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SAND2012-5788
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Printed July 2012

An Analysis of Electrostatic Discharge Considerations in the Use of Sodium Bicarbonate Media for De-Potting Sensitive Electronic Assemblies

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Abstract

Sodium bicarbonate blast media offers superior performance in removing low-to-medium density polyurethane foam potting materials from electronic assemblies compared to conventional abrasive or other low-hardness blast media. This work identifies a class of processing equipment suitable for potting removal in electronic assemblies and provides a technical evaluation of appropriate process controls that significantly reduce the potential for Electrostatic Discharge (ESD) degradation or damage.

Once appropriate process controls are added, the class of blast equipment demonstrated here, previously used only for non-ESD sensitive assemblies, can be safely used to provide new capabilities for component-level support. In many cases, assemblies that have been de-potted using sodium bicarbonate can be disassembled and rebuilt using normal production processes, enabling repair, reacceptance, and surveillance of assemblies that was previously impractical.

This paper presents the results of a study that identifies significant process variables and their contribution to ESD generation. Data are presented to quantify process-related peak ESD voltages and mitigation methods. A discussion of how to implement practical ESD controls and de-potting process test methodologies is provided.

The intent of this work is to document foundational experimental work that provides a technical basis for sodium bicarbonate as an ESD-safe material for use in de-potting processes when appropriate controls are implemented.

Acknowledgements

The following individuals contributed substantially to this work:

Linda Domeier, 8223: Report format consulting (retired)
Bob Franssen, 8247: Accublast system management and test conductor (retired)
Joel Groskopf, 8123: Experiment series test conductor and ESD equipment selection
Mike Ortiz, 8236: Blaster nozzle tip design and fabrication
Dawn Skala, 8238: Material property and report content consulting
Brett Wagstaff, 8226: Fluid flow consulting
Kelly Wendell, 8247: Ionizer air injection blast nozzle design refinement and fabrication

Peer Reviewers

The efforts that the following individuals made in ensuring completeness and accuracy improved this report significantly and are greatly appreciated

Seung Choi, 8237, B83 Systems
Linda Domeier, 8223, Materials Chemistry (retired)
Lee Druxman, 8231, W87 Systems
Barry McLaughlin, 8237, B83 Systems
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Contents

Figures

Tables

1. Why Sodium Bicarbonate?

A series of attempts was made to de-pot major components for the W80 to support aging studies and technical basis work, with mixed results. Existing methods included manual foam removal, abrasive blasting, and chemical removal. Manual foam removal was found to frequently cause inadvertent damage to Printed Wiring Assemblies (PWAs), cabling, and flex circuits, particularly in complex assemblies. Abrasive blasting produces surface damage to electronic components and circuit boards. Chemical removal results in damaged components having materials similar to the potting being dissolved. In short, it is not unusual for conventionally de-potted assemblies to exhibit damage and failures, complicating failure diagnosis when disassembly was performed specifically to identify the cause of electrical malfunctions. An unfortunate byproduct of this damage is that it tends to render traditional surveillance infeasible, since it is apt to obscure variables measurements.

A literature survey of alternate de-potting methods identified sodium bicarbonate as a media with good results for both large-scale industrial surface processing as well as for micro-abrasion applications. No description of work involving electronic component assemblies was identified. An evaluation of the suitability of this material for medium- to small-scale applications followed.

2. A Brief Background on Sodium Bicarbonate Media Blasting

Sodium bicarbonate blasting was developed in the 1980s, and was originally used as a method of stripping/cleaning industrial machinery. This media was most notably used in the restoration of the Statue of Liberty.

Sodium bicarbonate (also known as bicarbonate of soda) is a soft blast media with a higher specific gravity and lower hardness than most blast media (Table 1). The ability to remove coatings is the result of energy transfer from the media to the substrate. As the kinetic energy is proportional to the mass of the particle and the square of its velocity, a small, heavy grain moving at high speed will have more effect on a substrate than a larger, lighter particle. From this, it can be seen that heavier (denser) materials such as steel and silicon carbide are more efficient blasting media than lighter (less dense) media, such as sand and slag, though their hardness results in damage to sensitive assemblies. Another very important property of abrasive media is hardness. Hardness is a relative measure of the media's resistance to abrasion by other materials, and is an indicator of the ability to abrasively wear away other materials. Thus this relatively dense material with low hardness offers advantages in rapid removal of some materials while leaving others undamaged.

Table 1. Typical Blast Media Hardness Comparisons.

Blast Media Type	Hardness (Mohs)	Specific Gravity (gm/cm^3)
Sodium bicarbonate	2.5	2.2
Corn Starch media	2.5 - 3.5	0.6 - 1.0
Plastic media	3 - 4	1.1 - 1.5
Glass Bead	5.5	2.5
Silica sand	6 - 7	1.6
Glass (lead free)	7	1.6
Steel shot	6	2.2+
Aluminum oxide	9	3.9
Silicon carbide	9 - 10	3.2

Various Sources

Sodium bicarbonate blasting is usually done under a high volume, low pressure media feed using either wet or dry blasting equipment. The effectiveness of sodium bicarbonate depends on optimizing a number of operating parameters, including nozzle pressure, standoff distance, angle of impingement, flow rate, and traverse speed. This process, when properly controlled, can clean and remove surface coatings from a wide variety of materials.
For the most part, the sodium bicarbonate abrasive particles decompose into dust upon impact with the surface being processed. For this reason the sodium bicarbonate media cannot be reclaimed or re-used during the blast process.

While sodium bicarbonate is well suited to processing some materials, it has limited-to-no practical uses on other materials, such as resilient elastomers and hard coatings that require cutting or abrasion to remove. These features suggested that this media was an excellent candidate for potting foam removal without undue damage to other materials typically used in electronic assemblies.

3. Sodium Bicarbonate and Electrostatic Discharge

A drawback of sodium bicarbonate is that this material is capable of developing a triboelectric charge. Triboelectric charging most commonly occurs by the contact and separation of two similar or dissimilar materials, stimulating the transfer of electrons between materials. Another charge-producing mechanism is via fracture of a brittle material.

A simplified description of this process is that the atoms of a material with no static charge have an equal number of positive (+) protons in their nucleus and negative (–) electrons orbiting the nucleus. When the two materials are placed in contact and then separated, negatively charged electrons are transferred from the surface of one material to the surface of the other material. The material that loses electrons versus that which gains electrons depends on the natures of the two materials. The material that loses electrons becomes positively charged, while the material that gains electrons is negatively charged.

The charge developed is measured in coulombs, but it is common to describe the electrostatic potential on an object expressed as a voltage. This charge may be transferred from the material, creating an ESD event.

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4. Sodium Bicarbonate De-Potting Equipment

Available sodium bicarbonate de-potting equipment identified included very small-scale devices as well as large-scale equipment. Commercially-available micro-blast equipment uses a small hand piece designed primarily to remove very small areas of conformal coatings. This kind of equipment is typically designed to be capable of being ESD-safe, but is also too small to allow for practical de-potting of typical stockpile components. At the other end of the scale, industrially-sized equipment used for aircraft and automotive coating removal was too large to allow the fine control necessary for intricate work, such as encapsulated electronic component assemblies. A survey of glove box-type blast cabinets with correspondingly-sized sodium bicarbonate blast equipment followed.

A few manufacturers were located that produce cabinet-sized equipment typically used to process smaller mechanical components using sodium bicarbonate. No commercially-available equipment was identified that combined these larger blast capabilities with the required ESD-safe processing capabilities, however.

After recognizing that no suitable commercial equipment existed to support a need for de-potting electronic assemblies, it was determined that adapting commercial equipment to this application was appropriate. A series of discussions with a regional supplier for sodium bicarbonate media and equipment identified a system that had potential for supporting this application. The equipment selected was an Accublast 1.5 cu. ft. pressure system and cabinet (Figure 1).

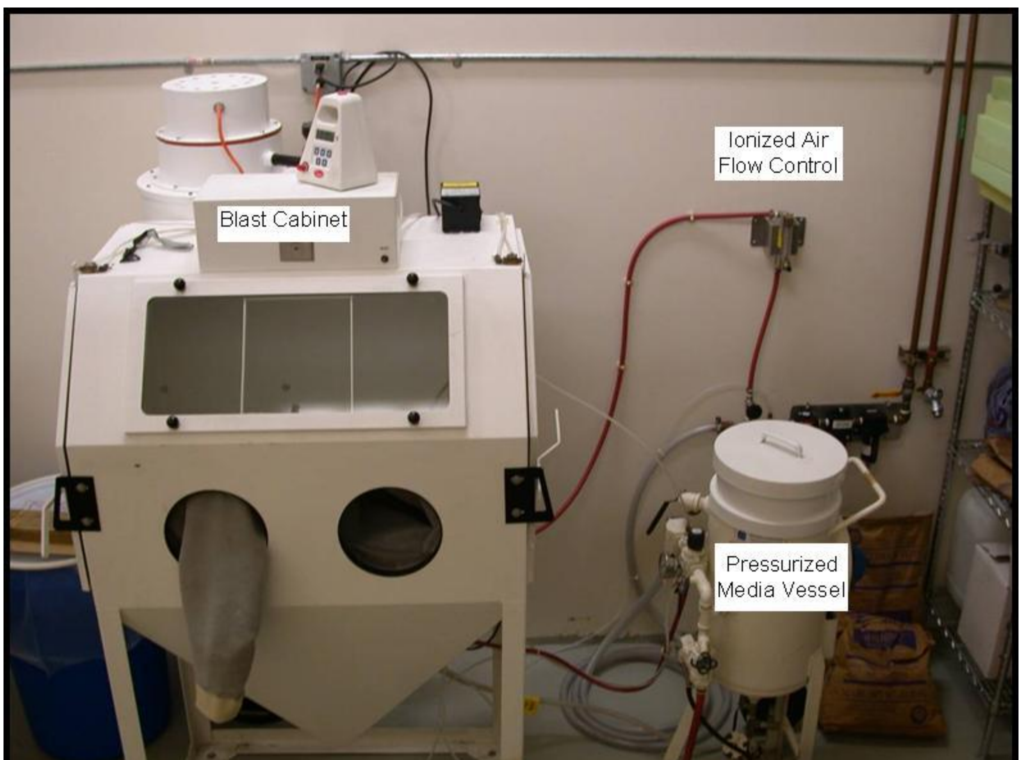

Figure 1. Accublast 1.5 Ft^3 System.

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5. Electrostatic Discharge Considerations

The first consideration for any de-potting process is to ensure that the component being processed will not be damaged. It was recognized that sodium bicarbonate can readily generate significant triboelectric charge during operation. The micro-abrasive equipment commercially available generally included one or more methods for mitigation of ESD. Larger scale industrial uses typically use a water-born media mixture to control dust, so early attempts at de-potting focused on the use of hydrophobically-modified sodium bicarbonate media delivered as water-born slurry. It was believed that the use of a water-based media would prove to be adequate to preclude the need for further ESD mitigation methods.

The results of the water-born media experiments were discouraging: the blast pressure and media flow rates required to remove the potting material were found to result in damage to the electronic assemblies comparable to abrasive media, and the potting removal rates were quite poor (Figure 2). Once the water-based media approach had been evaluated and discarded, the focus of the work concentrated on identifying practical methods of mitigating ESD that were compatible with equipment capable of processing assemblies at a useful rate.

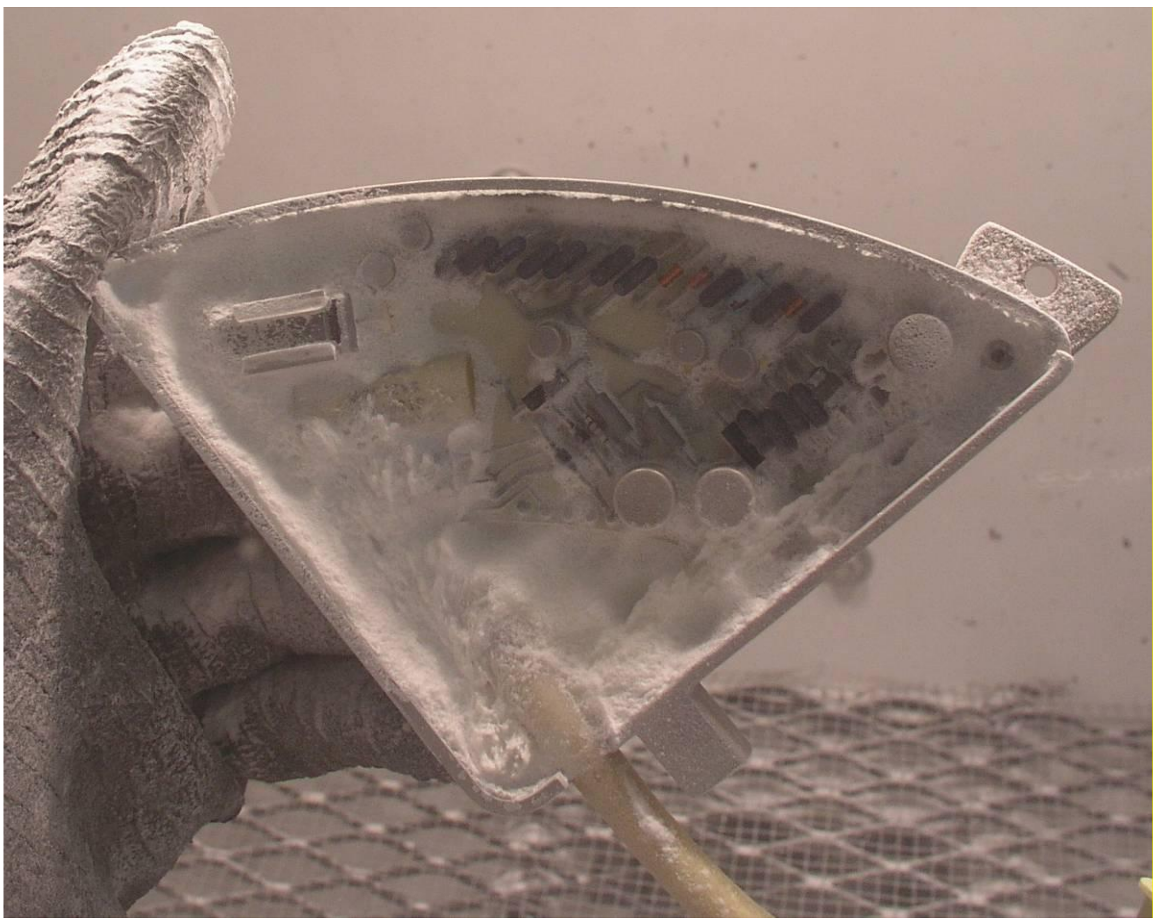

Figure 2. Water-Based Sodium Bicarbonate Test Sample.

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6. A Survey of Sodium Bicarbonate ESD Mitigation Techniques

In the micro abrasive conformal coating removal process, a mixture of dry air or inert gas with the abrasive media is forced through a very small orifice in a hand piece. This allows the mixture to be delivered at the target area of the conformal coating to be removed. A vacuum system is required to continuously remove the used materials and divert them through a filtration system for disposal. The process is generally conducted within an enclosed anti-static chamber and features various grounding techniques to dissipate the generated ESD charge.

Micro abrasive systems inherently generate static electricity as the high velocity non-conductive particles impinge on the surfaces of the material being blasted. The voltage generated at the area of impact can cause ESD damage to the parts and electrical circuits on a Printed Wiring Assembly (PWA).

ESD mitigation techniques typically used for micro-abrasive equipment typically include one or more of the following:

- **AC or DC pulsed ionized air bars in the blast cabinet**
  Technical discussions with manufacturers of ionized air bars indicated these devices would not be adequate due to degradation of the bars under the use conditions. Since reliability of the de-potting process is a fundamental requirement, equipment configurations that could lead to in-process ESD mitigation degradation or failure should be avoided.

- **Ionized air used as supply air for the blast process**
  Ionized air used as the source for the blast air supply was also discounted, recognizing that the charged ions in this supply would recombine and be depleted by the time that the air had traveled the approximately eight feet from the media chamber to the blast nozzle.

- **Point-ionization at the blast nozzle**
  Point ionization at the nozzle, where the media stream is passed over the ionization needle, was considered, but without a means of preventing contamination of the ionizer discharge needle, the likelihood of reliable operation was estimated to be small. Rapid degradation of the needle can also be expected.

- **Ionized air injection into the media stream at the blast nozzle**
  Ionized air injection at the blast nozzle was pursued as the option most likely to be successful, and an in-line ionizer as well as point ionization equipment was purchased to support the experimental work.

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7. Ionization Equipment Selection and Characterization

Equipment procured included a TAKK Industries Model 5860 In-Line Ionizer and a Model 5851 Point AC Static Eliminator. The point ionizer was procured with the intent of fabricating a custom blast nozzle. The in-line ionizer was intended as a backup in case the custom nozzle concept was found to be impractical.

After completing the equipment selection, it was necessary to consider a method for characterizing the blast equipment and process variables. Since ESD was a primary concern in this work, understanding and characterizing the factors involved in charge generation is a central interest.

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8. Potential Factors Influencing ESD Generation

Factors identified that could affect ESD generation included the following, roughly arranged in a descending order of relative importance:

- **Equipment grounding**
  The quality and thoroughness of grounding can be anticipated to be a strong contributor to charge generation. Grounding of the blast cabinet, the work surfaces internal to the cabinet, and the item being processed all need to be considered. Items such as blast cabinet gloves should be either conductive or static-dissipative. Some surfaces are difficult to ground, such as glass windows. These items can be made inherently difficult to transfer charge to the item being processed by tethering the item or by procedural controls.
- **Material properties**
  The type of materials involved and their triboelectric properties were expected to be a major factor. These materials include the blast media, the gas used to convey the media, the media feed tubing, and the materials being processed.
- **Media flow rate**
  The rate at which the media flows can be expected to contribute to material triboelectric responses, proportionally increasing ESD as the flow rate increases.
- **Blast pressure**
  The pressure used for the process affects the media and gas flow rate, which can be expected to proportionally contribute to ESD generation.
- **Dust level**
  Dust levels present in the blast cabinet can be expected to provide a charge transfer path, likely influencing ESD decay rates and therefore affecting the maximum charge that can be developed.
- **Humidity**
  The presence of humidity is a known factor that provides mitigation for charge buildup. It was recognized that humidity is not a process variable that could be controlled during the course of this experiment. A dry air supply was required to prevent caking of the sodium bicarbonate media. Thus the only time that humidity could be considered a factor is upon startup where the blast cabinet might have a more humid environment, which is a favorable condition that reduced ESD. The compressed air system air used in these experiments was controlled to a 37°F dew point (0.01ppm).
- **Temperature**
  Temperature could possibly affect the process by changing material properties and driving interactions between other factors listed here. Temperature was also not viewed as a controllable process variable. Ambient conditions in the building where the work was performed were non-adjustable.

To characterize the variables influencing ESD generation, this work sought to identify conditions leading to extreme ESD generation and then correlate with process variables. Representative materials typical of potted electronic assemblies were selected to represent a range across the triboelectric series (Table 2).

Table 2. Triboelectric Material Examples.

Experimental Measured Surface Voltages (Approx. V)	Triboelectric Reaction More Positive (+)	
600	**Polyurethane Foam**	Positive ↑
	Human Skin	
	Glass	
	Human Hair	
	Mica	
100	**MDS-Filled Nylon**	
	Lead	
	Aluminum	
	Paper	
-150	**Buna N Rubber**	
	Wool	Neutral
	Steel	Negative ↓
-100	**ABS**	
	Mylar	
	Nickel	
	Copper	
	Gold, Platinum	
	Polyester	
-250	**Polystyrene**	
	Acrylic	
	Polypropylene	
	Polyvinylchloride (PVC)	
-1500	**Teflon**	
	Silicone Rubber	
	Triboelectric Reaction More Negative (-)	

Various Sources

9. Characterizing ESD Charge Generation

The intent of this initial work was to stimulate the maximum achievable ESD voltages to provide bounds on the type of electronic assemblies that could be processed without any ESD controls using the selected equipment.

One of the most important factors affecting process efficiency and control is the design of the blast nozzle. Thus before beginning the characterization work, the nozzle design was optimized. The original nozzle provided with the blast machine consisted of a short piece of ¼-inch brass pipe inserted into the media feed hose. The goal of improving the design was managed by an SNL tool-and-die-maker in the site machine shop. The result was a set of nozzles that provided excellent process control over a variety of large and fine-detail assemblies as needed. Several combinations of orifice sizes and tip bend angles were developed and evaluated. Refer to Figure 2 for illustrations of some of the nozzle designs evaluated. Additional discussion on nozzle design appears later in this paper.

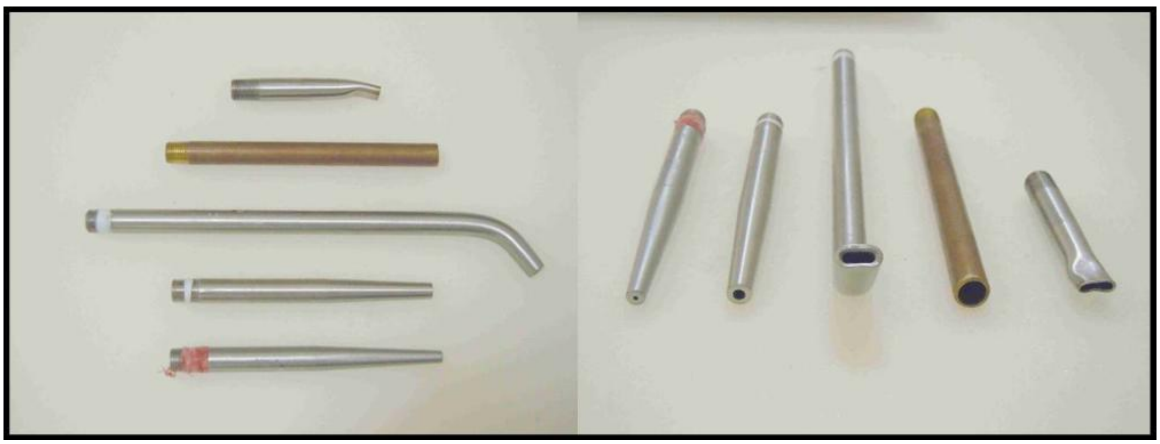

Figure 2. Abrasive Blast Nozzles.

Samples of the materials selected for the evaluation were exposed to the blast process with no ESD controls present. The blast nozzle found to offer the most general versatility in removing foam was used. The material samples were placed on a non-conducting (wood) surface inside the blast cabinet to maximize charge development. The blast cabinet and the blast nozzle were ungrounded. The following general operations were used to acquire data using an AlphaLab Surface DC Voltmeter Model SVM2.

The Accublast system used for this work was designed specifically for use with Armex brand sodium bicarbonate blast media, and in all cases discussed in this paper the only media used was the Armex XL media.

- Three different blast dwell times were used; 30 seconds, 60 s, and 120 s
- Surface voltage measurements were made prior to beginning the process, and repeated at 0 seconds (immediately upon stopping the blast process), 30 s, 60 s, and 90 s
- Between tests the material samples were returned to an approximate zero-charge state via manual touch-off, and verification measurements were made prior to beginning another test run

During the course of evaluation, the experiment test conductor noted that during one test the media feed valve was obstructed and the media flow rate dropped to near-zero. When the material sample was measured after this test it was found to have a charge voltage of roughly six times the other runs in this test (Figure 3). For this reason, additional experimental runs were added to evaluate the test samples under reduced flow conditions, referred to herein as "lean" blast processing. This lean condition was somewhat difficult to induce deliberately: media flow was required, i.e., air charging alone was not found to cause the condition, yet the media flow rate required to cause these conditions was a small fraction of what was needed to efficiently remove potting. During subsequent tests, however, this lean condition occurred naturally from time to time during the evaluations due to clogging of the media feed valve. While these runs were omitted from statistical evaluations as being non-representative, they were incorporated into an analysis intended to bound worst-case ESD charging.

10. Notes on Graphs

All measurements in this paper were made with the AlphaLab Model SVM2 described earlier. The data were read directly in kV with the SVM2 at a standoff distance of one inch from the sample material surface. This standoff distance was provided by a mechanical feature incorporated into the SVM2.

- Vertical axis scales are in ***negative kV*** when the charge developed was negative and in ***kV*** when the charge developed was positive
- In all graphs the sample material is defined in or under the chart heading
- Additional notes in the chart heading provide test notes, such as whether specific data were excluded from the analysis, and ESD controls implemented for the experiment
- The vertical scales selected for the individual graphs were selected to focus on the dynamic range of the chart rather than for graph-to-graph comparisons

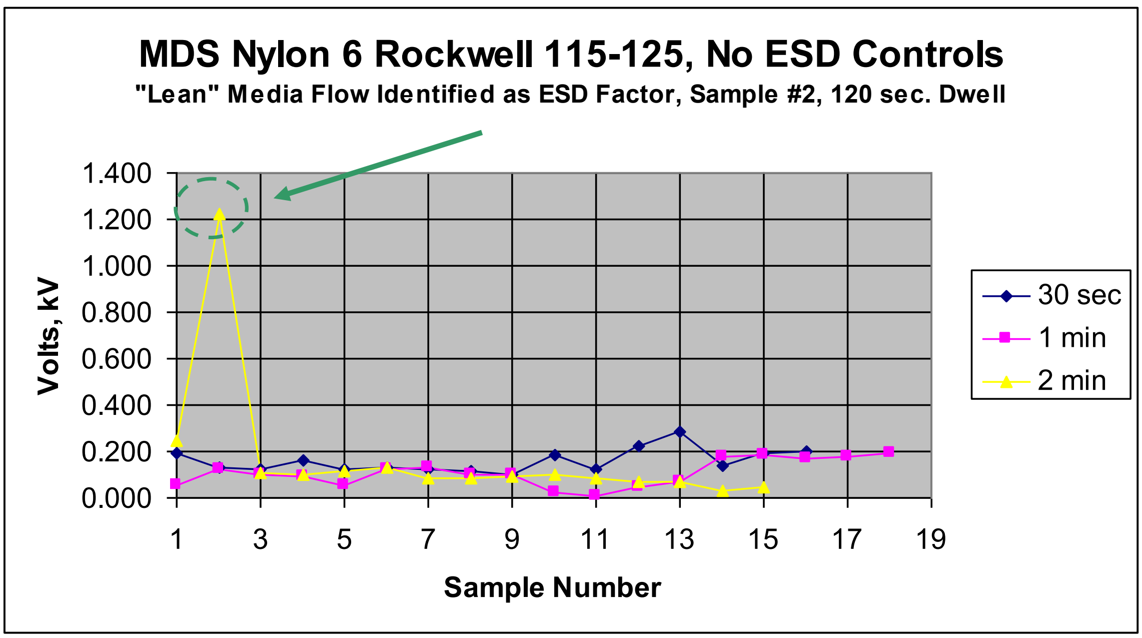

Figure 3. Media Flow Rate Effects.

Refer to Figures 4 through 9 for boxplots of the effect of blast dwell time. These boxplots consist of the upper and lower quartiles with extremes represented by the whiskers. The number of samples is noted on the respective graphs.

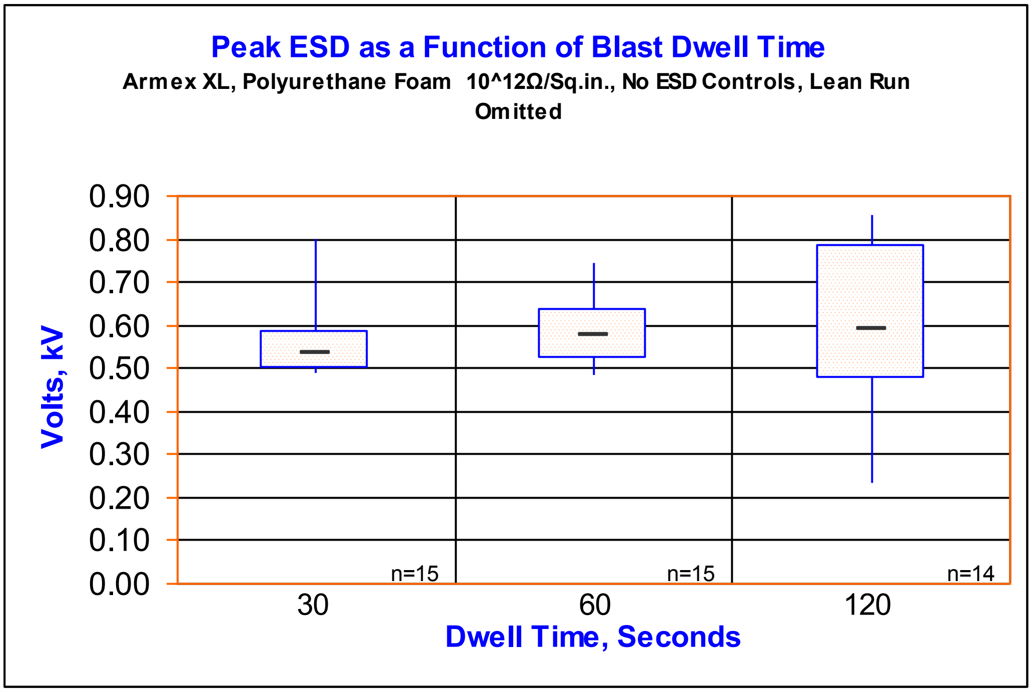

Figure 4. Blast Dwell Time, Polyurethane Foam Sample.

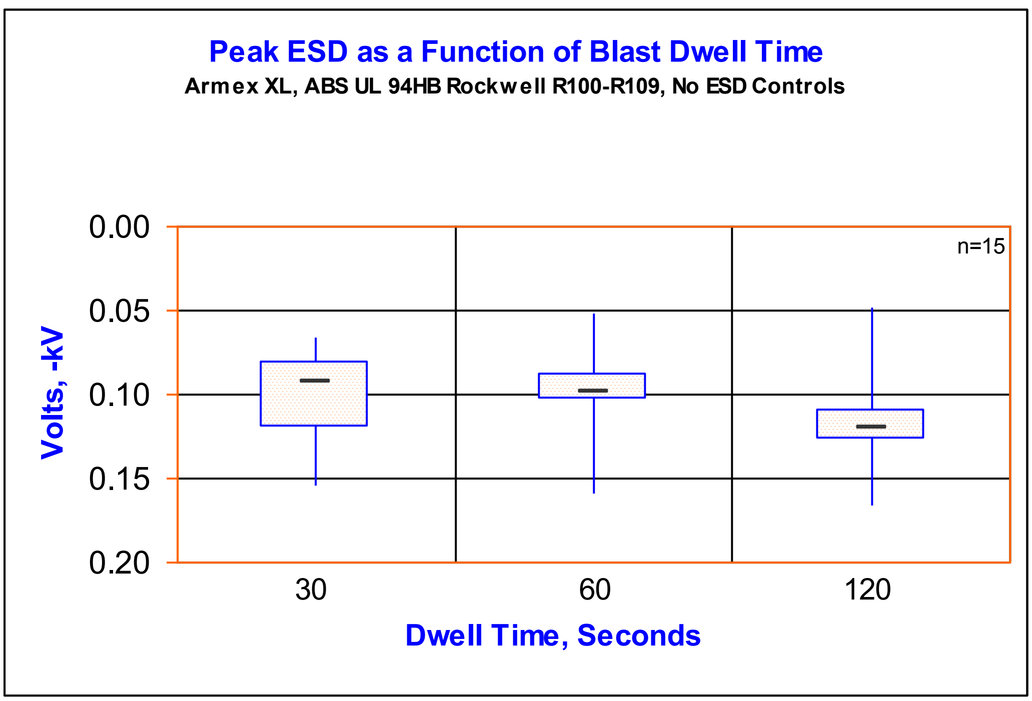

Figure 5. Blast Dwell Time, ABS Sample.

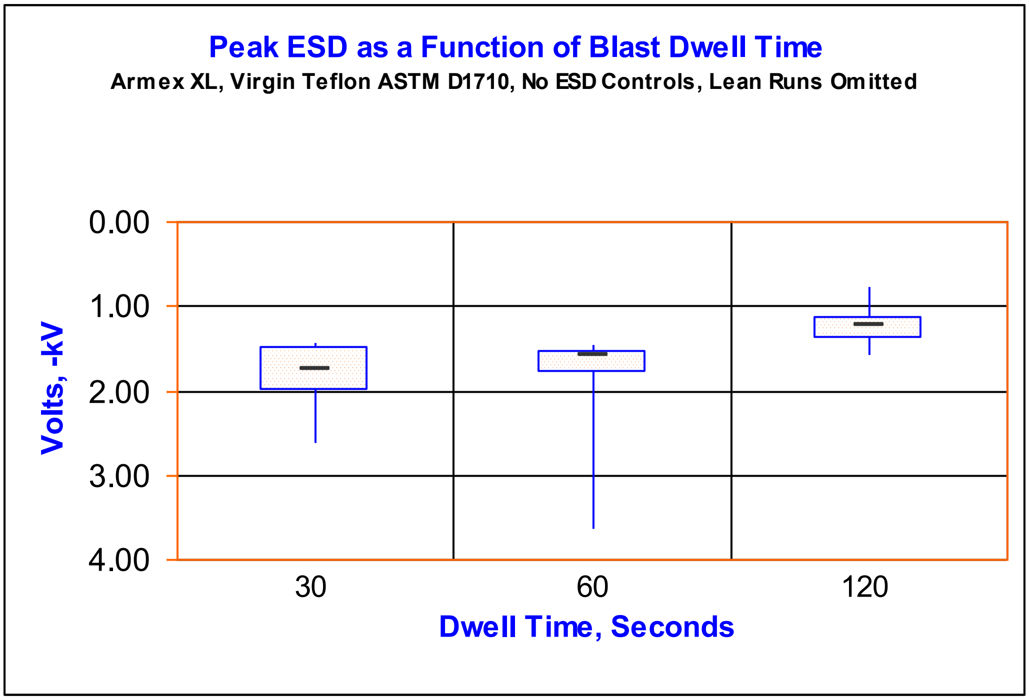

Figure 6. Blast Dwell Time, Teflon Sample.

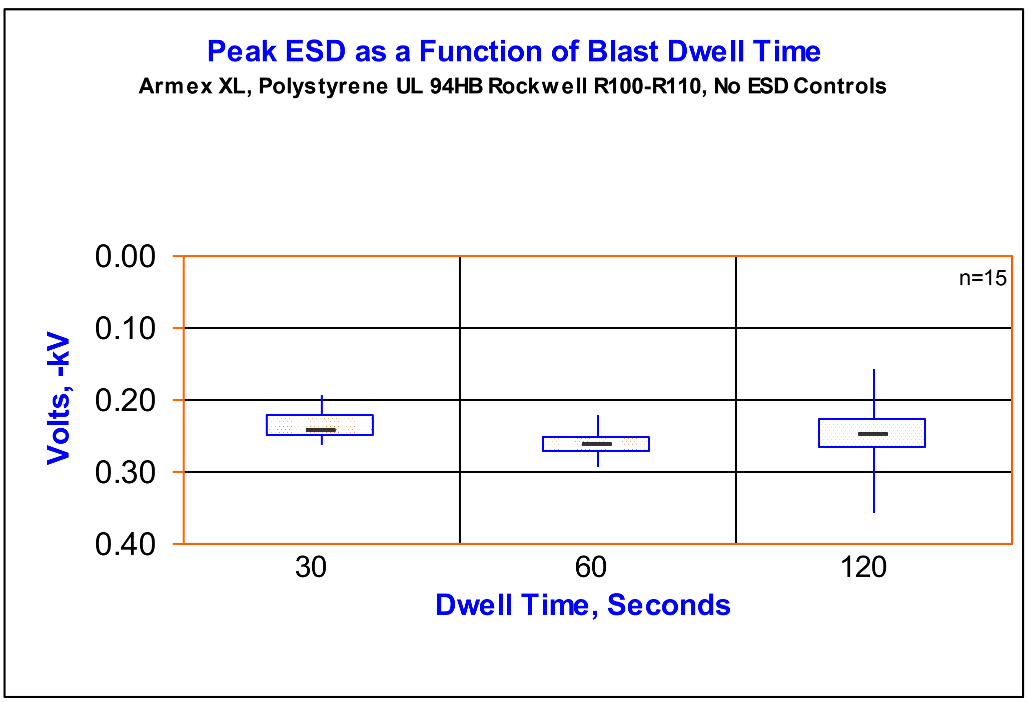

Figure 7. Blast Dwell Time, Polystyrene Sample.

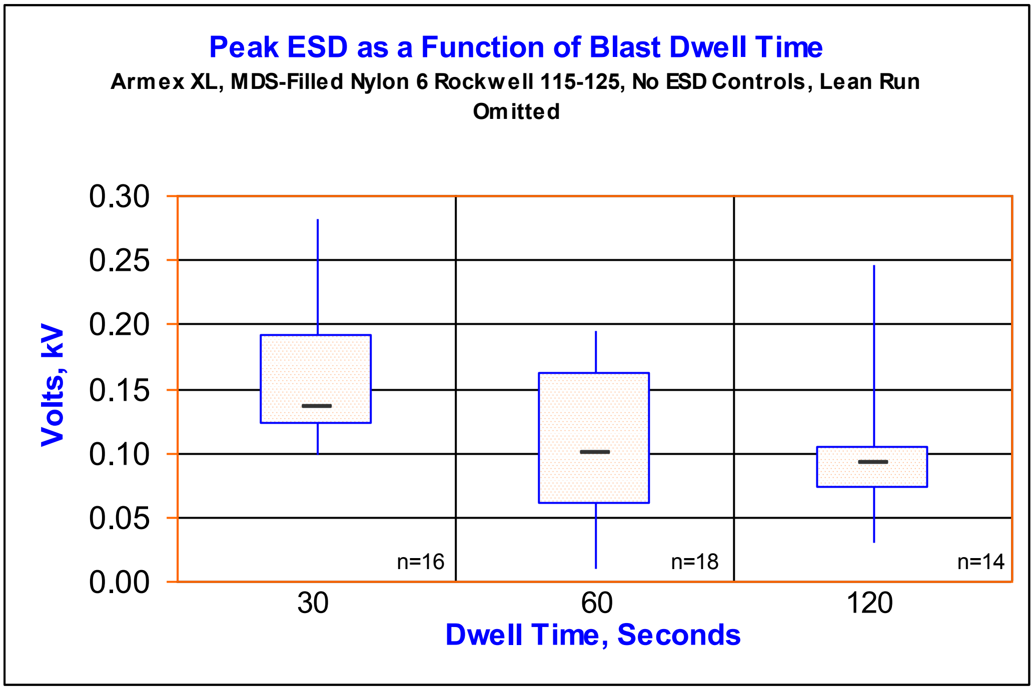

Figure 8. Blast Dwell Time, Nylon Sample.

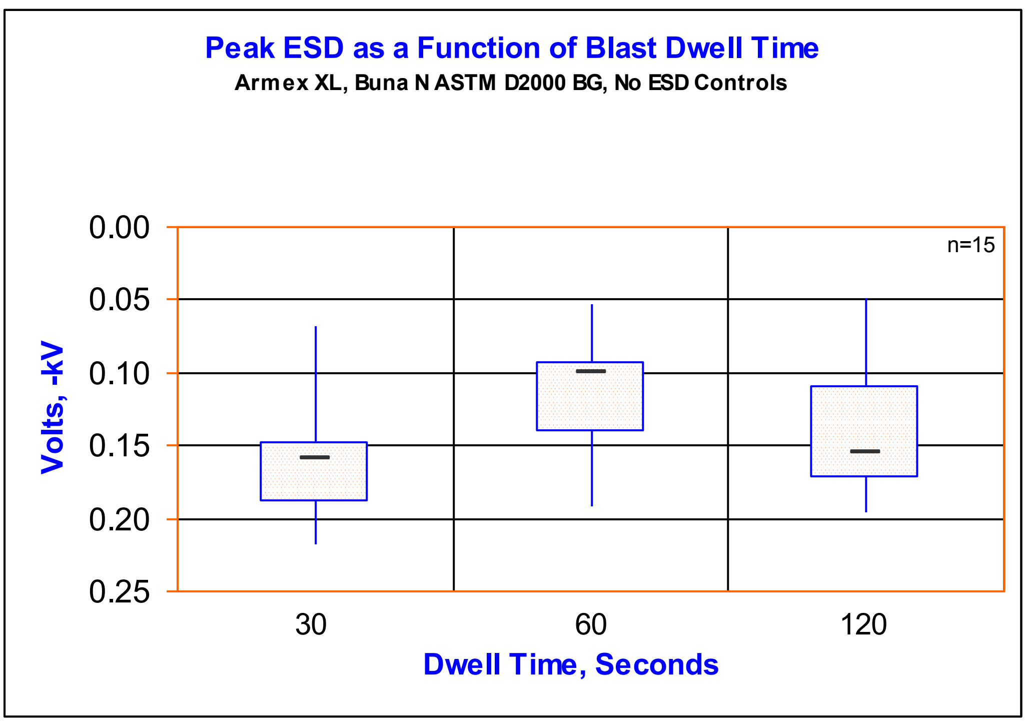

Figure 9. Blast Dwell Time, Buna N Sample.

It is worth noting that measurements for the test samples do not match what would be expected if the triboelectric series data shown earlier in Table 2 was ideal. This is not unexpected, given that the charge developed is the result of interactions between multiple materials, including the sodium bicarbonate media, the material being blasted, the materials involved in the feed tubing, and others.

An interesting effect observed in the raw test data from the test runs is that the first run in a series generally resulted in a somewhat higher voltage than subsequent runs. The cause of this observation was not pursued as a part of this work, but it is thought that process-related dust, which is minimal when beginning processing, may be a factor. This elevated voltage at the first run was not found to be statistically meaningful, so it is noted here only as a general observation.

Analysis of these boxplots suggests that the effect of process dwell time has no strong correlation with the peak ESD charge developed. Some test runs exhibited a weak increase in charge with respect to time, as in Figure 5, while others show the opposite, as in Figure 6. Some runs showed increased measurement variability with respect to blast time, as in Figure 4, while others showed decreased variability, as can be seen in Figure 6. Taken as a whole, these trends were not found to be significant.

ESD charge decay characteristics were evaluated using Teflon and polyurethane foam samples. The foam was selected because it was most representative of the potting typically used for encapsulation, in addition to being the highest positive charge-generating material. Teflon was selected because it was found to produce the most extreme levels of ESD and therefore was used throughout this experiment to bound the worst-case potentials.

Figures 10 and 11 represent the charge decay characteristics measured for these two material samples after 30 seconds of blast exposure. Figure 12 shows the charge decay characteristics of a test using only lean conditions, as defined earlier. As noted earlier, vertical axis scales are in negative kV when the charge developed was negative and in kV when the charge developed was positive

Note that the trend lines provided are a visual aid and is not intended to be representative of the actual charging rate.

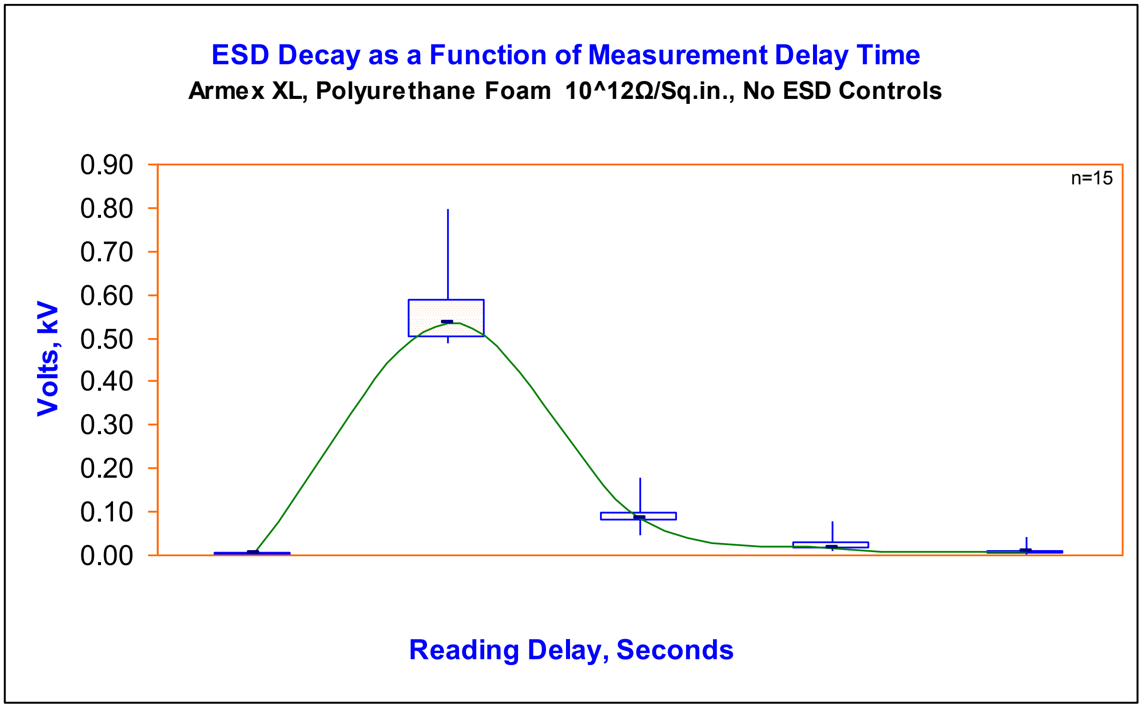

Figure 10. ESD Charge Decay, Polyurethane Foam Sample.

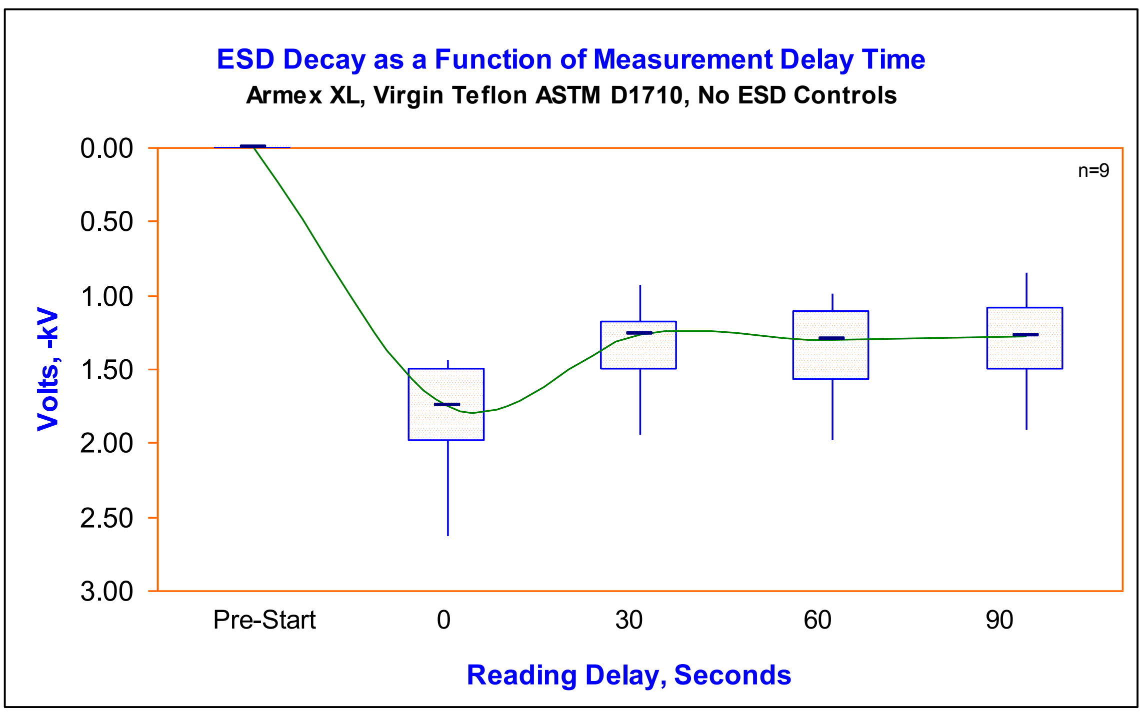

Figure 11. ESD Charge Decay, Teflon Sample.

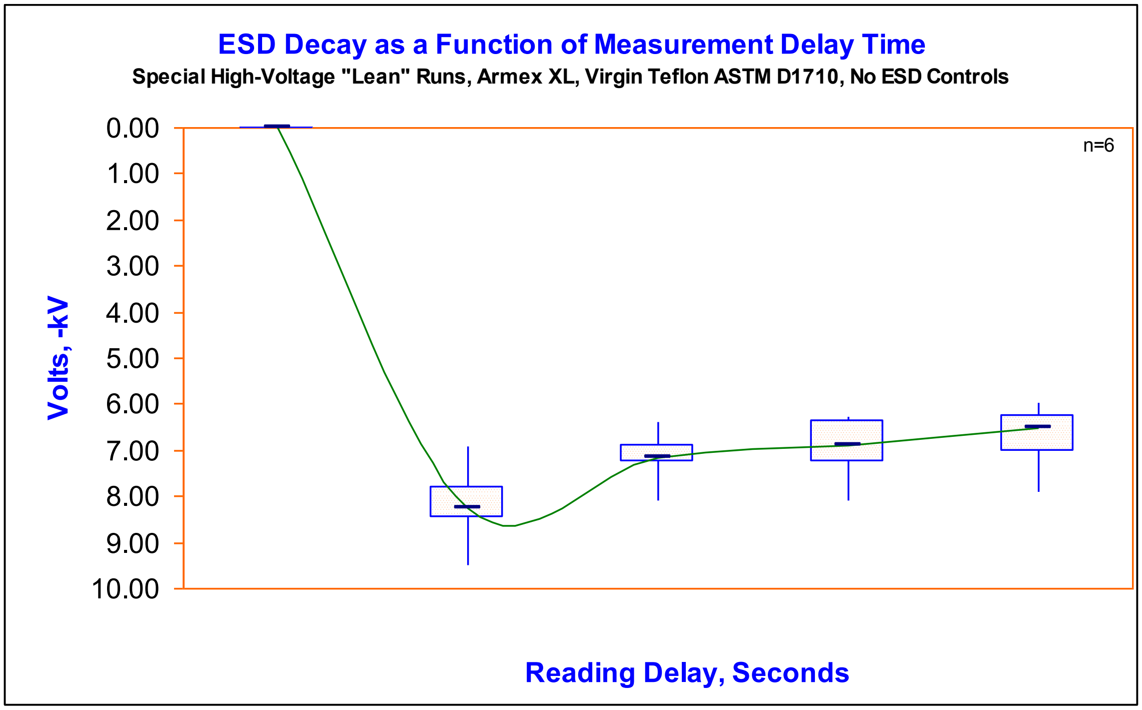

Figure 12. ESD Charge Decay, Special "Lean" Process, Teflon Sample.

As a whole, the data show that while the charge on the Polyurethane foam will decay fairly rapidly, the Teflon samples retain their charge. Since the Teflon samples retain their charge quite well, the fact that the dwell time does not provide an additive charge suggests that there are one or more mechanisms limiting the charge buildup. Literature surveys insinuate that process dust in the blast cabinet may serve as a charge transport, carrying off excess charge during the process. Previous surveys of micro-blast equipment made a point to provide a shield of clean air around the process area to avoid affecting the ESD measurements. This technique was not chosen for this experiment series for three reasons. The first reason being that prompt surface voltage measurements were made, with no intervening time between stopping the blast process and making the measurement. This aspect limited charge decay that would tend to minimize the voltage measurements to the time required for the surface voltage instrumentation to make the measurement. The second reason is that dust is a natural process byproduct of the blast operations. Eliminating this natural byproduct would result in non-representative process conditions. The final reason is that implementing an air shield without affecting the blast process was regarded as a difficult and unnecessary control.

The amount of charge developed using only non-ionized air, simulating post-processing blow-off of the hardware being de-potted, was also examined. Two sets of test runs evaluated both the blaster nozzle, simulating operations with the media feed valve shut off, as well as the blow-off air gun co-located in the blast cabinet. In both cases the charge was found to be on the order of -200 to -300 V (n=10).

Having established that relatively short blast dwell times were adequate for evaluation because increased dwell time did not have a significant effect, a 30 second blast exposure was selected for all subsequent experiments to minimize experiment time. The remaining work related to understanding which process variables significantly influence the development of peak charge on the selected test samples. The initial ESD mitigation methods implemented were to ground the blast cabinet and to introduce an ionized air stream into the blast media. This approach was thought likely to provide the most potential at moderating ESD buildup.

11. Experimental Blast Handpiece Design and Control

The intent of the blast handpiece design was to inject a supply of ionized air into the handpiece as late as possible prior to the media exiting the nozzle, in such a way as to provide a thoroughly mixed blend of the two supplies. A survey of literature suggested that the effective process distance for an ionized air stream is on the order of three to six inches. Thus the mixing was required to be performed as far downstream as practical: the ionized air immediately begins to recombine with opposite polarity ions.

It is worth noting that in characterizing the effectiveness of foam potting removal, the most effective working range of the blast nozzle was about ½ to two inches. Greater distances than roughly two to three inches results in poor effectiveness in foam removal, and closer distances makes monitoring the process difficult while carrying a risk of nozzle plugging.

Discussion with a fluid flow SME suggested that the most efficient nozzle design would likely involve introducing ionized air into the tip of the blast nozzle at a right angle to the media flow. Injecting the ionized air at an acute angle with respect to the media supply could be expected to result in stratification, and thus less thorough mixing between the charged media and the ionized air. Fabrication and modification of the prototype handpiece was performed by an SNL tool-and-die-maker in the site machine shop.

The final prototype was configured with a single ionizer needle installed into the blast nozzle in an air feed chamber separate from the media stream. A second air supply line was installed, passing air over the ionizer, which then was injected into the media stream. Thus the nozzle had three separate supply lines: the blast media stream, the supply air for the ionizer, and the high voltage supply cable for the ionizer (Figure 13).

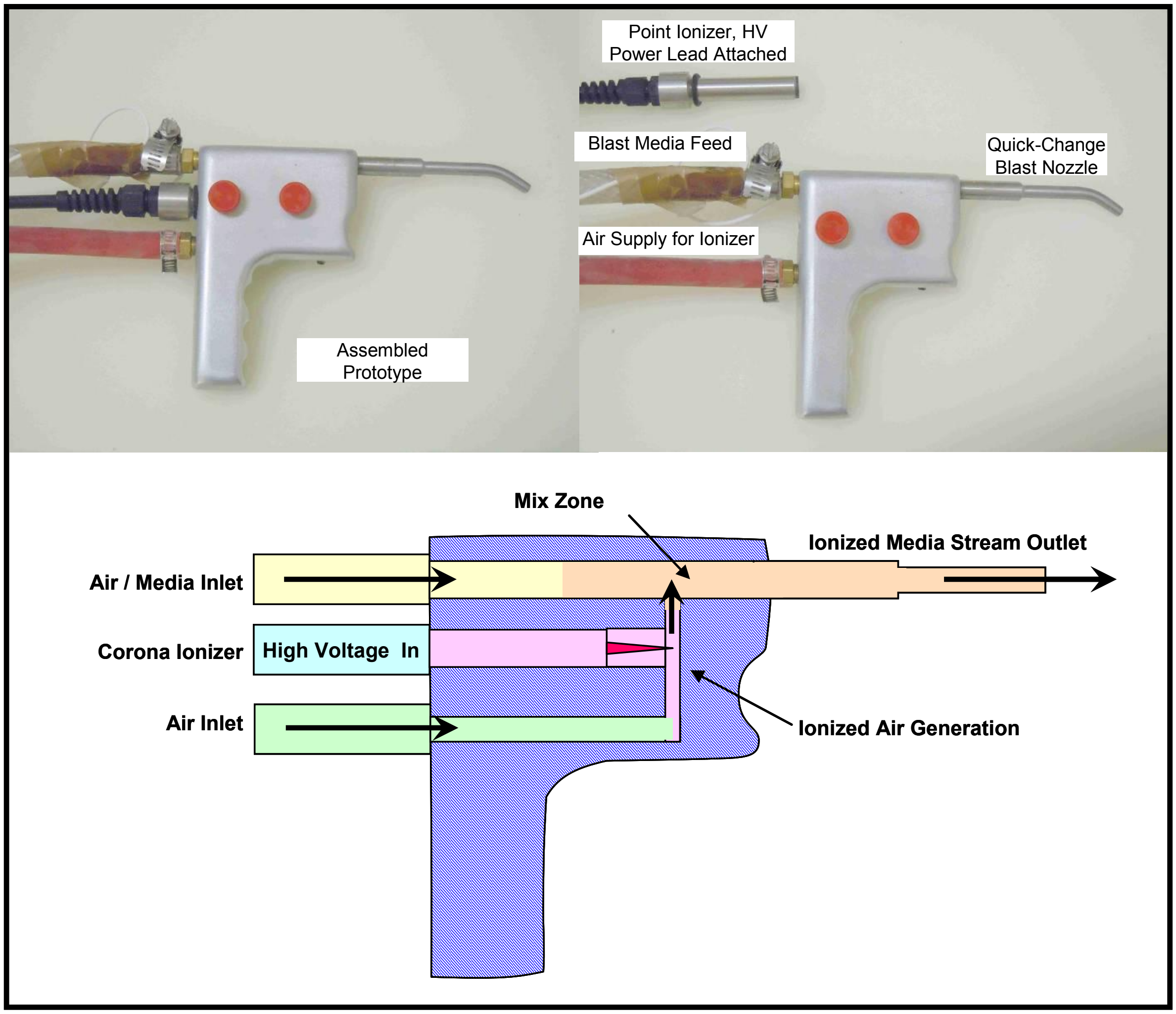

Figure 13. Ionized Air Injection Blast Nozzle.

The supply air for the ionizer was pressure-regulated separately from the media supply line. The ionized air supply was found to require a slightly higher pressure to provide for a continuous ionized air stream.

An initial evaluation of the prototype blast handpiece yielded very poor results. The combination of two separately-regulated air supplies with relatively long distances between the regulators and the nozzle chamber resulted in something akin to a tuned resonant pressure system. The ensuing pulsation in the media flow provided alternating blasts of too much media, regularly plugging the blast nozzle, followed by too-little media. Altering the settings on the two regulators to compensate yielded a method of adjusting the frequency of the pulsations, but the overall process was judged functionally non-useful.

The supply system was then modified to substitute flow control in place of the regulator for the ionized air, fed from the same regulator for the media controls. This control method worked far better than the previous method. A flow rate of 10,000 scc/min was used throughout this work. This rate was based on operator-optimized process efficiency combined with ESD mitigation observations.

12. Process Efficiency Comments

When the handpiece prototype was evaluated as a part of this experimental work it was identified that there was room for improvement in the supply controls. The configuration discussed here was adequate to provide good control over the de-potting process, but not as well as the previous media-only nozzle designs fabricated in-house that were discussed earlier in the ***Characterizing ESD Generation*** section. A visual examination of the media flow suggests that there was some stratification in the media flow, i.e., the media flow was visibly more dense on one side of the nozzle than on the other at the ejection point. As a follow-on activity to the body of this work a more ergonomic handpiece was developed that integrated replaceable ionized air metering orifices. Another improvement was a system of rapid fabrication of blast nozzles made from stainless steel tubing that proved to be very useful. At this writing, however, a third generation multi-position adjustable handpiece is under development that is intended to minimize the potential for repetitive stress injuries for operators that use the handpiece for long durations on a regular basis.

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13. ESD Mitigation Experiments

Once the blast nozzle design was judged to be suitable for use in de-potting process an assessment of the ESD generation characteristics was performed. Several sets of test runs were conducted using the new nozzle ungrounded with non-ionized air, grounded with non-ionized air, and grounded with ionized air.

The relative effect of these factors is well-illustrated in Figure 14. It is clear in this data set that grounding the blast nozzle is a very important factor, providing more charge attenuation than the ionization. This figure also illustrates the attenuation from ionization alone.

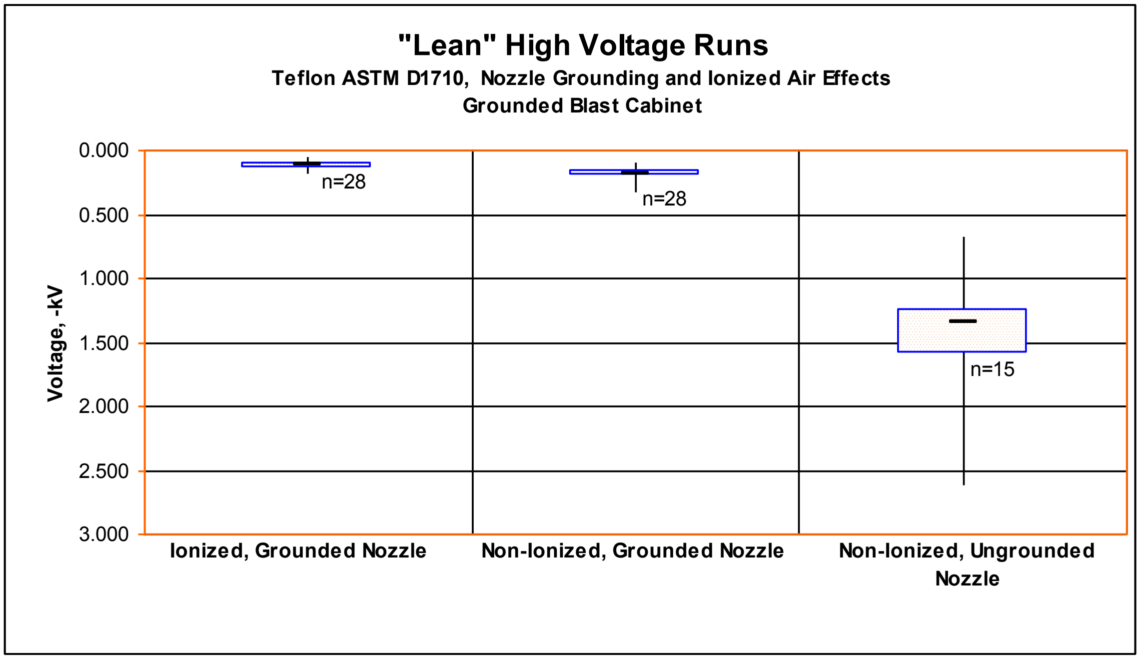

Figure 14. Relative Effects of Ionized Air Compared to Nozzle Grounding.

Finally, a set of three tests were performed to understand the effect of ESD charge and the working distance between the blast nozzle and the hardware being processed. It was expected that the charge developed would increase slightly as the nozzle was moved farther from the work surface because the ion levels in the media stream should recombine once beyond roughly six inches of the injection point. What was found, however, was that the charge dropped off steadily from normal working distances of ½ to 2 inches. At approximately 10" it was found that the media had no useful effect on the encapsulant being processed while the charge developed on a test sample dropped to roughly half of that developed at normal working distances. Comment on this observation is made later in this paper.

An analysis of the maximum achievable ESD charge on the selected worst-case material demonstrates that the combination of proper grounding techniques and ionized air limits ESD to less than 200 Volts.

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14. Process Evaluation

A number of electronic assemblies have been processed using the equipment described in this paper. These assemblies, when originally fabricated, were encapsulated in 4 to 6 pound per cubic foot polyurethane foam. Figure 15 illustrates typical before/after photos of a multi-PWA assembly that previously required destructive disassembly to allow surveillance testing of components. More than 25 of these assemblies were processed, allowing disassembly via removing the threaded fasteners used in original fabrication. De-potting of this component can be accomplished in approximately 20 minutes when the requirement is component recovery. Completely de-potting the component for use as a display unit, as shown in Figure 15, requires about 40 minutes, including separating the stacked PWAs in the component illustrated.

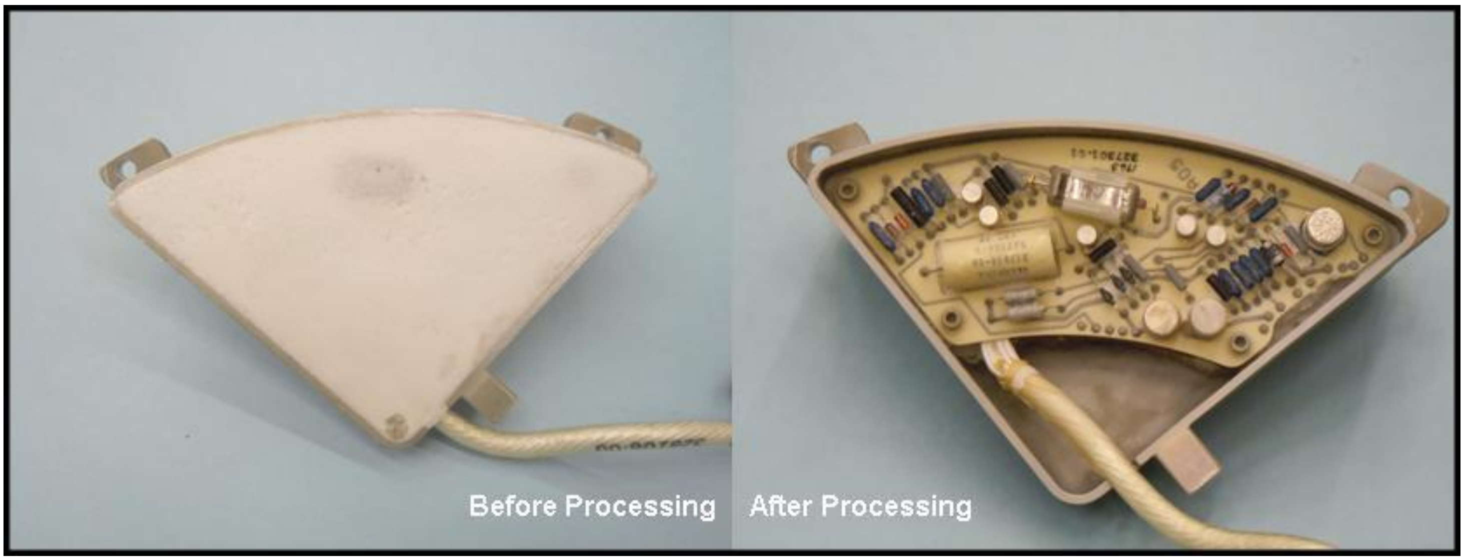

Figure 15. MC3268 De-Potting.

Figure 16 shows details of a typical post-process assembly. Component identification silk screens, inspection stamps, and subassembly identification markings are normally legible after processing.

Figure 16 illustrates an assembly that was processed as a part of a failure investigation. While this de-potting process is remarkably non-damaging physically to component assemblies, excessive dwell time can eventually erode component coatings. Difficult areas to process include narrow channels deeper than 3 to 4 inches, and between closely-spaced PWAs. Experiment results indicate that a skilled operator will be able to successfully de-pot assemblies that are not practical using more conventional de-potting methods, and these assemblies remain fully electrically functional. De-potting of this component can be accomplished in approximately one hour.

All components de-potted by this process to date have exhibited no electrical degradation or damage after bench testing, and evaluation via production testers was included for some products. It is important to recognize, however, that ESD-induced degradation is not necessarily observable. Thus it is vital to ensure that in-process ESD characterization is performed to assure that the peak charge developed is less than the damage threshold for the electronic components being processed.

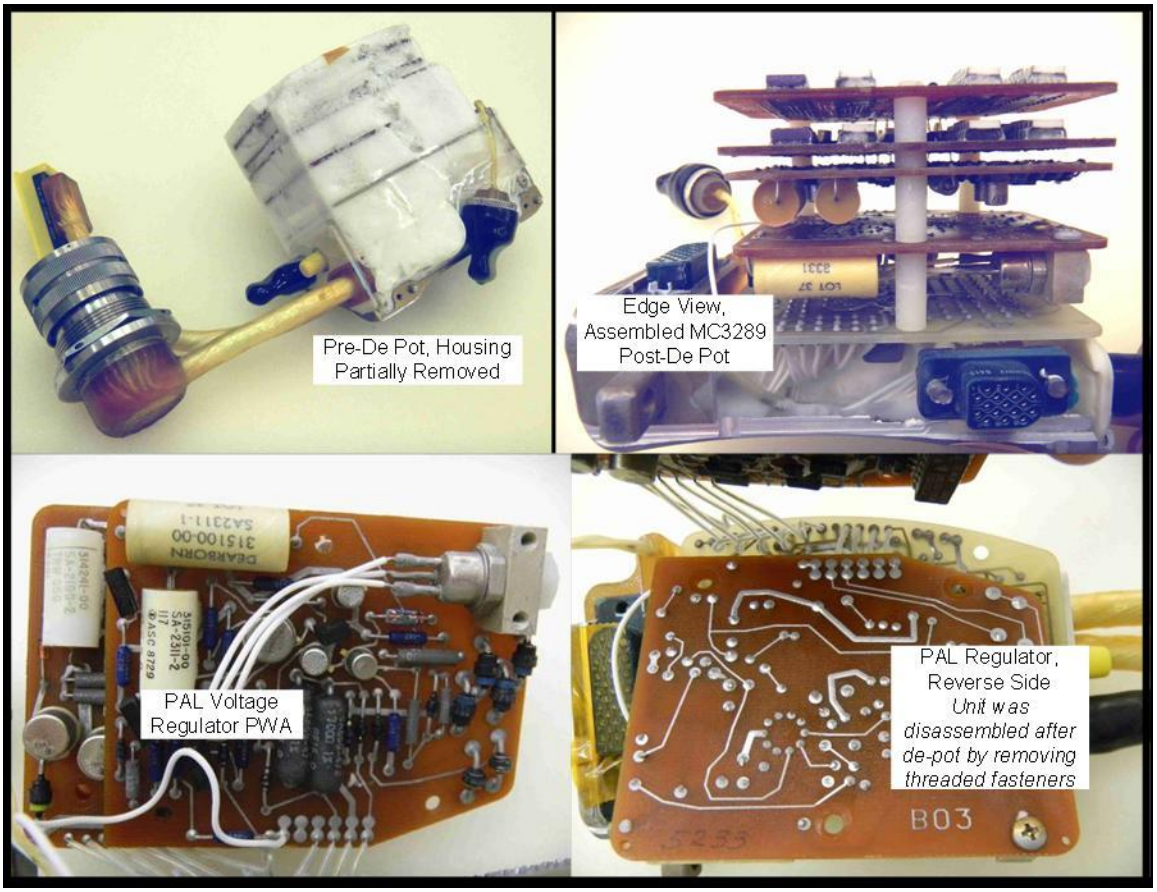

Figure 16. MC3289A De-Potting.

Approximately 30 firing sets, including high-voltage assemblies, have also been de-potted to date, allowing access to internal test points in these fully-functional assemblies and disassembly, yielding surveillance hardware. These results offer a practical means of investigating component failures and evaluating assemblies for aging effects using the original in-process test equipment.

More dense polyurethane foams have been evaluated and this process is less efficient on densities above 15 lbs. The removal rate subjectively appears to inversely proportional to the potting density, thus the dwell time required increases significantly for the denser materials. Attempts to improve the removal rate on dense foams by increasing blast pressure and/or feed rate can increase component coating damage. Extreme cases can result in cold-flow of Teflon wire insulation. The process is capable of potting removal in more dense foams, but the degree of patience required by the operator increases rapidly, while the benefits of the sodium bicarbonate media correspondingly diminish.

15. Post-Processing Residue Removal

A film of blast media residue will typically remain on the assembly. In cases where this residue requires removal a combination of ionized air blow-off followed by an IPA rinse has been found to be adequate for most applications. A follow-on study of materials issues related to any remaining blast media should be performed prior to processing critical assemblies, particularly if the component is being reprocessed or repaired and placed back in service.

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16. Process Control Factors

Establishing robust control of ESD requires careful consideration of equipment electrical grounding and ensuring a well-characterized media feed stream. A summary of items to consider include the following.

- Ground the cabinet and all separate internal cabinet parts to an electrically clean building ground
- Avoid the use of painted or coated process racks unless the coatings are determined to be static-dissipative
- Replace or cover screens with static-dissipative mesh or screens
- Do not ground the item being processed
- Ensure that the flow of ionized air is adequate to mitigate ESD buildup
- Ensure that the blast nozzle is well-grounded by running a drain wire directly clamped or screwed to the handpiece
- Have static-dissipative gloves installed in the glove box
- Use static-dissipative air and media tubing
- If a blow-off air line is used then ensure that this source is included in process evaluation, and ground the nozzle and/or use an in-line ionizer if needed
- Perform ESD audits on a regular basis to verify process compliance

If the components being processed are ESD-sensitive then characterization of the equipment and process is necessary.

- Fabricate test samples of representative materials and alter process variables to understand their contribution to ESD charge development
- Establish the bounds of credible charge generation by adjusting process variables to identify the worst-case conditions
- Implement written procedures and process controls to ensure key variables are controlled
- Ensure that required ESD controls are used, such as proper garments, wrist straps, local ionizers, static dissipative workbench outside the chamber, static-dissipative flooring, local air ionization, signage, etc.

It is recommended that the personnel that will be doing the work be involved in characterization experiments as well as the development of process controls and procedures.

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17. Process Control Evaluation Factors

Implement regular re-evaluation and testing to ensure that the process is controlled and operational.

- Verify surfaces inside the blast cabinet are static-dissipative by measuring the path to ground at regular time intervals
- As a part of normal procedures, test the system using a test sample and measure the charge developed before beginning a work shift
- If ionized air injection is used, implement procedures to verify flow and confirm that balanced ions are being produced
- When practical, make first-article charge measurements during the processing of new component assemblies to understand the actual ESD charge developed
- Re-characterize the system if media type, feed lines, equipment grounds, or materials being processed are changed.

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18. Environmental Safety and Health Considerations

While the residue from blast operations can normally be disposed as non-hazardous waste, planning ahead will reduce the likelihood of unexpected occurrences.

- Prior to beginning work, analyze the target component assemblies for materials properties and ensure that no hazardous residues will be generated
- Pre-coordinate disposal of residue and ensure that appropriate containers are available at the location where the work is being done
- In some cases it may be necessary to process a representative sample of hardware and have the residue tested to ensure that no hazardous materials are present, such as heavy metals

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19. Selected Sodium Bicarbonate Material Safety Data Sheet Information

Synonyms: Sodium hydrogen carbonate; sodium acid carbonate; baking soda; bicarbonate of soda

Molecular Weight: 84.01

Chemical Formula: NaHCO3

NFPA Ratings: Health: 1 Flammability: 0 Reactivity: 0

Label Hazard Warning:

As part of good industrial and personal hygiene and safety procedure, avoid all unnecessary exposure to the chemical substance and ensure prompt removal from skin, eyes and clothing

Label Precautions: None

Potential Health Effects

Inhalation: High concentrations of dust may cause coughing and sneezing

Ingestion: Extremely large oral doses may cause gastrointestinal disturbances

Skin Contact: No adverse effects expected

Eye Contact: Contact may cause mild irritation, redness, and pain

Chronic Exposure: No information found

Aggravation of Pre-existing Conditions: No information found

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20. Blast Nozzle Design Considerations

The purpose of the blast nozzle is to provide a means of directing the blast media stream at the hardware being processed. Some design considerations are summarized as follows.

- A variety of tips should be available to support the type of work being done
- In general, use the largest tip diameter that will allow adequate control of the media stream to minimize processing time. A smaller nozzle will enable more thorough encapsulant removal with the lowest probability of component damage, but requires more time
- Consider the tip angle. In many cases a slight bend in the nozzle tip will enable better access to tight areas between circuit boards and components
    - 20 to 30 degrees is a reasonable starting point
    - Excessive angles result in media degradation and resulting dust
- Do not use an internally-tapered tip or a smaller tip orifice than the nozzle body. This design is prone to tip plugging. A square upstream face can minimize this tendency where size reduction is necessary
- When complex assemblies are being processed, consider a quick-disconnect fitting to change nozzles. This improves the ability of the operator to quickly change from gross material removal to fine-detail work

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21. Ionized Air Injection Considerations

Ionized air injection has been demonstrated to be a useful ESD mitigation option. The following is a summary of design considerations.

- Inject the ionized air into the media stream as far downstream as possible to maximize the charge reduction benefits at the component being processed
- In general, injection should be at right angle to the media stream to ensure thorough mixing
- Utilize a flow control to establish a constant flow rather than relying on a simple pressure differential
- Multiple injection orifices may be required to ensure proper mixing. Different injection angles and positions may be required. Consider using replaceable metering orifices until the proper sizing and spacing is established
- A visual inspection of the media stream works well in determining adequacy of mixing. Adjust the injection orifice, orifice location, and injection flow variables until a uniform stream is obtained

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22. Electrostatic Discharge Class Recommendations and General Comments

Based on the worst-case materials data obtained in this experiment series, this blast process appears very well suited to ESD Class 1A electronic assemblies (Human Body Model), with Class 0 implemented only after a recommended assessment involving the target hardware is performed. This guidance is specific to the equipment used in this experiment series; evaluation of any other configuration would be required before a similar statement can be made.

It is worth noting that the Human Body Model is not necessarily the appropriate model to use in classifying abrasive blast equipment. The charge being developed during the de-potting process is cumulative in very small energy increments rather than transmitted in a sole capacitive discharge, but these classes are well-understood by the community and are thus used here.

As a general note on the specific media, test samples, and equipment used in these experiments, the data suggest that the ESD charge is, for the most part, generated by the media flowing through and making intermittent contact with the non-conductive media feed line rather than primarily by impingement on the surface being processed. This is evidenced by the much larger effect of simply grounding the conductive blast nozzle compared with injecting ionized air into the media stream at the blast nozzle. Using this model, the charge is deposited on the individual grains of media upstream of the blast nozzle, which then cumulatively builds on the hardware being processed up to the maximum voltage generated. If this is the case, it may be practical to incorporate static-dissipative feed lines as an additional means of reducing the charge developed upstream of the blast nozzle. The use of metallic lines would most likely degrade the media, resulting in reduced effectiveness and the generation of additional process dust as the particles erode.

Table 3. Experiment Series Summary.

Experiment Purpose	Number of Runs	Material Sample	Grounded Blast Nozzle	Grounded Glove Box	Ionized Air Injection	Special	Notes
Dwell time effects	16/18/14	MDS/Nylon					30s/60s/120s dwell times
Dwell time effects	15/15/14	Polyurethane Foam					30s/60s/120s dwell times
Dwell time effects	15/15/15	Buna N					30s/60s/120s dwell times
Dwell time effects	15/15/15	ABS					30s/60s/120s dwell times
Dwell time effects	15/15/15	Polystyrene					30s/60s/120s dwell times
Dwell time effects	9/13/15	Teflon					30s/60s/120s dwell times
ESD Charge Decay	15	Polyurethane Foam					0/30/60/90s measurements
ESD Charge Decay	9	Teflon					0/30/60/90s measurements
ESD Charge Decay, Special	6	Teflon				X	“Lean” run effects; peak charge developed
Ion Injection Effects	15	Teflon	X	X	X	X	
Ion Injection Effects	13	Teflon		X		X	
Multiple Effects	28	Teflon	X	X	X		“Lean” run with ionization
Multiple Effects	28	Teflon	X	X			“Lean” run without ionization
Multiple Effects	15	Teflon	X				
Blast Nozzle Distance	10	Teflon	X	X	X		2 – 3”
Blast Nozzle Distance	10	Teflon	X	X	X		8”
Blast Nozzle Distance	10	Teflon	X	X	X		10”
Cabinet Blow-Off Air Nozzle	10	Teflon	X	X		X	Air-only during test
Air-Only Nozzle	10	Teflon		X		X	Blow-off nozzle, ungrounded

Total Runs 443

23. Distribution

0344	K. Helean
0344	H. Murphy
0344	M. Rynders
0344	P. Smith
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0447	K. Eklund
0447	M. Hall
0447	P. Hoover
0447	M. Martinez
0492	R. Myers
0483	N. Dereu
0487	A. Hillhouse
0501	C. Brisson
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0634	D. Sherman
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