Jet Propulsion Laboratory
California Institute of Technology

Electrostatic Discharge Testing of Carbon Composite Solar Array Panels for NASA's Planned Europa Mission to Jupiter

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Presentation Agenda

- Introduction
  - Why do we care?
- Samples Tested
  - What was tested?
- Test Methods
  - How was the test performed?
- Results
  - What happened?
- Conclusion
  - What does it mean?

Introduction

Why do we care?

- NASA is currently planning a mission to investigate Jupiter's moon, Europa
- Mission hardware must survive harsh Jovian environment
  - Strong radiation environment
    - Energetic protons and electrons
  - Temperatures down to 50K
- Mission would involves a number of engineering challenges
  - Considering the use of solar arrays to provide the spacecraft power
  - Solar arrays would need to be large enough to provide power at 5.5 AU
  - Strong option involves carbon composite facesheets on an aluminum core
- Carbon Composites have dual natures
  - Conductors most of the time
  - Insulators under certain conditions
  - Which nature is dominant depends on the local environment
- Before selecting solar arrays as the baseline power system for a mission to Jupiter, the response of the carbon composites to energetic electrons while held at cryogenic temperatures needs to be determined

Note: Pre-Decisional Information -- For Planning and Discussion Purposes Only

Introduction

Theoretical Background

- Discharge is measured by the movement of image charge
  - As charge gathers in the non-conductor, image charge (opposite polarity) gathers in nearby conductors in proportion to the generated electric field
  - When a breakdown occurs, the collected image charge is reduced in proportion to size of the discharge
  - Image charge movement completes the current loop of the negative charge expelled from the material surface
  - Image charge movement can be measured as a voltage as the current passes through a resistor connected in series in the circuit loop

- Total discharge energy

$$E = \sum \frac{V^2}{R} \Delta t$$

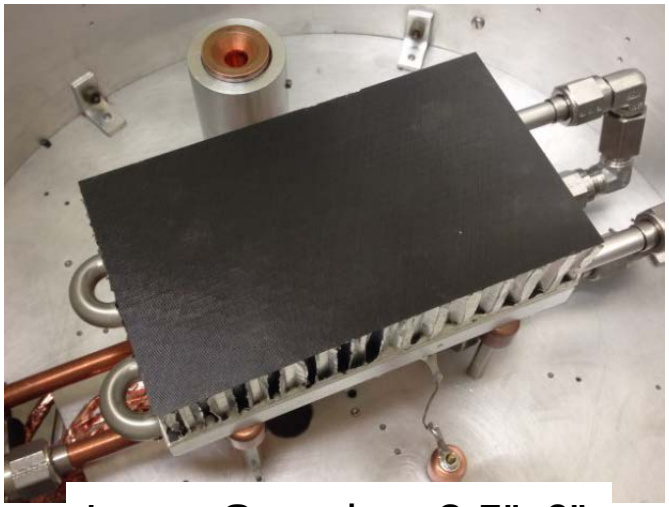
  - E is the energy dissipated in the measurement resistor, R; V is the voltage at each point measured on the oscilloscope; and Δt is the time increment between each scope measurement.

Samples Tested

What was tested?

- Sample panel structure obtained
  - M55J carbon weave facesheet with RS3 pre-preg
  - Aluminum honeycomb inner core
  - Similar to Juno heritage coupons
- Samples made in two sizes
  - Small 2”x2” samples
    - Initial room temperature testing
    - Measurement of stored charge
  - Large 3.5”x6” samples
    - Cryogenic temperature testing
- Sample surfaces for testing
  - M55J/RS3 facesheet abraded
    - Removed varying amounts of RS3 from surface
  - Three levels
    - ‘As Received’ – no abrasion
    - ‘Scotchbrite’ – moderate abrasion using red Scotchbrite pad
    - ‘Sanded’ – heavy abrasion using 220 grit sandpaper
  - Co-Cured Kapton surface
  - Test both before and after End of Mission radiation dose
    - 6.5×10^{15} electrons/cm^2 of 1 MeV electrons

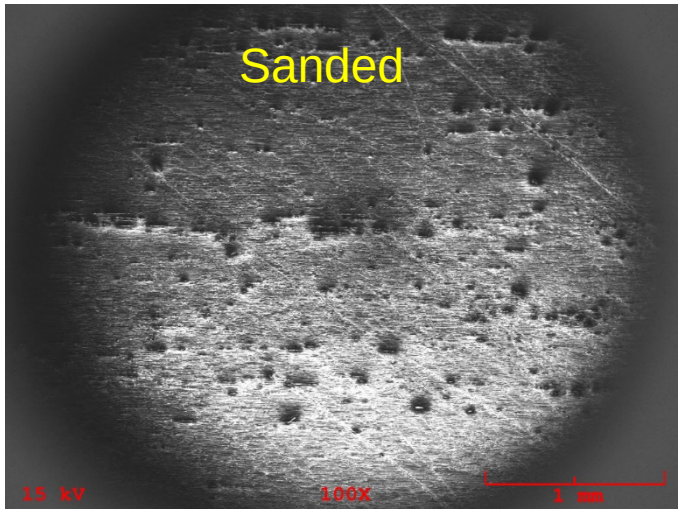
Small Sample – 2”x2”

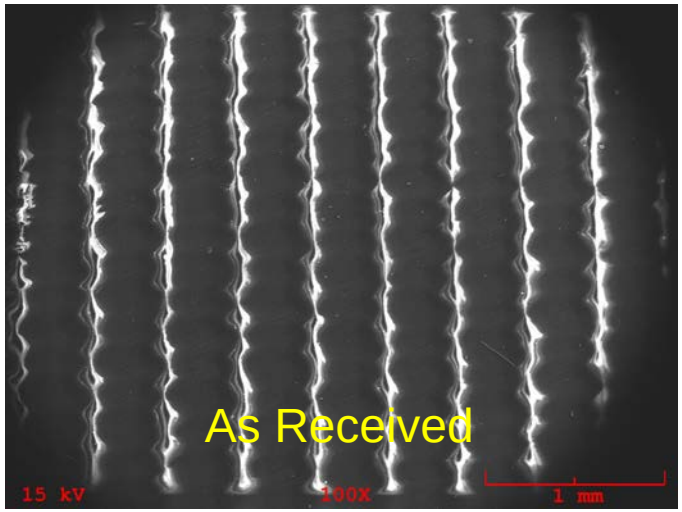


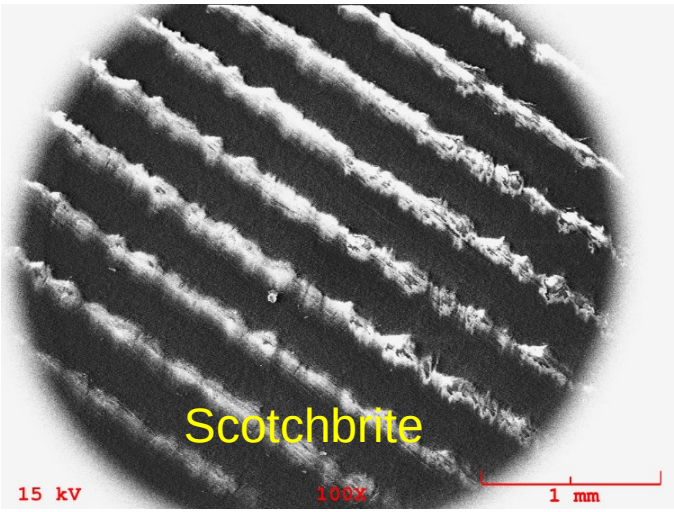
Large Sample – 3.5”x6”

Surface Preparation

- SEM images of M55J/RS3 samples
  - 100X magnification
  - White areas are charged non-conductor
  - As Received shows large rows of resin
    - Smeared in Scotchbrite sample
    - Smoothed to removed in Sanded sample



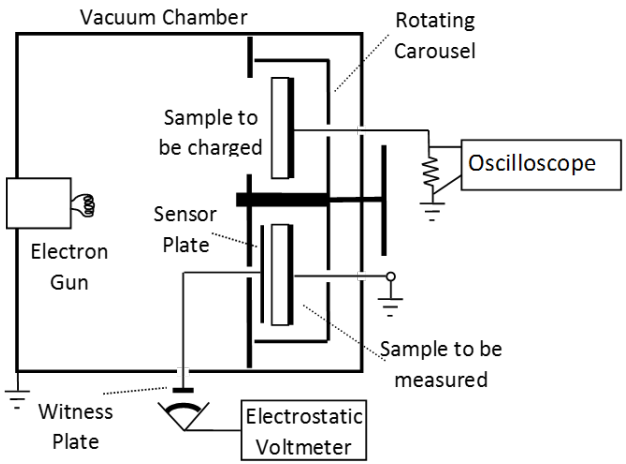


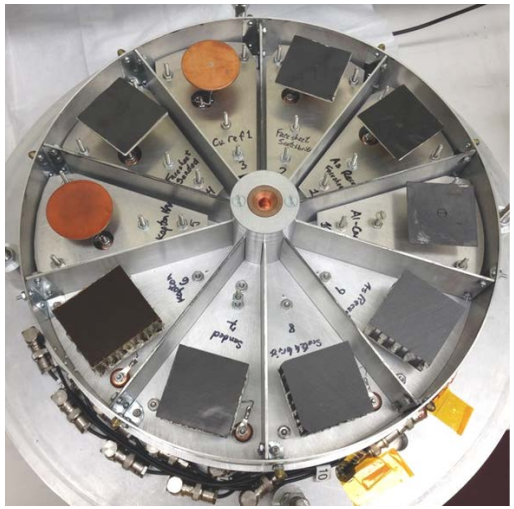


Test Methods

Small Samples – Initial testing

- Room Temperature
  - Due to the nature of the fixturing, only room temperature testing was possible
  - All tests performed at approximately 25ºC
- Multiple energies
  - 25, 50, 100 keV
- Surface Preparation effects
  - Removal of layers of RS3 pooling on the facesheet surface
  - Three samples tested
    - As Received (no surface modification)
    - Scotchbrite (moderate abrasion using Scotchbrite pad)
    - Sanded (heavy abrasion using 220 grit sandpaper)
- Charge Storage
  - All sample surface voltage measured post electron exposure
  - Measured voltage is average for the surface and may be larger at any particular point
- Effects of End of Mission Radiation dose

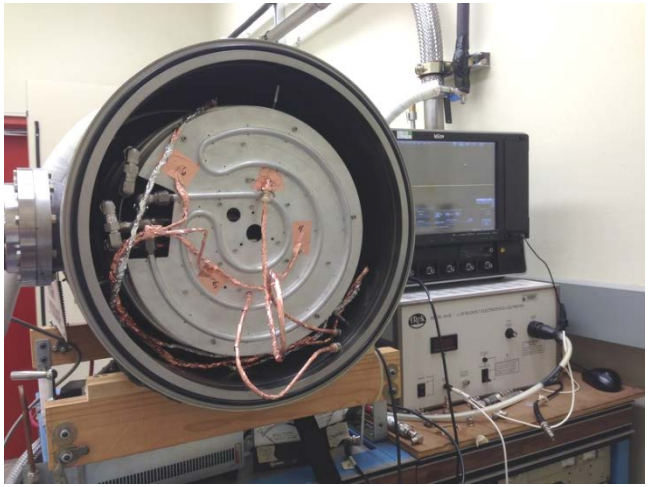


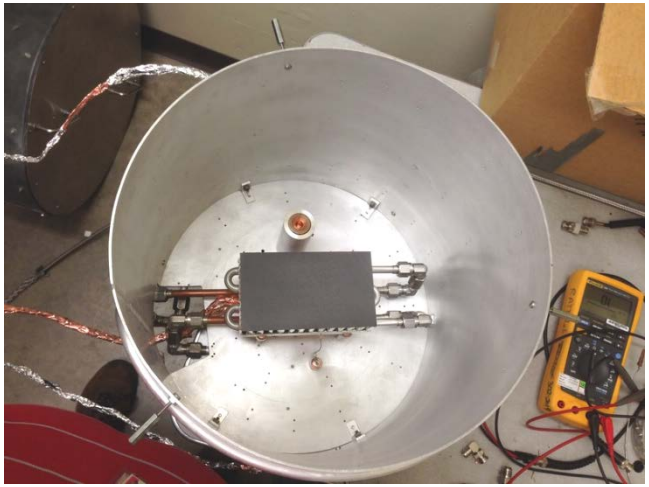


Test Methods

Large samples – Detail work with temperature

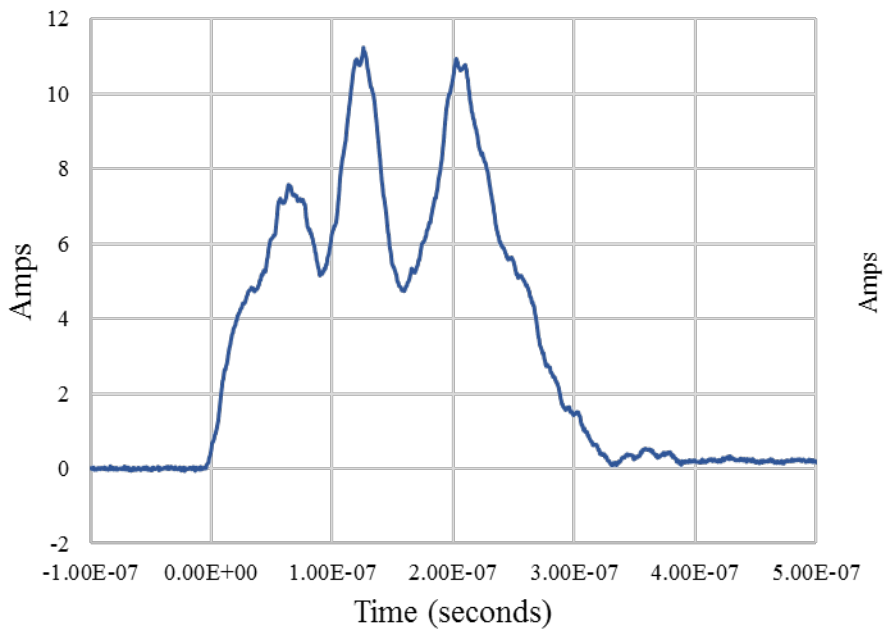
- Used small sample results to focus sample selection
  - Reduced sample runs based on small sample results
    - Majority of testing performed at 25 keV, 1 nA/cm^2
    - Added in some testing at 10 keV to see difference at lower energies
- Discharges as a function of temperature
  - Samples tested at 93K and 298K
    - -180ºC and 25ºC
- Discharges as a function of radiation dose
  - Samples given EOM dose of 6.5x10^{15} electrons/cm^2 of 1MeV electrons
  - Re-exposed to 25 keV electrons to evaluate differences in ESD production
- Longer exposures
  - Six hours per sample
  - Change in ESD production as a function of time



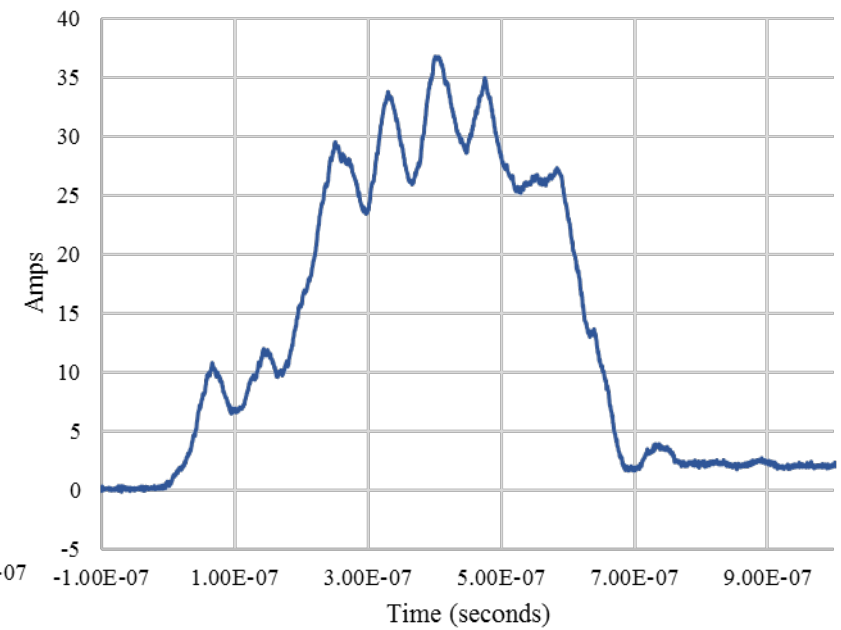


Results

What happened? – Discharges!



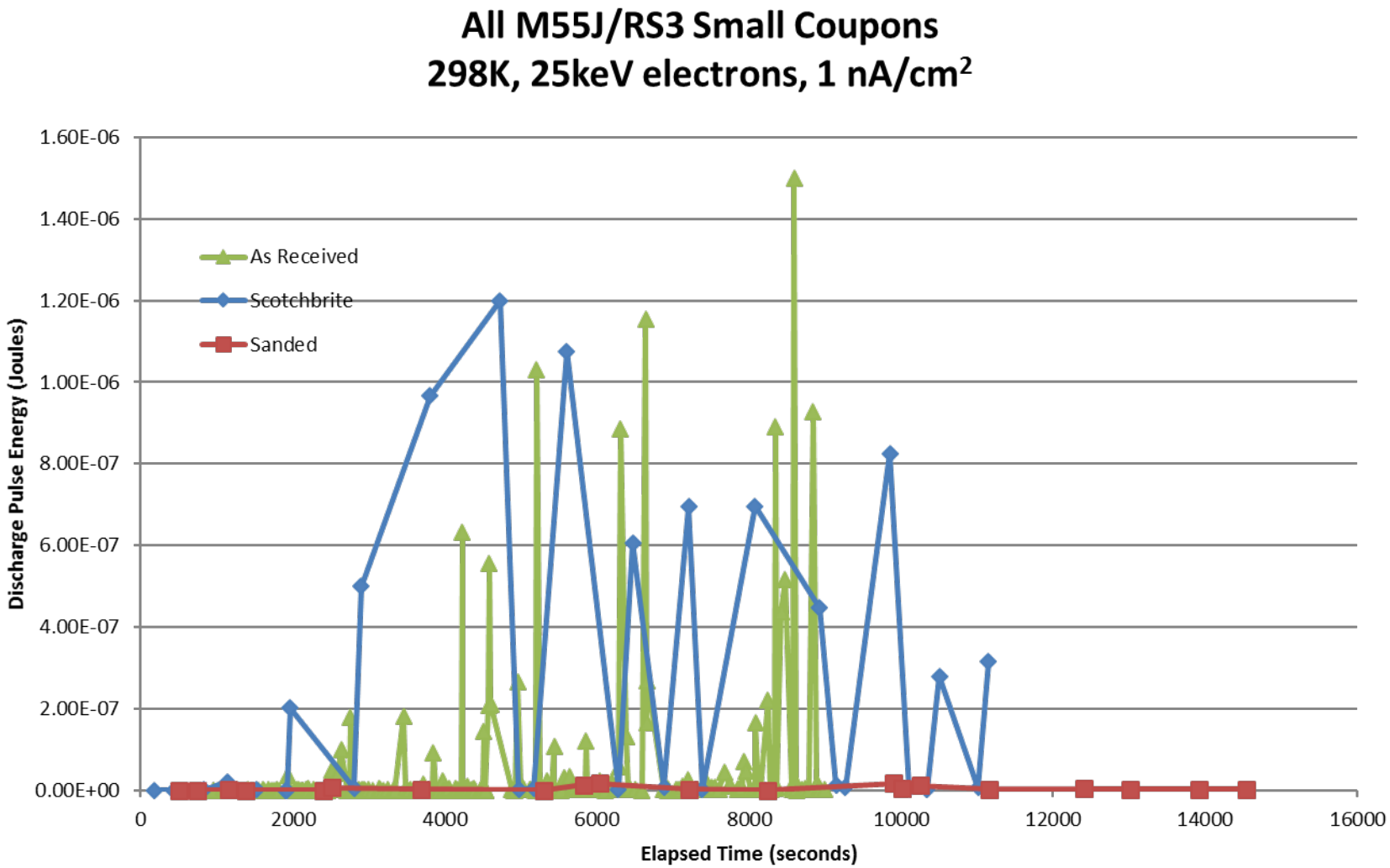
As Received large sample, 93K
11.2 amp peak, 680 μJ



Kapton large sample, 93K
36.7 amp peak, 17.9 mJ

- Oscilloscope image of two discharges from the Large Samples
  - Converted from measured voltage to current using Ohm's Law (I=V/R)

Results – Small Samples

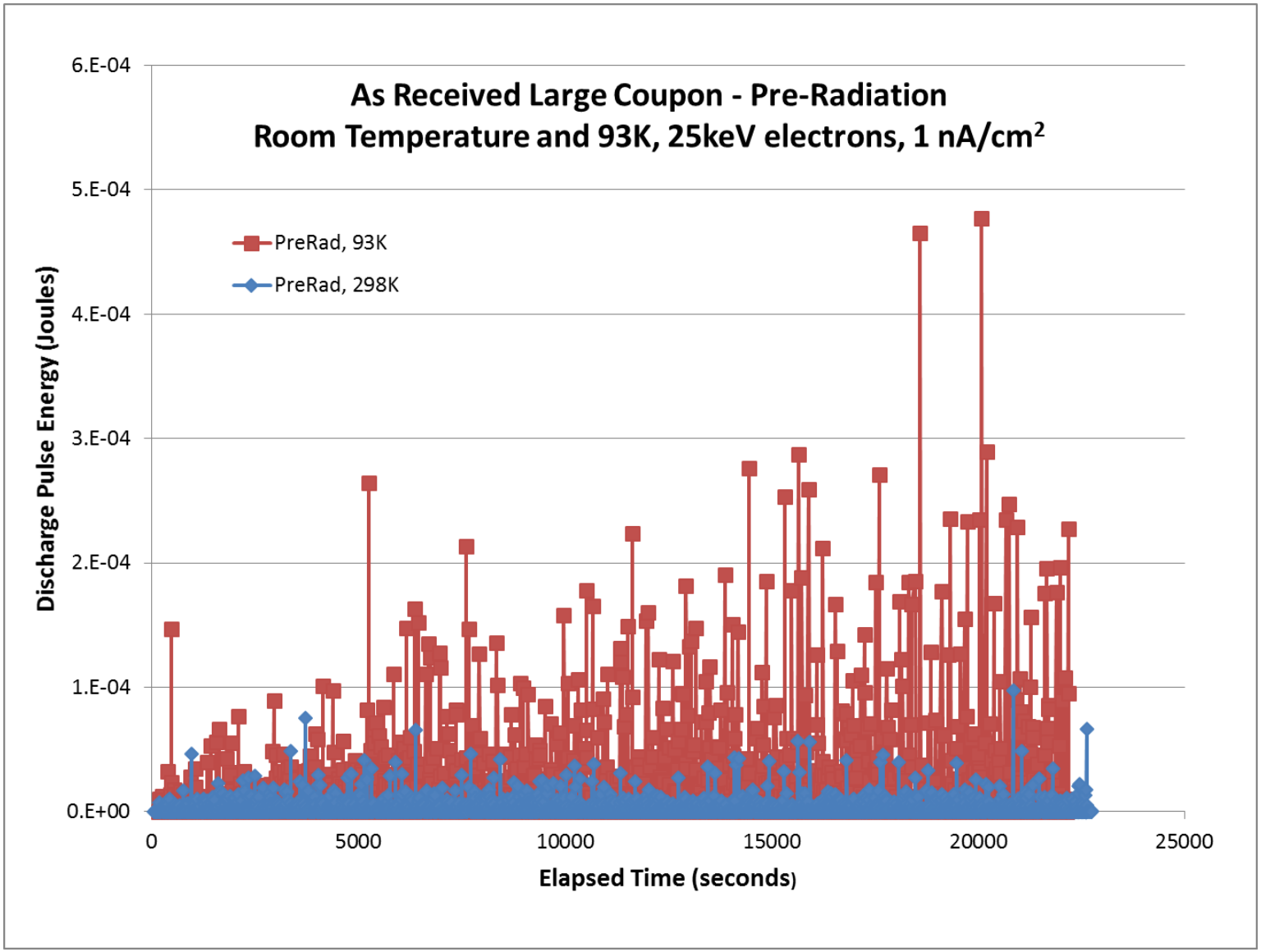


Small Samples – Numerical Results

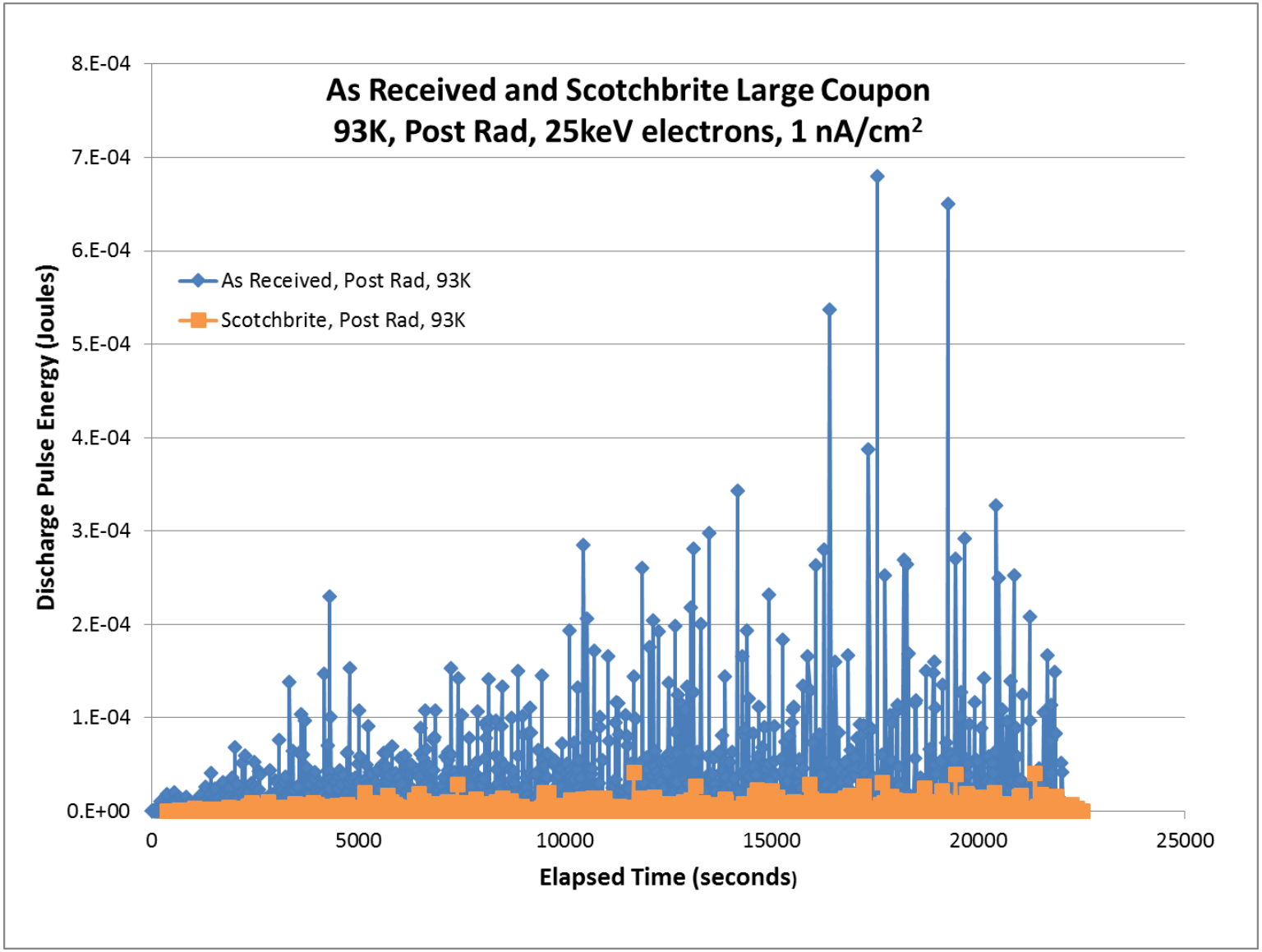
Sample Name	Elapsed Time	Number of ESD	Discharge Rate	Surface Potential	Current – Average	Current – Maximum	Energy – Average	Energy – Max
As Received	9000 seconds	258	28.7 mHz 1 per 35 s	-1334 volts	0.187 amps	1.502 amps	46.89 nJ	1.498 µJ
Scotchbrite	11460 seconds	31	2.7 mHz 1 per 369 s	-1051 volts	0.754 amps	2.611 amps	254.4 nJ	1.199 µJ
Sanded	14400 seconds	20	1.4 mHz 1 per 720 s	-20.7 volts	0.120 amps	0.298 amps	4.65 nJ	17.43 nJ
As Received Post-Rad	15990 seconds	286	17.9 mHz 1 per 56 s	-1730 volts	0.234 amps	2.227 amps	163.1 nJ	12.34 µJ
Scotchbrite Post-Rad	17400 seconds	85	4.9 mHz 1 per 205 s	-1162 volts	0.271 amps	2.210 amps	111.8 nJ	2.512 µJ
Sanded Post-Rad	18120 seconds	118	6.5 mHz 1 per 154 s	-19.4 volts	0.250 amps	1.376 amps	36.86 nJ	307.5 nJ

- Discharges seem to be directly related to quantity of RS3 on surface
  - No discharges for 50 keV and 100 keV electron energies
  - Largest reduction in discharge energy due abrasion of the surface
- Some increase seen with radiation dose
- Possible increase in discharge size with time
  - Inconsistent time for this data sets clouds this conclusion
- Energy as dissipated across a 50 ohm measurement resistor

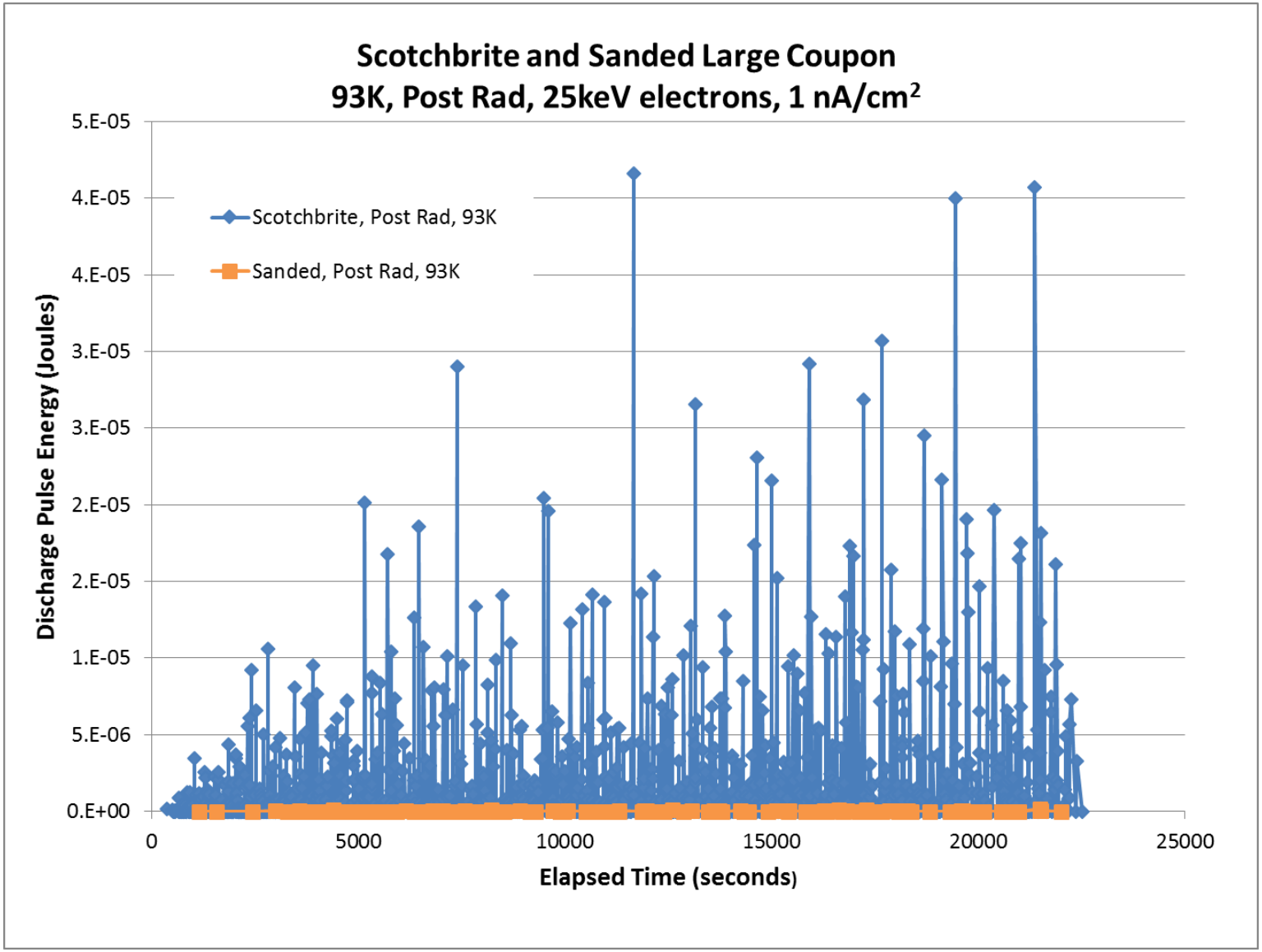
Large Sample – As Received with temperature



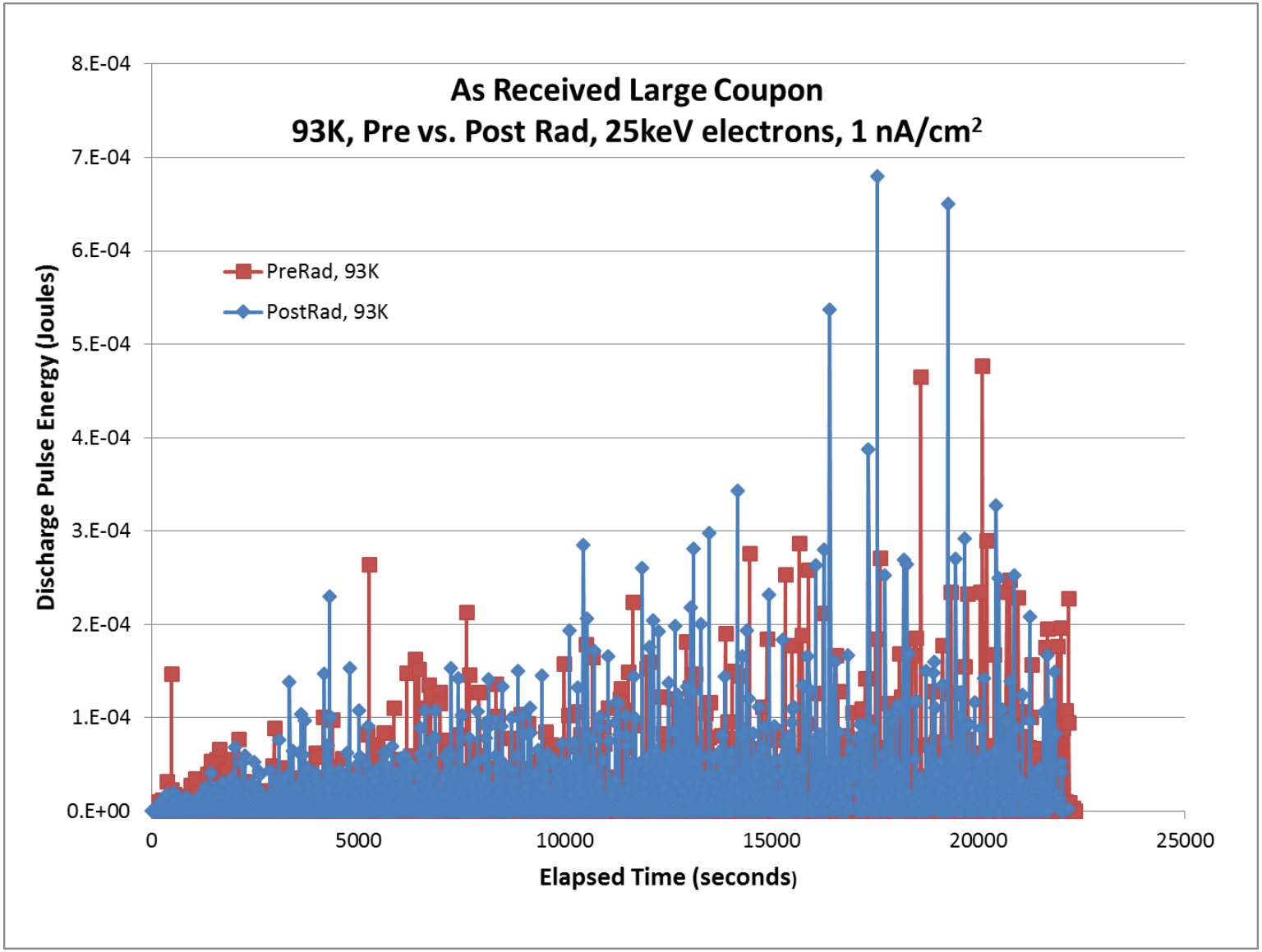
Large Sample – As Received vs. Scotchbrite



Large Sample – Scotchbrite vs. Sanded



Large Sample – As Received with radiation



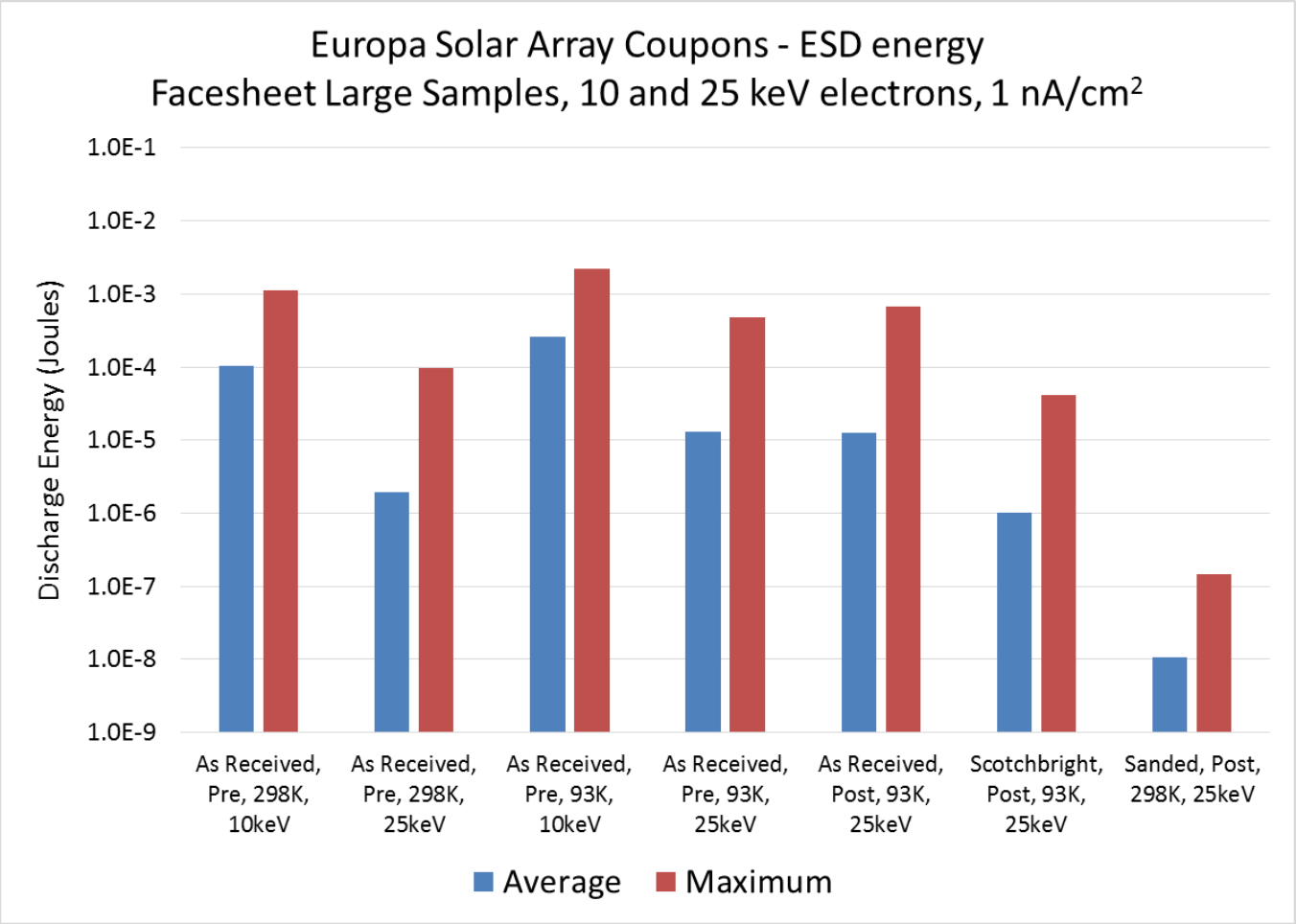
Large Samples – Discharge Energy

Sample Name	Temp.	Elec. Energy	Current – Average	Current – Maximum	Energy – Average	Energy – Max
As Received	298K	10 keV	3.969 amps	13.83 amps	103.8 µJ	1.116 mJ
As Received	93K	10 keV	5.257 amps	22.53 amps	258.2 µJ	2.210 mJ
As Received	298K	25 keV	0.709 amps	5.529 amps	1.944 µJ	97.17 µJ
As Received	93K	25 keV	1.518 amps	9.765 amps	12.85 µJ	477.3 µJ
As Received Post-Rad	93K	25 keV	1.423 amps	11.23 amps	12.61 µJ	679.8 µJ
Scotchbrite Post-Rad	93K	25 keV	0.488 amps	4.506 amps	1.020 µJ	41.60 µJ
Sanded Post-Rad	93K	25 keV	0.121 amps	0.391 amps	10.68 nJ	145.3 nJ
Co-Cured Kapton	298K	25 keV	12.52 amps	27.78 amps	1.886 mJ	8.506 mJ
Co-Cured Kapton	93K	25 keV	21.95 amps	61.13 amps	7.023 mJ	20.89 mJ
Co-Cured Kapton Post-Rad	298K	25 keV	8.164 amps	20.10 amps	567.7 µJ	2.245 mJ
Co-Cured Kapton Post-Rad	93K	25 keV	17.48 amps	56.95 amps	5.320 mJ	17.95 mJ

Large Samples – Rate of discharges

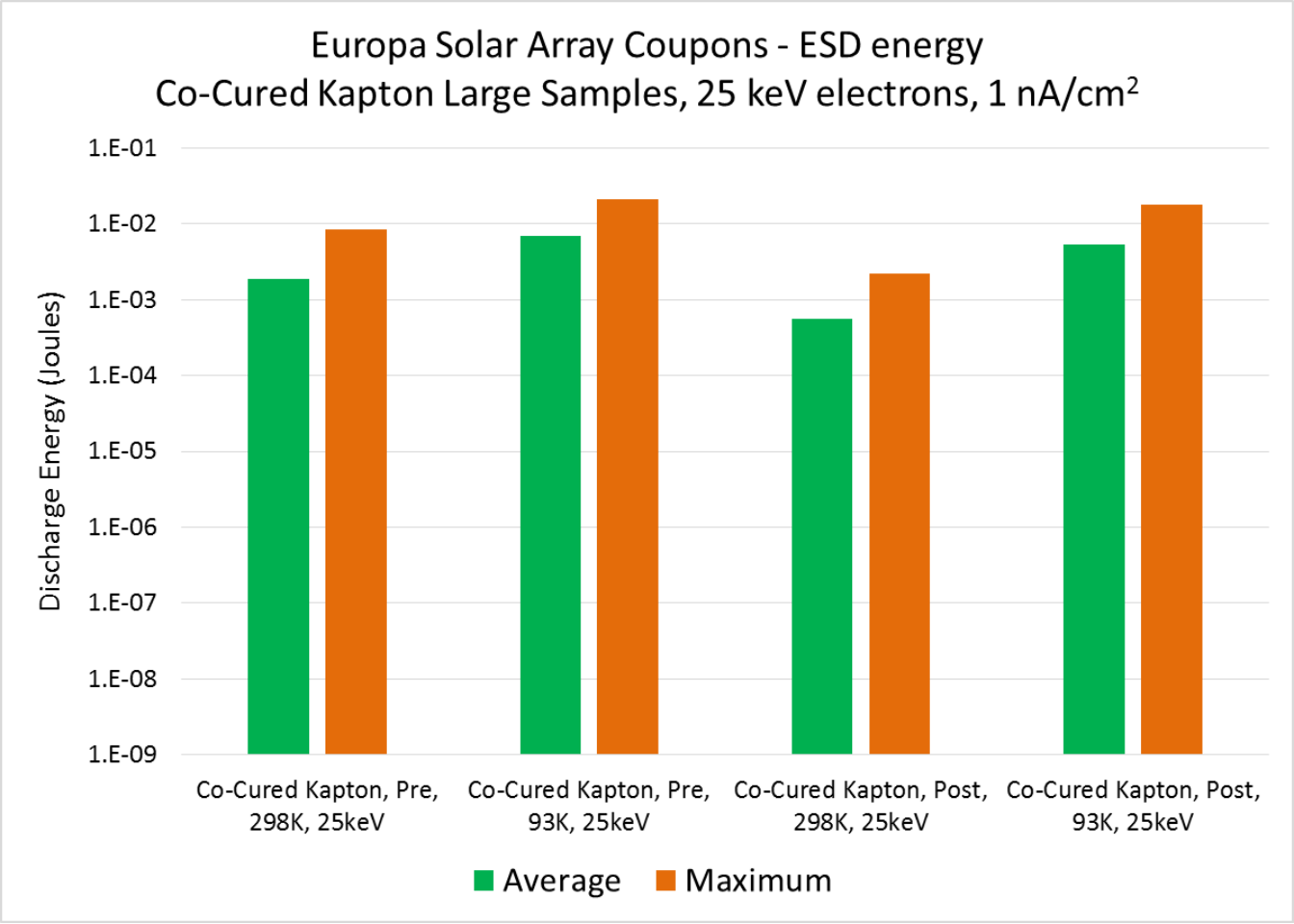
Sample Name	Temp.	Elec. Energy	Elapsed Time	Number of ESD	Discharge Rate >1 nJ	Discharge Rate >1 µJ
As Received	298K	10 keV	22297 seconds	266	12 mHz 1 per 84 s	9.9 mHz 1 per 101 s
As Received	93K	10 keV	22024 seconds	139	6.3 mHz 1 per 158 s	5.3 mHz 1 per 186 s
As Received	298K	25 keV	22761 seconds	4202	185 mHz 1 per 5.4 s	51 mHz 1 per 19 s
As Received	93K	25 keV	22340 seconds	2995	134 mHz 1 per 7.5 s	65 mHz 1 per 15 s
As Received Post-Rad	93K	25 keV	22180 seconds	3406	153 mHz 1 per 6.5 s	64.6 mHz 1 per 15 s
Scotchbrite Post-Rad	93K	25 keV	22522 seconds	2690	119 mHz 1 per 8.4 s	21.2 mHz 1 per 47 s
Sanded Post-Rad	93K	25 keV	22003 seconds	123	4.5 mHz 1 per 222 s	none
Co-Cured Kapton	298K	25 keV	22721 seconds	152	6.7 mHz 1 per 149 s	5.8 mHz 1 per 173 s
Co-Cured Kapton	93K	25 keV	22830 seconds	156	6.8 mHz 1 per 146 s	6.0 mHz 1 per 168 s
Co-Cured Kapton Post-Rad	298K	25 keV	22476 seconds	111	4.9 mHz 1 per 202 s	4.5 mHz 1 per 222 s
Co-Cured Kapton Post-Rad	93K	25 keV	22333 seconds	184	8.2 mHz 1 per 121 s	6.5 mHz 1 per 153 s

Large Samples –M55J/RES3



Large Sample test results for M55J/RS3 coupons showing energy dissipated in a 50 ohm resistor

Large Samples – Co-Cured Kapton



Large Sample test results for Co-Cured Kapton coupons showing energy dissipated in a 50 ohm resistor

Conclusion

What does it mean?

- It is clear that energetic electrons can indeed produce electrostatic discharges on solar array structures.
- The size and frequency of the discharges is heavily influenced by a number of parameters.
  - The discharges seem to result from electrons that come to rest in non-conductive RS3 pre-preg that pools on the surface of the M55J carbon weave.
    - Higher energy electrons passed through surface dielectric layer
    - Lower energy electrons produced discharges
  - The abrasion of the surface to reduce the quantity of RS3 on the surface gave a substantial reduction in the size and frequency of the discharges
  - The temperature of the material was another contributing factor. A reduction from 298K to 93K produced a 5 fold increase in the size of the discharges produced.
  - End of mission radiation showed some increase in ESD production on the small samples, but had negligible effect on the larger samples.
- The strongest result from these tests on how to reduce the risk to the solar arrays from electrostatic discharges is to reduce the quantity of non-conductor on the surfaces of the structural facesheets

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