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A Review of ESD Rates Observed in Orbit

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Purpose of Briefing-Address Question: How Many Arcs Are Enough to Qualify a Solar Array?

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ISO 11221 Qual Process [1]

- Establish discharge threshold (6.1)
- **Predict total number of discharges/mission (6.6)**
  - Charging analyses with parametric environment (n, T)
  - Climatology (LANL data set) to establish frequency of charging for parametric environments
- Power degradation test (8.1)
- Secondary arc test (8.2)

- Process applied to WIND [2]
- **Total: 2990 trigger arcs/yr**
  - 2434 in sunlight (for sustained arcing test)
- Artifacts in LANL data set [3],[4]
  - Some n,T combinations non-physical
  - Artifact of algorithm used to correct properties for charging of host spacecraft
- **arcs/yr dropped to 105-762**
  - When arcs predicted using suspect data sets removed (lower bound)
  - Authors [4] did not repeat full analysis of [2], so arc rate uncertain

REVIEW IN-ORBIT DATA TO CLARIFY THE RATE OF ARCS PER YEAR EXPECTED FROM ANALYSIS

In-Orbit ESD Counts from Transient Pulse Monitor on GEO Spinner

- Magnetically Quiet Day [5]
  - Ap index = 5
  - Current sensor showed only normal diurnal variation of photocurrent (due to sun angle variation around orbit)
  - **217 arcs** detected in 24hrs = **9/hr rate**, most around 16:00-22:00 LT
  - Plot of arcs vs spin angle shows clustering in narrow range of angles
    - Small area discharging
    - Not azimuthal symmetry expected from cylindrical solar panels
  - Ignore background rate for estimates of array discharges
- Magnetically Disturbed Day [5]
  - Ap = 19 (Moderate Substorm)
  - Current sensor showed 3.5hr injection around local midnight
  - Large ESD count around midnight
    - Rate peaked at 6arcs/min
  - **335arcs/3.5hrs = 96/hr**, 10x quiet day rate
  - Pre-storm rate from 18:00-23:00 similar to quiet day
  - Post storm rate about 2x quiet day
  - Plot of arcs vs spin angle showed nearly azimuthal symmetry, consistent with arcs from array
- 1 storm produce ~50% of yearly discharges predicted from reduced LANL data set
- *How many storms/year?*

NOAA Climatology & TPM Arc Count Rates Leads to Very High Yearly ESD Rates

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- NOAA Space Weather Scales define # of geomagnetic storms /11 yr cycle by Kp index [6]
  - Kp = 9 (Ap = 400): 4/cycle
  - Kp = 8 (Ap = 204): 100/cycle
  - Kp = 7 (Ap = 132): 200/cycle
  - Kp = 6 (Ap = 80): 600/cycle
  - Kp = 5 (Ap = 48): 1700/cycle
  - Kp to Ap conversion per [7]
- Shaw et al found trend in arc rate vs Ap index [5]:
  - Rate = (11+34*Ap/50) arcs/hr
  - Ignore quiet day rate of 11/hr
  - Active day rate = 34*Ap/50
- Assume charging limited to midnight-to-dawn quadrant

- Spacecraft has 1 in 4 probability of exposure to substorm plasma injection
- Counts/event based on 3 hours storm duration
- Derived arcs/year below

Kp	Ap	Counts /hr	events /cycle	Arcs /cycle	Ave. Arcs /yr
0	0	0	Assumed all discharges for Kp<5 are from background asymmetric discharging & not array discharges		
1	4	0			
2	7	0			
3	15	0			
4	27	0			
5	48	33	1700	41,616	3,783
6	80	54	600	24,480	2,225
7	132	90	200	13,464	1,224
8	204	139	100	10,404	946
9	400	272	4	816	74
					8,253

SCATHA Detected the Fewest Discharges

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- SCATHA was a spin stabilized s/c flown in near-GEO orbit
- Carried multiple instruments to monitor charging and discharges
- Koons et al. [8], [9], [10] reported 316 discharge pulses over 1527 days = 0.21/day = 76/year
  - 8389 total transients / 1527 days = 2005/year (close to WIND estimate)
  - >96% of transients rejected as discharges, deemed other responses-majority were command responses
  - 1 second data cadence, lot of command activity—lot of missed ESD?
- Majority in midnight to dawn quadrant as expected
- Most pulses occurred in bursts on a few days
- On high arc rate days, discharges were synchronized to spacecraft 60 second spin period
  - single source?

CTS TEC Captured 3000 Transients in 91 days

- CTS was 3-axis stabilized spacecraft with 2 large blanket solar array wings [11], [12]
- Transient event counter added late in program
- 3 sensor wires laced to harness bundles
  - A3 went to array power (unshielded, routed along edges of array)
  - A2 to array signal lines (unshielded, routed down middle of array)
  - A1 tied to attitude sensor harness bundle
- Almost 3000 arcs in 91 days
  - A1 (ACS) 942 arcs
  - A2 (array signal lines) 1411 arcs
  - A3 (array power) 640 arcs
- A2 array signal sensor ave. 5660/yr, A3 array power ave. 2567/yr
  - Occurred at all local times
  - Filtered low-impedance power lines less likely to reach ESD detection threshold
- Total = 8227/yr on array (12,005 if A1 ACS harness counts included)

Conclusion: In-Orbit Rates Do Not Give Clear Guidance on Test Durations

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- WIND estimates have ~ 1 order of magnitude spread
  - 2990/year array discharges
  - 105-762/year reduced LANL dataset
- Measured rates have 2 orders of magnitude spread
  - TPM: ~8300/year
  - CTS: ~8200/year
  - SCATHA: 76/year
- Space climatology cannot account for differences in rates
  - TPM data taken at peak in solar cycle number of disturbed days/year ($Ap \geq 25$)
  - CTS data taken near solar cycle minimum disturbed days/year
  - SCATHA data taken from near min to max and back down to near min
- Differences due to instrument / sensor sensitivity?
- Due to different S/C designs?
  - Models able to capture differences?

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