) Coating Materials
E172-1019	5/78	C4 Electrostatic Discharge Precautions
E086-1454	11/77	Susceptibility of Low Power Schottky Devices to Electrostatic Discharge
E085-1662	12/77	Electrostatic Discharge Damage to Integrated Circuits
E064-1994	11/76	Protective Requirements for Electrostatic-Sensitive Electronics
E126-2232	11/76	Handling of Static Electricity Sensitive Devices
E062-1493	8/76	Handling of MOS, CMOS Devices
E047-0679	10/75	Manufacturing Alert Installation Operation Static Free Stations
E024-1176	8/74	Electrostatic Sensitive Devices Marking and Handling Thereof
E041-1101	7/74	Electrostatic Sensitive Part Listing, Marking, Handling & Packing
E3306	9/73	Flammability and Electrostatic Testing of Black Latex Treated Webbing
E2525	4/73	Electrostatic & Flammability Tests Various Nylon Cloths
E2331	11/72	Electrostatic Test of Weblon - 44
E2330	10/72	Electrostatic Evaluation of MMC Aclar
E2329	10/72	Electrostatic and Flame Resistance Testing of Nylon 6 Tubing
E2327E011	10/72	Electrostatic and Flame Resistance Tests of 100% Cellulose Cloth
E2318	10/72	Electrostatic Evaluation of Reigelstat Fabric
E1783	9/72	Electrostatic Testing of NOMEX Coveralls
E098-0609	4/78	Electrostatic Damage Susceptibility of Semi-conductor Devices

TABLE A-II: GIDEP SEARCH ON ELECTROSTATIC DISCHARGE (Cont'd)

GIDEP Access Number	Date	Title/Subject
JH-A-81-02	6/81	ALERT Open resistor in Controlled Static Wrist Straps
A042-3C14	6/81	Indiscriminate use of any Pink Plastic in an ESD Application
E218-1911	5/80	DOD-STD-1686
E218-1835	5/80	DOD-HDBK-263
E110-0714	5/78	Electrostatic Discharge Damages Integrated Circuits and Discrete Semiconductor Devices
E167-1889	2/78	Understanding and Controlling Electrostatic Discharge
E067-1060	4/77	Protective Requirements for Electrostatic Sensitive Electronics
E039-1195	3/75	Evaluation of Transparent Antistatic Polyethylene (RCAS-1200) for Packaging Parts and Devices
E044-2029	1/75	Electrostatic Discharge in Microcircuits Detection and Protection Techniques

TABLE A-II: GIDEP SEARCH ON ELECTROSTATIC DISCHARGE (Cont'd)

DOCUMENTS NOT RELATED TO ESD STUDY ON ELECTRONICS

GIDEP Access Number	Date	Title/Subject
E162-2519	4/79	An Investigation into the Noise Interference Problems at Logan Airport, Boston
E156-1327	2/79	The Characterization of a Slurry Explosive-Teledent
E140-1004	11/78	Comparison of the Sensitivities of Batch and Continuous Process Composition B, Explosives
E068-1064	4/77	Response of Primary Explosives to Gaseous Discharges in an Improved Approaching-Electrode Electrostatic Sensitivity Apparatus
E124-1642	10/76	Photographic Video Disc Technology Assessment Report
E063-1432	9/76	Methods of Monitoring Initiating Sources in Pyrotechnic Process
E040-0954	2/75	Electrical and Photographic Characterization of Low-Intensity Capacitor Spark Discharges
E3274E016	10/73	Error Propagation Calib. + Reset - Advanced Marine SP stab Nav Sys
E3123E015	6/73	Resp. of Lead Azide to Spk Disch Via a Prl Pl. Es Sens. Appar.
E2861E014	12/72	Foggy Cloud IV, Phase II, Warm Fog Modification
E151-1142	9/72	Evaluation of Electric Discharge Machining Surface and Subsurface Integrity Using Photo-micrographs
E049-0743	4/75	Safety Evaluation Tests of Conductive Floor Coverings for Ordnance Facilities

APPENDIX B

SUPPLIERS OF ESD PROTECTIVE MATERIALS AND EQUIPMENTS

SUPPLIERS OF ESD PROTECTIVE MATERIALS AND EQUIPMENT

Acheson Colloids Company 1635 Washington Avenue P.O. Box 288 Port Huron, Michigan 48060 (313) 984-5581	Antistatic liquids and sprays
Adams & Russell Modpak Division 80 Cambridge Street Burlington, Massachusetts 01803	Modpak Packaging System
ADE, Inc. 1560 East 98th Street Chicago, Illinois 60628 (312) 221-3400	Plastic Cushion (cancel)
Advance Engineering 18255 S. Hoover Street Gardena, California 90248 (213) 321-3100	Work stations
ALX Technical Service Ltd. P.O. Box 84 Niagara Falls, New York 14305 (416) 636-6700	Wriststrap
American Top Company 9612 Owensmouth Avenue Chatsworth, California 91311 (213) 882-9993	Conductive table top
Analytical Chemical Laboratories 2424 Pan Am Boulevard Elk Grove Village, Illinois 60007 (312) 981-9212	Antistatic liquids and sprays, static locators
Anderson Effects, Inc. P.O. Box 657 Mentone, California 92359 (714) 794-3792	Electrostatic voltmeters, soldering iron, labels and signs, wrist straps, soldapult static meter, ESD simulator board
Andy Hish Associates 5401 Burnet Avenue Van Nuys, California 91411 (213) 997-1332	ESD simulators, EMI Detector
Angelica Uniform Group A Division of Angelica Corporation 700 Rosedale Ave St. Louis, Missouri 63112 (314) 889-1111	Antistatic Garments

Aratex, Inc. 16001 Ventura Boulevard P.O. Box 3000 Encino, California 91316 (213) 995-2551/995-2500	Antistatic clean room garments (rental services)
Armand Manufacturing, Inc. 725 Mateo Street Los Angeles, California 90021 (213) 623-4131	Antistatic bags, covers, zipclose cushion bags, booties, cancel, antistatic bubble pouches and covers, black conductive bags and covers
Automated Packaging Systems, Inc. 8400 Darrow Road Twinsburg, Ohio 44087 (216) 425-4242	Antistatic plastics: bench tops, autobag plastic stopper
The Baxter Corporation Astro-Pack Division 1956 Sabre Street Hayward, California 94545 (415) 782-9400	Antistatic plastics: bags, cushioning; sheets, cushioning
Beckman Instruments, Inc. Cedar Grove Operations 89 Commerce Road Cedar Grove, New Jersey 07009 (201) 239-6200	Precision hygrometer (Humi-Chek II)
Bengal, Inc. 9757 Eton Avenue Chatsworth, California 91311 (213) 709-0011	Antistatic plastics: bags, plain; bottles, tubing, vials, foam; sheets, plain; tote boxes
Bestway/Araclean One North Beacon Street La Grange, Illinois 60525 (312) 352-3200	Antistatic garments
Biggam Enterprises, Inc. 2124 Bering Drive San Jose, California 95131 (408) 298-6810	Antistatic plastics: bags, cushioning; bench tops; bottles, tubing, vials; containers, tote boxes, trays; sheet cushioning; sleeve protectors (gauntlets). Conductive plastics: aprons, coats, smocks; containers, tote boxes, trays; foam; seat covers; sheeting; wrist straps, warning labels and shunt bars. Air ionizers, static meter
Calmark Corporation 4915 Walnut Grove Avenue San Gabriel, California 91776 (213) 287-0451/287-9942	Antistatic plastics: containers, tote boxes, trays, card retainers, card puller, card inserter - extractor and connector backshells

Central Containers Corp. 4041 Hiawatha Avenue Minneapolis, Minnesota 55406 (612) 721-6224	"Tech-Case", antistatic and conductive foam lining, "The Flat Box", (circuit board shipping boxes).
Chapman Corporation P.O. Box 427 Portland, Maine 04112 (207) 773-4726	Air ionizers, electrostatic voltmeters, static generators, static eliminating bars, brushes, power supplies for the bars, antistatic liquids and sprays, static meter
Charleswater Products 3 Walnut Park Wellesley Hills, Massachusetts 02181 (617) 237-5942	Conductive plastics: bags, foam, strips (shunt bar), wrist straps, aprons, gloves Mica stat table top laminates, static free floor mats, trays, tote boxes
Clean Room Products, Inc. 56 Penataquit Avenue Bay Shore, New York 11706 (516) 968-8282	Ion flow grids, antistatic gloves, static meters, Air ionizers; Microstat, ground ionizing work surface, antistatic cleaner
Colvin Packaging Products, Inc. 1391 Hundley Street Anaheim, California 92806 (714) 630-3850	Antistatic plastics: bottles, tubing, vials, containers, tote boxes, trays, formed shapes, shunt clips, wrist straps bags, foam, shipping containers Air ionizers, static meters
Conductive Containers, Inc. 417 Green Park Court Deerfield, Illinois 60015 (312) 945-7190	Drum liners, corstat cartons
Controlled Static, Inc. Divsion of CSS Industries, Inc. 9836 Jersey Avenue Santa Fe, California 90670 (213) 692-0768	Antistatic plastics: bags, plain; containers, tote boxes, trays, foam, sleeve protectors, tubing, topical antistat. Conductive plastics: Mats (bench and floor). Air ionizers, electrostatic voltmeters, soldering iron, labels and signs, wrist straps, ground straps, field service kit gauntlets, static meters
Custom Scientific Instruments, Inc. 13 Wing Drive, P.O. Box A Whippany, New Jersey 07981 (201) 538-8500	Electrostatic voltmeters, static testing devices, electrical resistance testers
Dayton-Granger Aviation, Inc. P.O. Box 14070 812 N.W. First Street Ft. Lauderdale, Florida 33302 (305) 463-3451	Static neutralizers

DM Laboratories Corporation 1827 Business Center Drive Duarte, California 91010 (213) 357-3273	Topical antistat (Resque)
DuPont Company Rm. 25086 Wilmington, Delaware 19898	Antistatic foam (microfoam)
EDCO Supply Corporation 323 - 36th Street Brooklyn, New York 11232 (212) 788-8108	Antistatic plastics: bags (plain), sheets (plain) Conductive plastics: sheeting
Electro-Tech Systems, Inc. 35 E. Glenside Avenue Glenside, Pennsylvania 19038 (215) 887-2196	Electrostatic voltmeters, static level alarm indicator, static decay meter, ESD simulator
Emerson and Cuming, Inc. 59 Wapole Street Canton, Massachusetts 02021 (617) 828-3300	Conductive plastics: conductive adhesives and coatings. Antistatic liquids and sprays
Experimental Physics Corporation 26010 Eden Landing Raod Suite 2 Hayward, California 94545 (415) 782-2303	ESD Simulator
Floating Floors, Inc. 795 Berdan Avenue P.O. Box 6627 Toledo, Ohio 43612 (419) 476-8772	Floating Floor System
Fluoroware Jonathon Industrial Center Chaska, Minnesota 55318 (612) 448-3131	Antistatic and conductive trays and boxes
FoamFab Inc. P.O. Box 328 Mansfield, Massachusetts 02048 (617) 339-5721	Conductive foam, boxes
Free-Flow Packaging Corporation 2500 Middle Field Road Red Wood City, California 94063 (415) 364-1145	Protective packaging (Flo-Pak)

Frontier Electronics, Inc. **Poinsett Highway** **P.O. Box 625** **Greenville, South Carolina 29602** **(803) 246-4927**	**Air ionizers, static neutralizers**
Gary Plastic Packaging Corporation **770 Garrison Avenue** **Bronx, New York 10474** **(212) 893-2200**	**(LEMCEN) Antistatic polymer**
Glen-Mitch Tools, Inc. 722 West Morse Street Schaumburg, Illinois 60193 (312) 529-8161	Containers, pouches, boxes (soft cell), printed circuit board holders (uptight)
L. Gordon & Son Packaging, Inc. 1050 South Paca Street Baltimore, Maryland 21230 (301) 539-6537	Conductive plastics: vacuum forming facilities to form conductive plastic; foil lined boxes
Harold Edwards, Inc. 7722 Willow Vine Ct. Dallas, Texas 75230 (214) 987-3342	Ionizer (x-static)
Henry Mann Inc. Box 496 Mann Road Huntingdon Valley, Pennsylvania 19006 (215) 355-7200	WESCORP products
Herbert Products, Inc. 180 Linden Avenue P.O. Box 384 Westbury, New York 11590 (516)334-6500	Air ionizers, soldering iron
High Voltage Systems, Inc. Central Garrett Industrial Park Accident, Maryland 21520 (301) 826-8651	Surge generator
H&S Industries 9851 Alburtis Avenue Santa Fe Springs, California 90670 (213) 949-4335	Antistatic and conductive material gloves and finger cots, tote boxes, wrist straps
Hyatt Tool Company 26010 Eden Landing Road, #2 Hayward, California 94545 (415) 782-2303	Electrostatic voltmeters, ESD simulators

Hy-Test Corporation 1509 Washington Avenue St. Louis, Missouri 63166 (314) 342-7046	Conductive shoes
Isles Industries, Inc. Production Systems 576 Explorer Street Brea, California 92621 (714) 529-2126	Antistatic work surface (Lamistat)
Jiffy Manufacturing Company La Miranda, California 90638 (714) 523-0382/(213) 944-3246	Conductive bags, cushioning
Jiffy Packaging Corporation 360 Florence Avenue Hillsdale, New Jersey 07205 (201) 688-9200	Conductive bags
Julie Associates, Inc. P.O. Box 141 Billerica, Massachusetts 01821 (617) 667-1958	Conductive Plastics: Foot acessories, sheeting. Electrostatic voltmeter, antistatic liquids and sprays manufacturing representatives
Kern Foam Products Corp. 412 Roycefield Road Somerville, New Jersey 08876 (201) 526-4999	Conductive coatings for foam
Lewis Systems Menasha Corporation 426 Montgomery Street Watertown, Wisconsin 53094 (414) 261-3162	Antistatic plastics: boxes, trays, containers
Life Line Products 1215 Pioneer Way El Cajon, California 92020 (714) 444-2737	Antistatic plastics: bottles, tubing, vials containers, tote boxes, trays, carriers
Lindgren RF Enclosures, Inc. 1228 Capitol Drive Addison, Illinois 60101 (312) 628-9100	Electrically isolated RF enclosures

Lydall, Inc. Federal Packaging Corporation 3401 Nevada Avenue, North Minneapolis, Minnesota 55427 (612) 533-1631	Antistatic plastics: bags, cushioning; bags, plain; containers, tote boxes, trays; sheets, plain, PCB boxes, custom cases, antistatic treatments. Conductive plastics: aprons, coats, smocks, foam, sleeve protectors (gauntlets). Electrostatic voltmeters, labels and signs, wrist straps
Merix Chemical Company 2234 East 75th Street Chicago, Illinois 60649 (312) 221-8242	Antistatic liquids and sprays
Micro Electronic Systems, Inc. 159 Main Street Danbury, Connecticut 06810 (203) 797-1441	Static free work stations
Minnesota Mining & Mfg. Company (3M) Static Control Systems Laboratory Building 207-N, 3M Center St. Paul, Minnesota 55101 (612) 733-3078	Conductive plastics: aprons, coats, smocks, bags, containers, tote boxes, trays, drum liners, foam, foot accessories, mats (bench and floor), sheeting, straps, (wrist and leg), strips (shunt bar), conductive assembly bins and racks; conductive ground cord; film, flex hose, blocks, rods, pipe and tubing, adhesives. Air ionizers, electrostatic voltmeters, static neutralizers, stool covers, velostat sheets, field service grounding kit, sleeve protector
Misco Inc. P.O. Box 399 Holmdel, New Jersey 07733 800-631-2227	Antistatic liquids and sprays, mats, work station
Mohawk, Inc. Mr. John Golisano National Contract Manager 57 Lyon Street Amsterdam, New York 12010	Static control carpeting
Monroe Electronics, Inc. 100 Housel Avenue Lyndonville, New York 14098 (716) 765-2254	Static meters, electrostatic voltmeter, electrometer followers; static electricity detector/monitor; limit detector/alarm

Norland Industries, Inc. 13429 Sunny Lane Lakeside, California 92040 (714) 443-5423	**Shielded enclosures, conductive paint**
NRD Division 2937 Alt Boulevard, N. Grand Island, New York 14072 (716) 773-7634	**Static eliminators, grounding kits, static field meter, wrist straps**
Nuber & Nuber, Inc. 1634 Lincoln Avenue Utica, New York 13503 (315) 735-7539	**Vinyl glove products**
Olympic Plastics Co., Inc. 5800 W. Jefferson Boulevard Los Angeles, California 90016 (213) 837-5321	**Antistatic plastics: containers, tote boxes, trays**
Packaging Industries, Inc. Sentinel Foam Division Hyannis, Massachusetts 02601 (617) 775-5220	**Antistatic plastic: bags, cushioning; foam; sheets, cushioning; with pressure sensitive cohesive coating**
Parsons Mfg. Corporation 1055 O'Brien Drive Menlo Park, California 94025 (415) 324-4726	**Antistatic plastics: trays, tote boxes, cases, foam cushions.**
Pervel Industries, Inc. Community Avenue P.O. Box 61 Plainfield, Connecticut 06374 (203) 564-2741	**Antistatic film, antistatic mats, conductive foam**
Plastic Systems, Inc. 88A Ellsworth Street Worcester, Massachusetts 01608 (617) 799-2600	**Conductive sheets, table mats**
Protecta-Pack Systems Div. of Liberty Carton Company 870 Louisiana Avenue, South Minneapolis, Minnesota 55426	**Protective bags, cushions, pouches, warning labels**
Pulsar Products, Inc. A Subsidiary of Physics International Co. High Voltage Electronics 2949 Whipple Road Union City, California 94587 (415) 487-5400	**ESD simulator, pulse generator, voltage probes pulse transformers**

Rawson-Lush Instrument Co., Inc. 80 Harris Street Acton, Massachusetts 01720 (617) 263-3531	**Electrostatic voltmeter**
Republic Packaging Corporation 9160 S. Green Street Chicago, Illinois 60620 (312) 233-6530	**Antistatic and conductive foams, conduct-o-carton**
Richmond-Division of Dixico, Inc. Colton & Opal Streets P.O. Box 1129 Redlands, California 92373 (714) 794-2111	**Antistatic plastics: bags, cushioning; bags; plain; bench tops; bottles, tubing, vials; containers, tote boxes, trays; foam; sheets, cushioning; sheets, plain** **Labels and signs, wrist straps, topical antistats**
Rohde & Schwarz Sales Company, Inc. 14 Gloria Lane Fairfield, New Jersey 07006 (201) 575-0750	**Transient testers**
Royel Soldering Systems, Inc. 213 S. Brand Boulevard Glendale, California 91204 (213) 245-1077	**Soldering iron, zero voltage switching soldering stations**
SANTEX, Inc. 4095 N. 28th Way Hollywood, Florida 33020 (305) 922-8282	**Air ionizers, static meters, ion ion generators, static neutralizers**
SAT Inc. Solder Absorbing Technology 357 Cottage Street Springfield, Massachusetts 01104 (413) 788-6191	**Conductive rubber mat (high temperature)**
Schaffner EMC Inc. 377 Route 17, Suite 602 Hasbrouck Heights, New Jersey 07604 (201) 288-6860	**ESD simulator, EMI filter stick, high voltage testers**
Scientific Enterprises, Inc. 2801 Industrial Lane, Box 220 Broomfield, Colorado 80020 (303) 469-7801	**Antistatic plastics: bags, plain** **Air ionizers, static meters, electrostatic-voltmeters, air guns, antistatic bars, wrist straps, tote boxes, antistat polyethylene**
Sealed Air Corporation 30 West End Road Totowa, New Jersey 07512 (201) 785-4070	**Antistatic plastics: bags, cushioning**

Semtronics Corporation P.O. Box 592 Martinsville, New Jersey 08836 (201) 561-9520	Conductive plastics: bags, containers, tote boxes, trays, foam, mats (bench and floor), seat covers, sheeting, straps (wrist and leg), sleeve protectors. Air ionizers, electrostatic voltmeters, static neutralizers, insulated work benches, ground straps for test equipment, static locators, rubber mats for work benches, shorting bars, conductive rollers, conductive coatings Static meters, heel protectors, antistatic warning labels
Sentinel Foam Products, Inc. Member of Packaging Industries Group Hyannis, Massachusetts 02601 (617) 775-5220	Anti-stat foam, shippers for floppy disc
Sensitive Research Instruments 25 Dock Street Mt. Vernon, New York 10550 (914) 699-9717	Electrostatic voltmeters
Shell Container Systems 342 Great Neck Road Great Neck, New York 11021 (516) 466-5208	Conductive foam, conductive plastic containers
Signetics Corporation 811 East Argues Avenue P.O. Box 409 Sunnyvale, California 94086 (408) 739-7700	Molded epoxy packages ("SO" package)
Simco Company, Inc. 920 Walnut Street Lansdale, Pennsylvania 19446 (215) 368-2220	Conductive plastics: bags, containers, tote boxes, trays, drum liners, foam, foot accessories, mats (bench and floor), sheeting, straps (wrist and hand), strips (shunt bar). Air ionizers, static generators, static neutralizers, antistatic liquids and sprays, wrist straps, special profiles, ESD locators, static bars, antistatic coats and smocks, conductive grounding straps Work station grounding kit, seat covers, boots, heel grounders
Southern Mills, Inc. 585 Wells Street, S.W. Atlanta, Georgia 30312 (404) 688-8900	Conductive cloth

Spraylot Corporation 716 S. Columbus Ave Mt. Vernon, New York 10550 (914) 699-3030	Conductive coatings
Sprayway, Inc. 484 Vista Avenue Addison, Illinois 60101	Antistatic spray
Stanley-Vidmar 11 Grammes Road Allentown, Pennsylvania 18103 (215) 797-6600	Conductive cabinets and bins
Static, Inc. P.O. Box 414 Lee, Massachusetts 01238 (413) 243-0455	Air ionizers, electrostatic voltmeter, ESD locator, sheet and web cleaner, static cleaner, static neutralizer, ground ionizing work station
Stephen Gould of California 1720 South Amphlett, Suite 219 San Mateo, California 94402 (415) 574-4500	EOS/ESD controlling packages using the best combinations of antistatic and conductive materials available
B.K. Sweeney Manufacturing Company 6300 Stapleton South Drive Denver, Colorado 80216 (303) 320-4800	Electrostatic voltmeter, lightning warning meters, static meters
Tafa Metallisation, Inc. P.O. Box 1157 Dow Road Bow (Concord), New Hampshire 03301 (603) 224-9585	Air sprayers for static discharge coatings, antistatic liquids and sprays
Takk Company 6667 Mullen Road Cincinnati, Ohio 45239 (513) 941-4920	Air ionizers, static neutralizer
Tech-Spray, Inc. P.O. Box 949 Amarillo, Texas 79105 1-800-858-4043	Antistatic spray, antistatic freeze spray
Techni-Bag Company 57 Lakeview Avenue Clifton, New Jersey 07011 (201) 340-1165	Antistatic plastics: bags, plain; mats, foam, labcoats and smocks, ESD lcoator meter

Techni-Tool, Inc. 5 Apollo Road, Box 368 Plymouth Meeting, Pennsylvania 19462 (215) 825-4990	Conductive plastics: aprons, coats, smocks, foot accessories, mats (bench and floor), straps (wrist and leg). Soldering iron, little dipper DIP inserter; DIP contractor IC dispensers, production aids, conductive epoxies, PCB racks and cabinets, antistatic smocks, conductive ground straps, conductive seat covers
Texwipe Company P.O. Box 575 Upper Saddle River, New Jersey 07458 (201) 327-5577	Conductive plastics: mats (bench and floor). Static neutralizers
Thielex Plastics Corporation 201 Eleventh Street P.O. Box 518 Piscataway, New Jersey 08854 (201) 968-5300	Conductive dipstick, antistatic coatings
Transmet Corporation 4290 Perimeter Drive Columbus, Ohio 43228 (614) 276-5522	Transmet modified plastic
TREK, Inc. 1674 Quaker Road Barker, New York 14012 (716) 795-3211	Electrostatic fieldmeters, electrostatic voltmeters
Tylinski Associates, Inc. 425 Northern Blvd. Great Neck, New York 11021 (516) 466-9070	"Fred" wrist strap
United Technical Products, Inc. 32 S.W. Industrial Park Westwood, Massachusetts 02090 (617) 326-7611	Conductive plastics: mats (bench and floor), carpeting
Vinyl Plastics, Inc. 3123 S. 9th Street, Box 451 Sheboygan, Wisconsin 53081 (414) 458-4664	Conductive vinyl flooring (conductile)
Visilox Systems, Inc. Road 5, Box 116 Spring Avenue, Ext. Rt. 154 Troy, New York 12180 (518) 283-5963	Conductive coatings

Walter G. Legge Company, Inc. 101 Park Avenue New York, New York 10017 (212) 689-3083	Conductive plastics: foot accessories, sleeve protectors (gauntlets). Antistatic liquids and sprays, wrist straps, legsure cleaner and polisher, legstat
Weller Division of Cooper Industries Department 101 7 Cypress Drive Burlington, Massachusetts 01803 (617) 272-5051	Soldering iron, TC 201Z zero voltage soldering pencil
Wescorp/Dal Industries, Inc. 1155 Terra Bella Avenue Mountain View, California 94043 (415) 969-7717	Antistatic plastics: containers, tote boxes, trays. Conductive plastics: aprons, coats, smocks, bags, containers, tote boxes, trays, drum liners, foam, mats (bench and floor), tubing. Conductive heel protectors, seat covers, grounding straps, sleeve protectors (gauntlets), straps (wrist and leg), strips (shunt bar). Air ionizers, electrostatic voltmeters, partable work stations, DIP shipping tubes Work station kit, westat liquid coatings, westat chair mats, westat warning labels
Western Static Eliminator Company 215-219 S. Western Avenue Chicago, Illinois 60612 (312) 666-2746	Conductive plastics: bags, foam, foot accessories, sheeting, straps (wrist and leg), strips (shunt bar). Air ionizers, electrostatic voltmeter, static neutralizers, antistatic liquids and sprays, antistatic brushes
Worklon Division of Superior Surgical Manufacturing Company, Inc. Superior Surgical Park Seminole Boulevard at 100th Terrace Seminole, Florida 33542 (813) 397-9611	Conductive clothing
Yokogawa Corporation of America 5 Westchester Plaza Elmsford, New York 10523 (914) 592-6767	Electrostatic voltmeters

SOURCES OF AWARENESS BRIEFINGS AND CONSULTANTS

Bendix Corporation
P.O. Box 1159
Kansas City, MO 64141
(816)997-4986
Attn: Whitson Kirk

Electrostatic Discharge Consultants
Data Technology Group
1311 South Anaheim Blvd.
Anaheim, CA 92805
(714)772-5120

Evaluation Research Corporation
2341 Jefferson Davis Hwy.
Arlington, VA 22202
Attn: Jack Galleher

Honeywell DSD
2600G Ridgeway Pwky.
Minneapolis, MN
(612)931-6134
Attn: C. Fred Mykkanen

Owen J. McAteer
11511 Sherwood Road
Upper Falls, MD 21156
(301)592-8410

Reliability Sciences Incorporated
2361 S. Jefferson Davis Hwy.
Arlington, VA 22202
(703)979-1414
Attn: Ed McMahon

Richmond - Division of Dixico
Colton & Opal Streets
P.O. Box 1129
Redlands, CA 92373
(213)628-8263
Attn: Dan Anderson

Simco Company
920 Walnut Street
Lansdale, PA 19446
(215)368-2220

Static Control Systems/3M
3M Center-223-2SW
St. Paul, MN 55101
(612)733-9420

SAR Associates
RR2 Box 500
Rome, NY 13440
(315)339-3968
Attn: Roy Walker

Reliability Analysis Center
RADC/RBRAC
Griffiss AFB, NY 13441
(315)330-4151
Attn: Norman B. Fuqua

APPENDIX C

APPLICABLE DOCUMENTS BY SOURCE

U.S. GOVERNMENT DOCUMENTS

Specification Sales (3FRSBS)
Bldg. 107, Washington Navy Yard
General Services Adminstration
Washington, DC 20407

FED-STD-101B: Preservation, Packaging and Packing Materials Test Procedures; Test Method 4046: Electrostatic Properties of Materials

The test method in this standard describes the procedures to use for testing the electrostatic properties of various materials.

PPP-C-1842: Cushioning Material, Plastic, Open Cell (For Packaging Applications)

This specification covers the requirements for Plastic Open Cell Cushioning Material designed for shielding, packaging and storage of static-sensitive devices.

Commanding Officer
Naval Publications and Form Center
5801 Tabor Avenue
Philadelphia, PA 19120

DOD-HDBK-263: Electrostatic Discharge Control Handbook for Electrical and Electronic Parts, Assemblies and Equipment

This handbook provides guidelines for the establishment of an Electrostatic Discharge (ESD) Control Program in accordance with DOD-STD-1686. This document is applicable to the protection of electrical and electronic parts from damage due to ESD.

DOD-STD-1686: Electrostatic Discharge Control Program for Electrical and Electronic Parts, Assemblies and Equipment

This standard provides direction for the establishment and implementation of an Electrostatic Discharge (ESD) Control Program for any activity that designs, tests, inspects, services, manufactures, processes, assembles, installs, packages, labels, stores or stows or otherwise handles electrical or electronic parts susceptible to damage caused by static electricity.

NAVORD OD 46363: Requirements for the Electrostatic Discharge Protection of Electronic Components and Assemblies

This ordinance document covers the general and detail requirements for the electrostatic discharge protection of electronic components and assemblies. (This document has been incorporated in its entirity in the preceeding two documents and may be considered obsolete.)

MIL-STD-129H: Marking for Shipment and Storage

Paragraph 5.4.38 of this standard specifies the marking requirements of unit, intermediate and exterior packs of sensitive electronic (ESDS) items.

MIL-STD-758B: Packing Procedures for Submarine Repair Parts

Appendix C of this standard covers protection for sensitive electronic items such as, but not limited to, diodes, transistors, integrated circuits, and equipments incorporating such items which are susceptible to damage from electrostatic, electromagnetic, or both field forces.

MIL-STD-883B: Test Methods and Procedures for Microelectronics; Test Method 3015: Electrostatic Discharge Sensitivity

The test method in this standard establishes the means for measuring the electrostatic discharge sensitivity for all microcircuits, which will be used to determine the particular sensitivity class and the appropriate packaging requirements for each device type.

MS-90363G: Box, Fiberboard, with Cushioning for Special, Minimum Cube Storage and Limited Reuse Applications

Dash Nos. 6, 7, and 8 of this standard specify the packaging and marking requirements of electrostatic sensitive devices.

MIL-B-117: Bags, Sleeves and Tubing, Interior Packing

This specification covers bags, sleeves and tubing, and interior packing for the preservation-packaging, field force protection (shielding), packing and container marking of electrical and electronic devices.

MIL-S-19491: Semiconductor Devices, Packaging of

This specification covers the requirements for the preservation-packaging, field force protection (shielding), packing and container marking of all types of semiconductor devices (such as diodes and transistors).

MIL-M-38510: Microcircuits, General Specification for

This specification (revision E) requires all those devices covered by the specification to be tested for ESD sensitivity during initial qualification and any subsequent product redesign in accordance with MIL-STD-883 method 3015.1 or the applicable detail (slash sheet) specification. Those devices determined to be sensitive to ESD (category A 2000 volts or less) or untested devices shall be marked accordingly either a) with the MIL-STD-129 symbol, b) an equilateral triangle, or c) utilizing a bright orange marking ink.

Slash sheets covered under this specification contain VZAP requirements for CMOS and MOS integrated circuits.

MIL-M-55565A: Microcircuits, Packaging Of

This specification covers the requirements for the preservation-packaging, field force protection (shielding), packing and container marking of all types of microcircuits.

MIL-B-81705B: Barrier Materials, Flexible, Electrostatic-Free, Heat Sealable

This specification covers opaque and transparent heat sealable, electrostatic-free, flexible, barrier materials for the packaging of missiles, explosive powered and electro-sensitive devices, microcircuits, semiconductors and thin film resistors.

MIL-P-81997A: Pouches, Cushioned, Flexible, Elecrostatic-Free, Reclosable, Transparent

This specification covers the requirements for flexible electrostatic-free reclosable transparent porches designed for shielding, packaging and storage of static-sensitive electronic devices.

NAVSUP/SPCC Form 36, Contract Requirement G-64: Packaging Intructions For Electromagnetic and Electrostatic Protection

This contract clause specifies the packaging instructions for the protection of field force sensitive items.

NAVSEA SE 003-AA-TRN-010: Electrostatic Discharge Training Manual

The intent of this manual is to compliment an ESD Awareness Training Course which is a key part of any effective ESD control program. This manual was produced by Reliability Sciences Inc. from funds supplied by NAVSEA 6151, System Effectiveness Branch.

This manual covers topics such as: principles of static electricity, charging and discharging, prime static generators, static electrification of electrical and electronic parts, elements of an ESD control program, ESD protective materials, ESD protective equipment, packaging and marking of ESDs items, ESD in design, ESD handling precautions and procedures, and monitoring of ESD control programs.

INDUSTRY DOCUMENTS

American Society for Textile Chemists and Colorists
AATCC Technical Center, P.O. Box 12215
Research Triangle Park, NC 27709

AATCC Test Method 134-1975: Electrostatic Propensity of Carpets

This test method is designed to assess the static propensity of carpets by controlled laboratory simulation of conditions which may be met in practice, and more particularly, with respect to those conditions which are known from experience to be strongly contributary to excessive accumulation of static charges.

American National Standards Institute
1430 Broadway
New York, NY 10018

ANSI Test Method 47 (Secretariat) 707 (Proposed): Electronic Devices Sensitive to Electrostatic Discharges

This test method is designed to determine which electronic devices are sensitive to electrostatic discharge to the degree that they require special handling precautions.

ANSI Standard 241.3-1976; Conductive Safety-Toe Footwear

This standard provides the requirements for the design of conductive safety-toe footwear which protects against the hazards of the buildup of static electricity.

American Society of Testing and Materials
1916 Race Street
Philadelphia, PA 19103

ASTM Test Method D257-78: D-C Resistance or Conductance of Insulating Materials

This test method covers direct-current procedures for the determination of d-c insulation resistance, volume resistance, volume resistivity, surface resistance and surface resistivity of electrical insulating materials or the corresponding conductances or conductivities.

ASTM Test Method D991-75: Rubber Property-Volume Resistivity of Electrically Conductive and Antistatic Products

This test method covers the detemination of volume resistivity of rubbers used in electrically conductive and antistatic products.

ASTM Test Method D2679-78: Electrostatic Charge

This test method covers the determination of the amount of electrostatic charge present on or in a specimen or of the electrostatic charge transferred between two material objects upon contact.

ASTM Test Method D3509-76: Electrostatic Strength Due to Surface Charges

This test method covers the determination of the value of electrical field strength at and near a variety of objects such as metal surfaces at high voltages and insulating bodies with electrostatic charge.

Electronic Industries Association
2001 Eye Street
N.W. Washington, DC 20006

EIA Standard RS-471: Attention Symbol and Label for Electrostatic Sensitive Devices

This standard provides a distinctive caution symbol and label to be used to identify those electronic devices that require special handling to prevent damage due to electrostatic discharge.

National Standards Association
1321 Fourteenth Street N.W.
Washington, DC 20005

NAS853: Field Force, Protection For

This standard provides for the protection of items, components and assemblies which may be damaged by field forces (electrostatic, electromagnetic, magnetic or radioactive) encountered in nonoperating environment.

National Fire Protection Association
470 Atlantic Ave
Boston, MA 02210

NFPA Standard 56A: Inhalation Anesthetics; Section 46: Reduction in Electrostatic Hazard

Section 46 of this standard provides the requirements to reduce the possibility of electrostatic spark discharges, with consequent ignition of flammable gases in anesthetizing locations.

NFPA Standard 77: Static Electricity

This standard provides recommended practices that assist in reducing the fire hazard of static electricity by presenting a discussion of the nature and origin of static charges, the general methods of mitigation and recommendtions in certain specific operations for its dissipation.

Underwriter's Laboratory
383 Pfingsten Road
Northbrook, IL 60062

UL Code 217: Single and Multiple Station Smoke Detectors; Section 36: Static Discharge Test

Section 36 of this code provides a test to determine if smoke detector units are sensitive to electrostatic discharges.

BRITISH GOVERNMENT DOCUMENTS

Ministry of Defense
Directorate of Standardization
First Avenue House
High Holborn
London WCIV 6HE

Defense Standard 59-98; Handling Procedures for Static Sensitive Devices

This standard provides guidance relating to the handling, identification and packaging of static sensitive devices.

British Standards Institute
2 Park Street
London W1A 2BS

BS5783: 1979; Code of Practice for Handling of Electrostatic Sensitive Devices

This code of practice recommends the precautions for the storage, transportation, handling and testing of all kinds of electrostatic sensitive devices (ESDS), circuits, and assemblies.

APPENDIX D

ESD AWARENESS FILMS AND VIDEO TAPES

ESD AWARENESS FILMS AND VIDEO TAPES

1 "ZAP STATIC AWARENESS" — No. 35407DN
Navy Version 17 minutes — 3/4" video cassette or 16 mm film

Available to Government agencies, not available to public (Government contractors make request through their sponsor)

Contact (East of the Mississippi):
Commanding Officer
Naval Education and Training Support Center, Atlantic
Building W313
Naval Station
Norfolk, VA 23511
(AV) 690-4011

Contact (West of the Mississippi):
Commanding Officer
Naval Education Training Support Center, Pacific
Fleet Station Post Office
Building 110
San Diego, CA 92132
Attention: Film Library
(AV) 933-8894

2 "ZAP STATIC AWARENESS"
GD or Tektronix version 45 minutes — 3/4" video cassette

Available to the public for loan and copying

Contact:
Dan Anderson
Richmond-Division of Dixico Inc.
Box 1129
Redlands, CA 92373
(714)794-2111

3 "STATIC HAVOC"
Westinghouse 20 minutes — video cassette
(presented at EOS/ESD Symposium in Denver)

Available to the public for purchase

Contact:
K.L. Wingert, MS-7745
Westinghouse Electric Corp.
1111 Schilling Road
Hunt Valley, MD 21030
(301)667-3265 or 667-3264

4 "PLEASE.......DON'T GIVE ME ANY STATIC!"

McDonnell Douglas 3 versions all 3/4" video cassette

C-1-89 Non Technical Version-For shipping and expediting personnel (≃29 min)
C-1-90 Technical Version-For Electrical Engineers and Lab Technicians (≃32 min)
C-1-91 Technical Version #2-For electrical assembly and lab personnel (≃34 min)

Available to the public for loan and copying for handling cost

Contact: Video Tapes
Evaluation Engineering
1282 Old Skokie Rd.
Highland Park, IL 60035
(312)831-3090

5 "STATIC SAFEGUARD SYSTEMS"

3M 36 minutes 3M - 1/2" or 3/4" video tape or 16mm film

Available to the public for purchase

Contact: 3M Static Control Systems
3M Center
Bldg. 223-2SW
St. Paul, MN 55101
(612)733-9420

6 "HAZARDS OF STATIC ELECTRICITY"

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