https://wpo-altertechnology.com/es/total-ionizing-dose-tid-testing-update-escc22900/

Extending A Probabilistic Method for Total Ionizing Dose Failure to Multi-Component Systems

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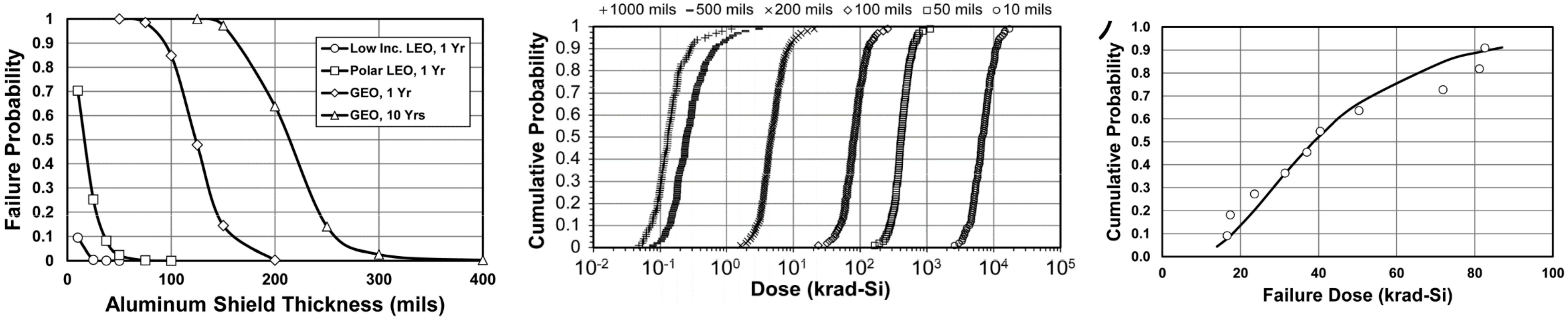
Background – Total Dose Hardness Assurance

- TID = total ionizing dose
  - Accumulation of radiation dosage over time
  - Results in electronics shifting out of spec and/or failing
- Radiation environment in space normally characterized as worst-case constant
  - Necessary for critical missions, such as those involving human life
  - Could lead to unnecessary/expensive overdesign for smaller, less critical missions (i.e., CubeSat missions)
- Incorporating variability of the space radiation environment can help prevent overdesign

Background – *Inclusion of Radiation Environment Variability in Total Dose Hardness Assurance Methodology*

- Xapsos, et. al. examined failure probabilities for 1 bipolar transistor (SFT2907A)
- Goal: expand method to 2, 5, and 10 devices for 1-year GEO

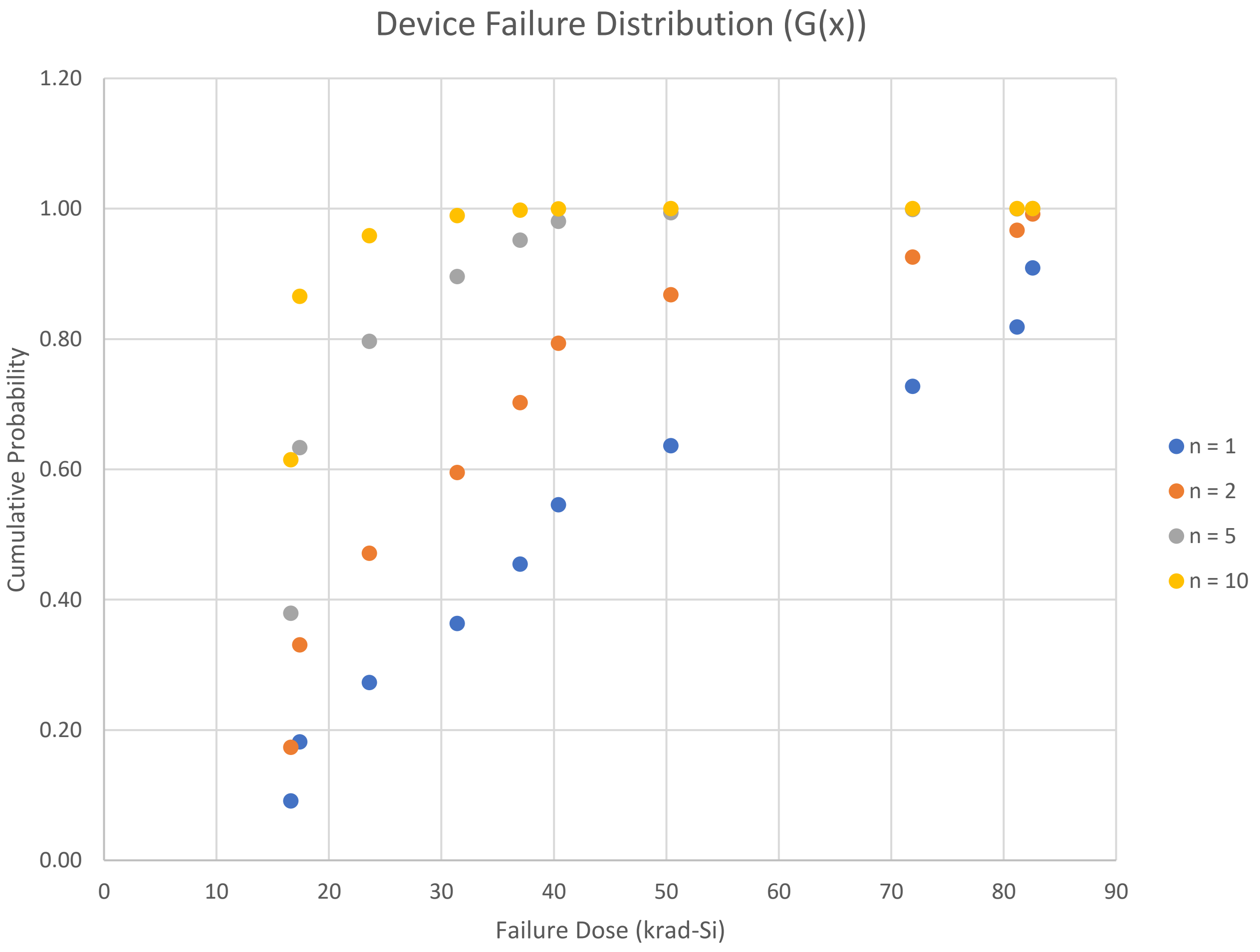


Graphs from [1]. Left: Total probability of system failure at various orbits. Middle: Radiation environment distributions as functions of dose and shielding thickness. Right: Failure distribution for BJT as a function of total dose

[2],[3]

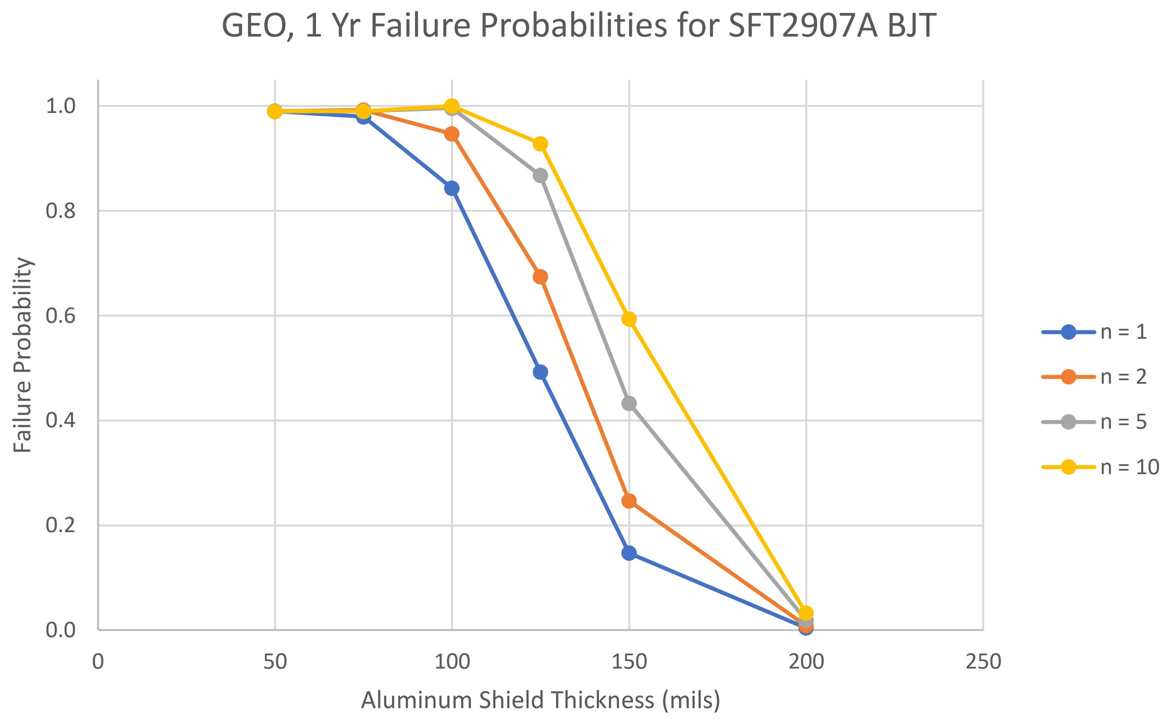
Methods

- Extreme Value Theory – characterizes distribution tails, traditionally underestimated
- In our study, care about **first** device to fail (minimum extreme)
- Order Statistics – framework for EVT with small sample sizes



Results from Applying Methods to BJT Data

- Blue = graph from Xapsos, et. al. (first slide), other colors represent expansion of method (this work)
- Our graphs follow logical trend – more devices in series = higher failure probabilities at lower doses
- Differences exaggerated at shield thicknesses between 100 mils and 150 mils, others result in similar probabilities



$$P_{fail} = \int [1 - H(x)] \cdot g(x)\, dx$$

g(x) = $f_{(1)}(x) = nf(x)(1 - F(x))^{n-1}$

Future Work: Likelihood Approach to Bound Distributions

- Maximum likelihood – most likely parameters of the distribution in question
    - As you go outward from max, confidence level that parameters are within the given range increase
- Need to be careful with small samples – if distribution not well-behaved (i.e., thick-tailed), this approach may not work well

90% WC

μln \ σln	0.11	0.22	0.33	0.44	0.55	0.66	0.77	0.88	0.99	1.1
3.44	0.000	0.000	0.008	0.029	0.037	0.033	0.026	0.019	0.014	0.010
3.54	0.000	0.002	0.043	0.075	0.068	0.050	0.035	0.024	0.017	0.012
3.64	0.000	0.033	0.162	0.158	0.109	0.070	0.045	0.029	0.020	0.014
3.74	0.000	0.278	0.420	0.271	0.1[illegible]4	0.089	0.053	0.034	0.022	0.015
3.84	0.015	1.035	0.753	0.376	0.190	0.103	0.059	0.036	0.023	0.016
3.94	0.102	1.685	0.935	0.425	0.206	0.109	0.062	0.038	0.024	0.016
4.04	0.026	1.201	0.804	0.390	0.195	0.105	0.060	0.037	0.024	0.016
4.14	0.000	0.374	0.479	0.292	0.162	0.092	0.055	0.034	0.022	0.015
4.24	0.000	0.051	0.198	0.177	0.118	0.074	0.047	0.030	0.020	0.014
4.34	0.000	0.003	0.057	0.088	0.075	0.054	0.037	0.025	0.018	0.012
4.44	0.000	0.000	0.011	0.035	0.042	0.036	0.027	0.020	0.015	0.011

Max. Lik. | 90% CL | 95% CL | 99% CL

Fig. 4. Likelihood contours for lognormal fits to the JANTXV2N2222 failure levels in the inset if Fig. 3. The worst case (WC) for the 90% CL is the set of parameters (lognormal mean μln and standard deviation σln) that yields the highest failure level (indicated by the arrow).

Picture from [5].

Summary

- Typical characterization of space radiation environment as worst-case constant can result in unnecessary overdesign – incorporating probabilistic nature can help prevent this
- Work from Xapsos, et. al. developed method for 1 BJT – we showed this could be expanded to multiple BJTs in series with EVT and Order Statistics to develop reasonable probability curves for predicting system failure in 1-year GEO
- Future work is needed to characterize the error of these distributions since small sample sizes are used

References

1. M.A. Xapsos, et. al., “Inclusion of Radiation Environment Variability in Total Dose Hardness Assurance Methodology,” *IEEE Trans. Nuclear Sci.*, vol. 64, no. 1, pp. 325-331, Jan. 2017, doi: 10.1109/TNS.2016.2607021.
2. R. R. Kinnison, “Extremes of Small Samples” in *Applied Extreme Value Statistics*. Richland, WA, USA: Pacific Northwest Laboratory, 1983, ch. 10, sec. 1-2, pp. 151-156.
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4. R. Ladbury and T. Carstens, “Development of TID Hardness Assurance Methodologies to Capitalize on Statistical Radiation Environment Models,” *IEEE Trans. Nuclear Sci.*, to be published, doi: 10.1109/TNS.2021.3055694.