NEW APPROACH TO TOTAL DOSE SPECIFICATION FOR SPACECRAFT ELECTRONICS

Michael Xapsos

NASA Goddard Space Flight Center, Greenbelt, MD

Supported by the NASA Living With a Star Space Environment Testbed Program

To be presented by Mike Xapsos at the 2017 Applied Space Environment Conference (ASEC), Huntsville, Alabama, May 15-19, 2017

Acronyms

- AE9 – Aerospace electron model-9
- AP9 – Aerospace proton model-9
- CDF – cumulative distribution function
- COTS - commercial off the shelf
- DDD – displacement damage dose
- ESP – Emission of Solar Protons (model)
- FP – failure probability
- GEO – geostationary Earth orbit
- HST – Hubble Space Telescope
- JUNO – JUpiter Near-polar Orbiter
- LEO – low Earth orbit
- MMS – Magnetospheric MultiScale
- NOVICE – Numerical Optimizations, Visualizations and Integrations on Computer Aided Design (CAD)/Constructive Solid Geometry (CSG) Edifices
- PDF – probability density function
- RDM – radiation design margin
- TID – total ionizing dose

Outline

- Background
- Device Failure Distributions in Total Dose
- Total Dose Distributions in Space
- Device Failure Probability during a Mission
- Conclusions
  - Failure Probability (P_{fail}) vs. Radiation Design Margin (RDM)

Space Environment Model Use in Spacecraft Life Cycle

Mission Concept

Mission Planning

Design

Launch

Operations

Anomaly Resolution

Space Climate
Minimize Risk

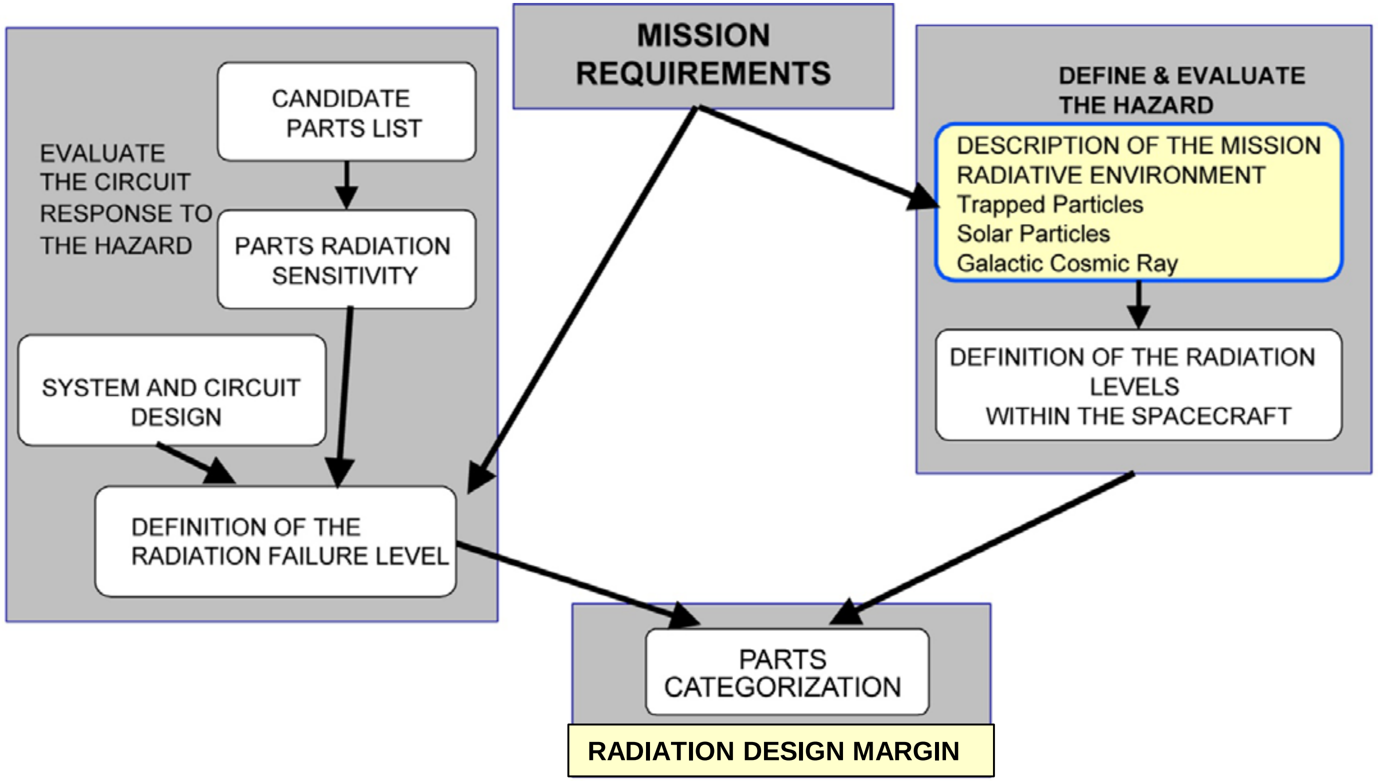
Space Weather
Manage Residual Risk

Both

To be presented by Mike Xapsos at the 2017 Applied Space Environment Conference (ASEC), Huntsville, Alabama, May 15-19, 2017

Radiation Hardness Assurance Overview

- **Starting with mission requirements, methodology consists of 2 branches of analyses that lead to parts categorization**
  - **Parts analysis**
  - **Environment analysis**



Radiation Hardness Assurance Overview

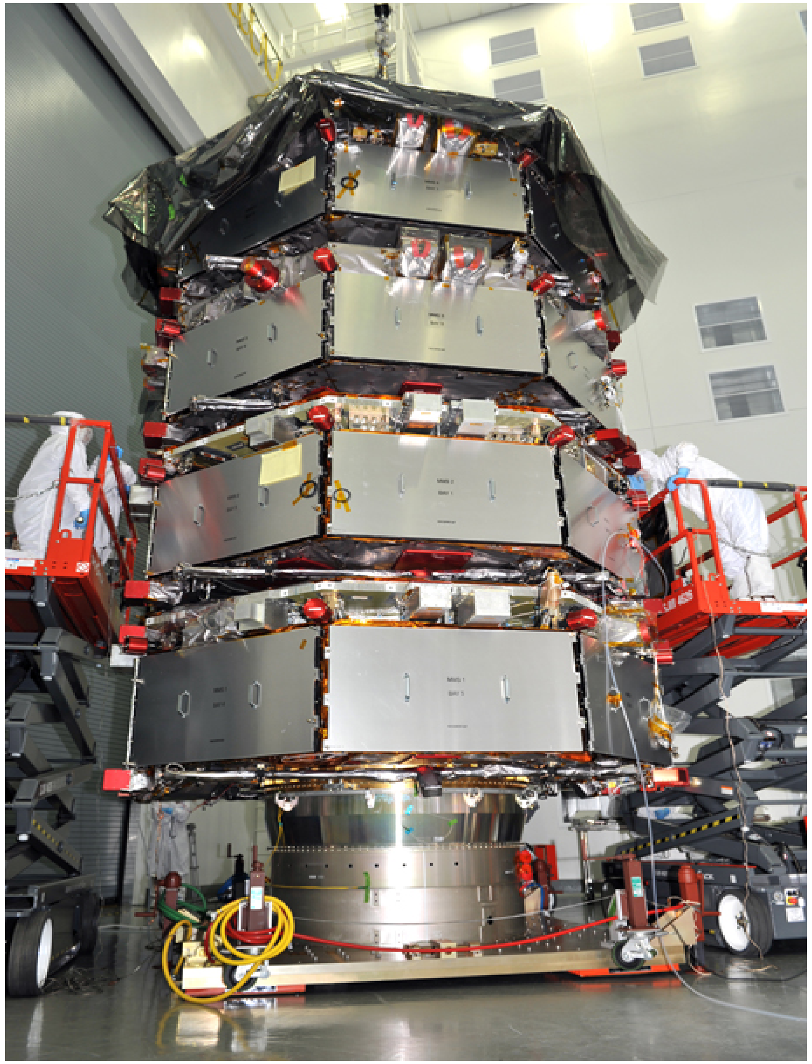
- **Parts are categorized for flight acceptability and possible radiation lot acceptance testing by Radiation Design Margin (RDM).**
- **RDM = R_{mf} / R_{spec}**
- **R_{mf} is mean failure level of part**
  - **Part failure levels can vary substantially from the mean, especially COTS**
- **R_{spec} is total dose level of space environment**
  - **Environment is dynamic and must be predicted years in advance**
  - **Some environment models are deterministic; some are probabilistic**
  - **Results in inconsistent and arbitrary approach**
- **RDM used as a "catch-all" to cover all uncertainties in environment and device variations**
- **Propose modified approach**
  - **Use device failure probability during a mission instead of RDM**

Devices Tested

- **Solid State Devices, Inc. SFT2907A bipolar transistors**
  - Used for high speed, low power applications
  - 10 devices TID tested for MMS project at NASA/GSFC gamma ray facility to 100 krad(Si)

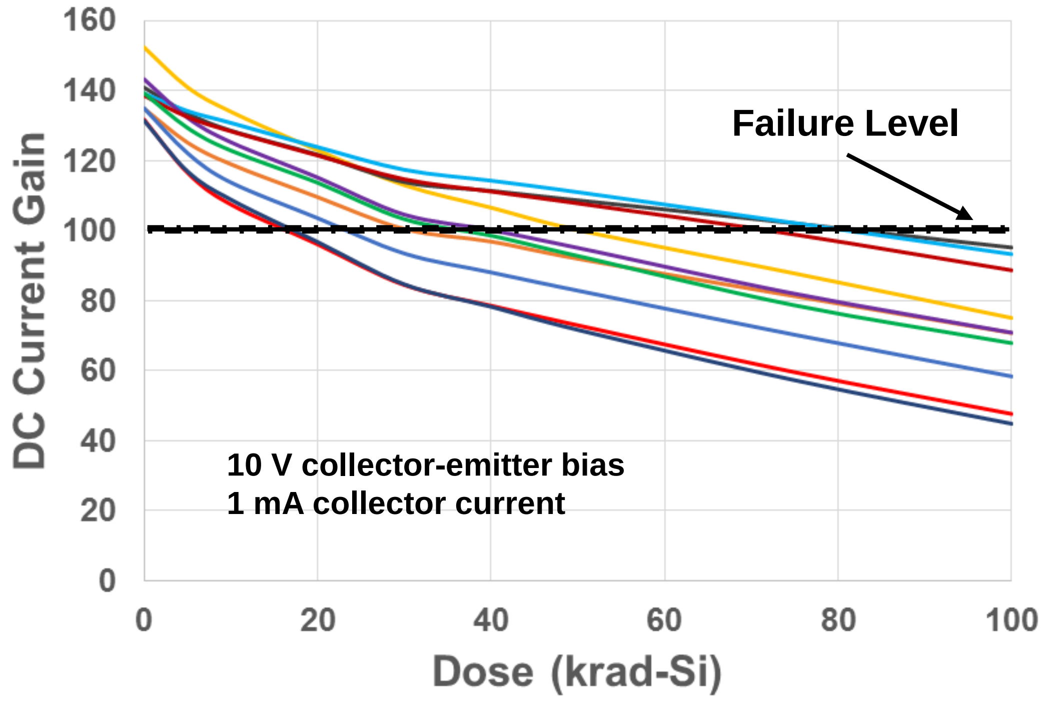
- **Amptek, Inc. HV801 optocouplers**
  - GaAlAs parts manufactured in liquid phase epitaxially grown process
  - 6 devices DDD tested for JUNO project at UC Davis Cyclotron with 50 MeV protons

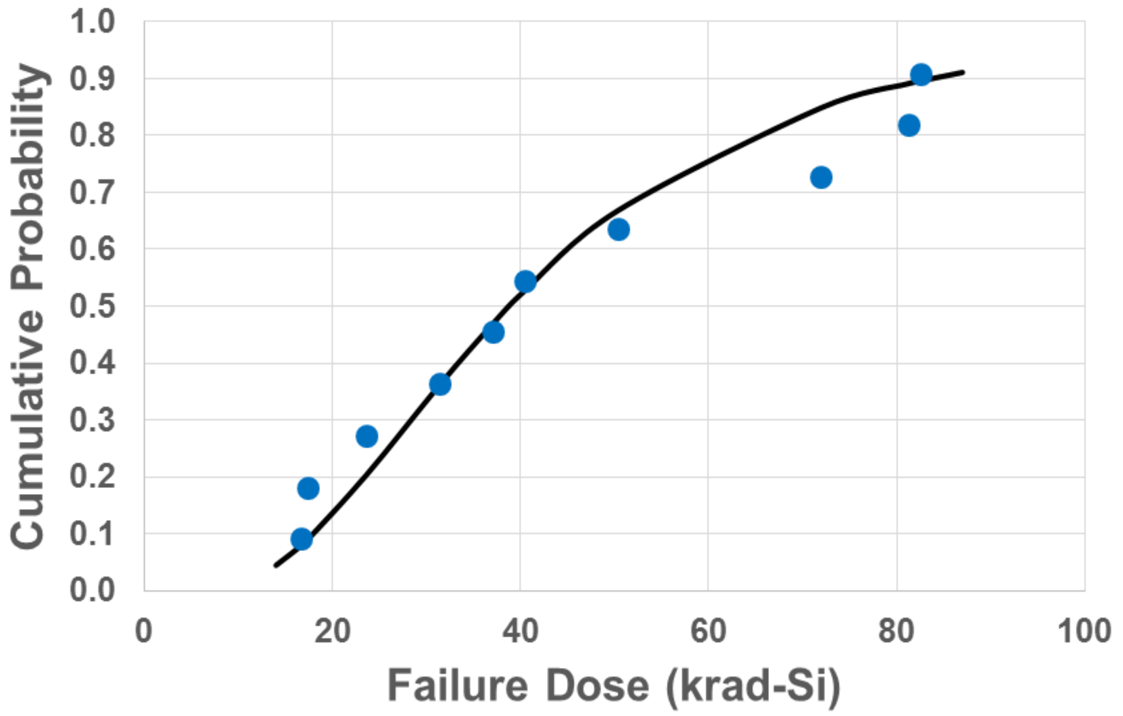
4 stacked MMS spacecraft



Credit: http://mms.gsfc.nasa.gov

Device Failure Distribution
SFT2907A Bipolar Transistors



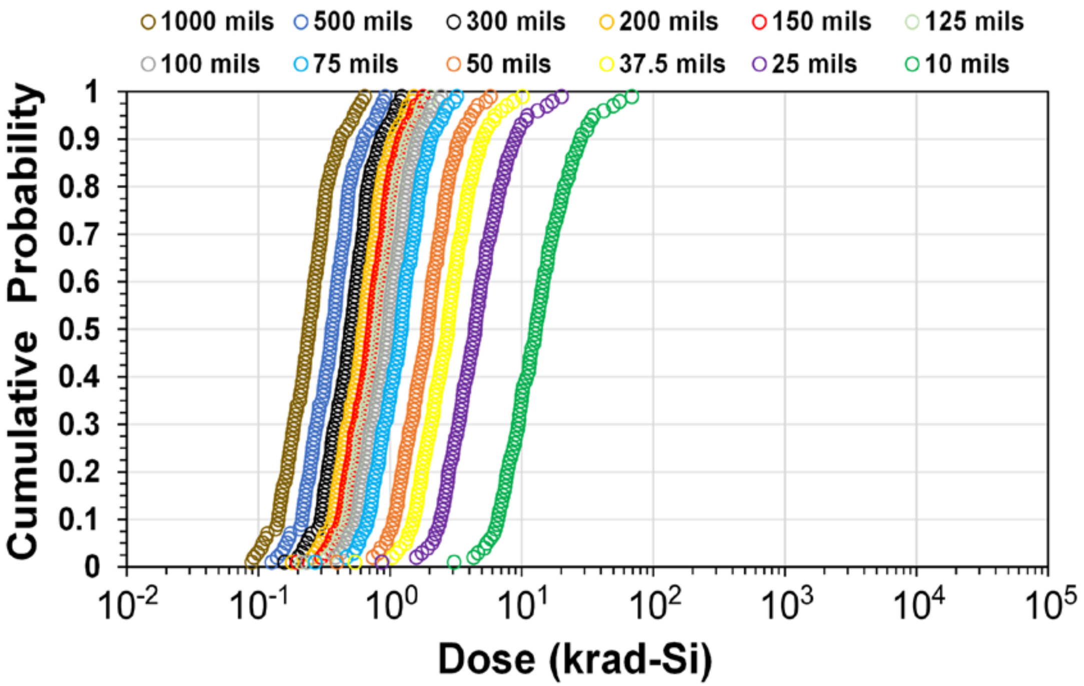


Total Dose Probability Distribution Calculations

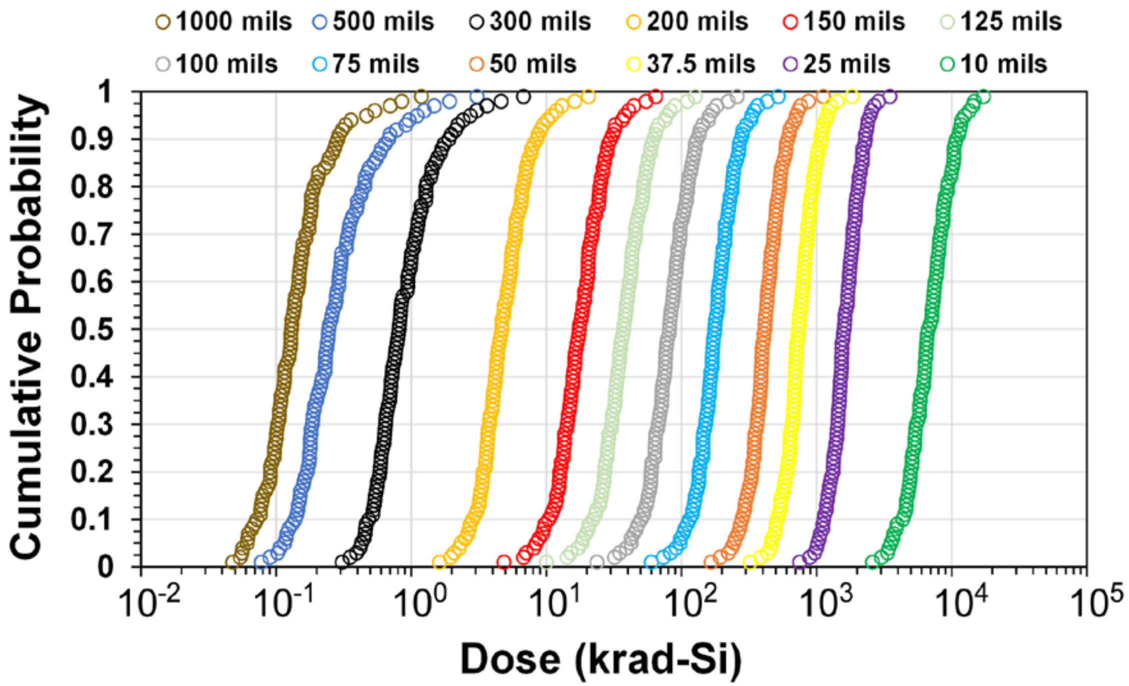
- **TID and DDD probability distributions were calculated for each orbit and mission duration for confidence levels ranging from 1 to 99%**
  - **AP9/AE9 Monte Carlo code used to simulate 99 histories for each case**
  - **ESP solar proton calculations done for 1 to 99% confidence levels**
  - **All energy spectra were transported through shielding levels from 10 to 1000 mils Al using NOVICE code and converted to doses**
  - **TID and DDD for each radiation were separately ranked for confidence levels ranging from 1 to 99% and summed for same confidence and shielding levels**

TID Probability Distributions for 1 Year
10 – 1000 mils Aluminum

Low Inclination LEO



GEO

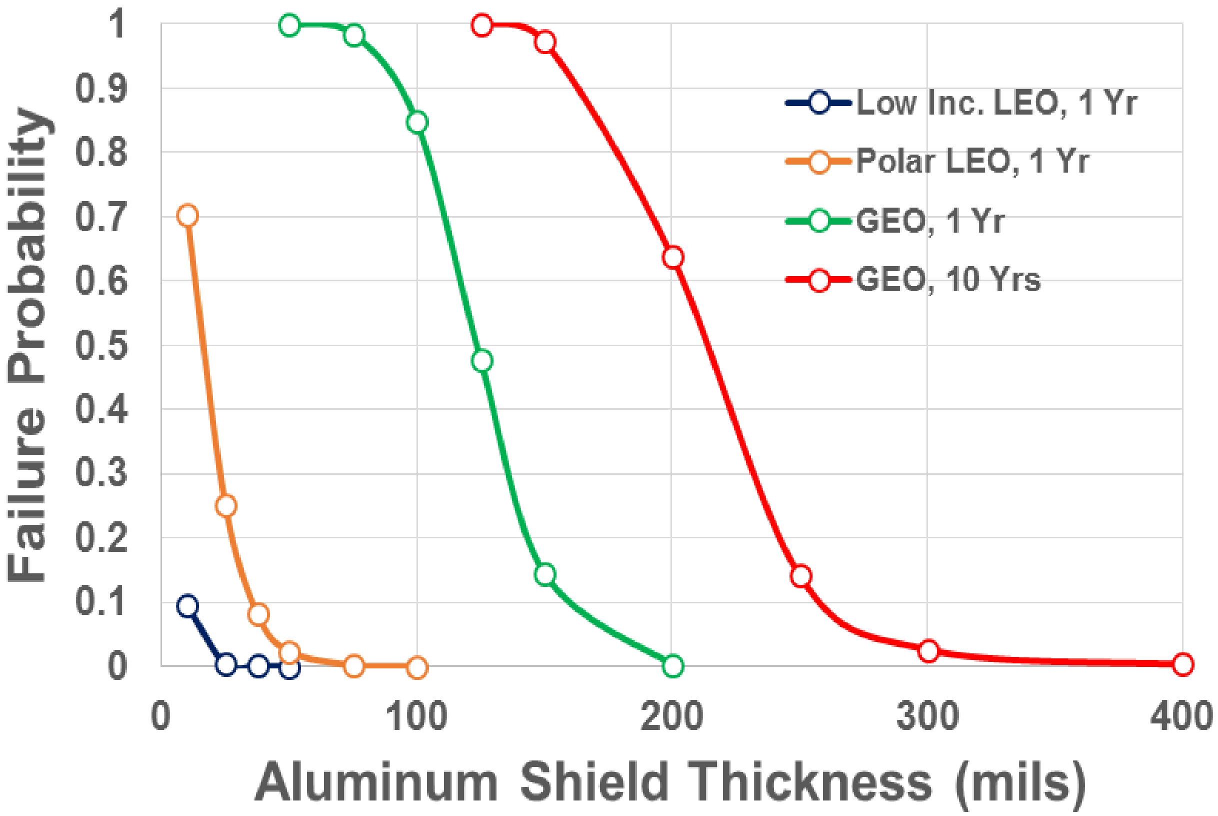


Failure Probabilities
SFT2907A Bipolar Transistor

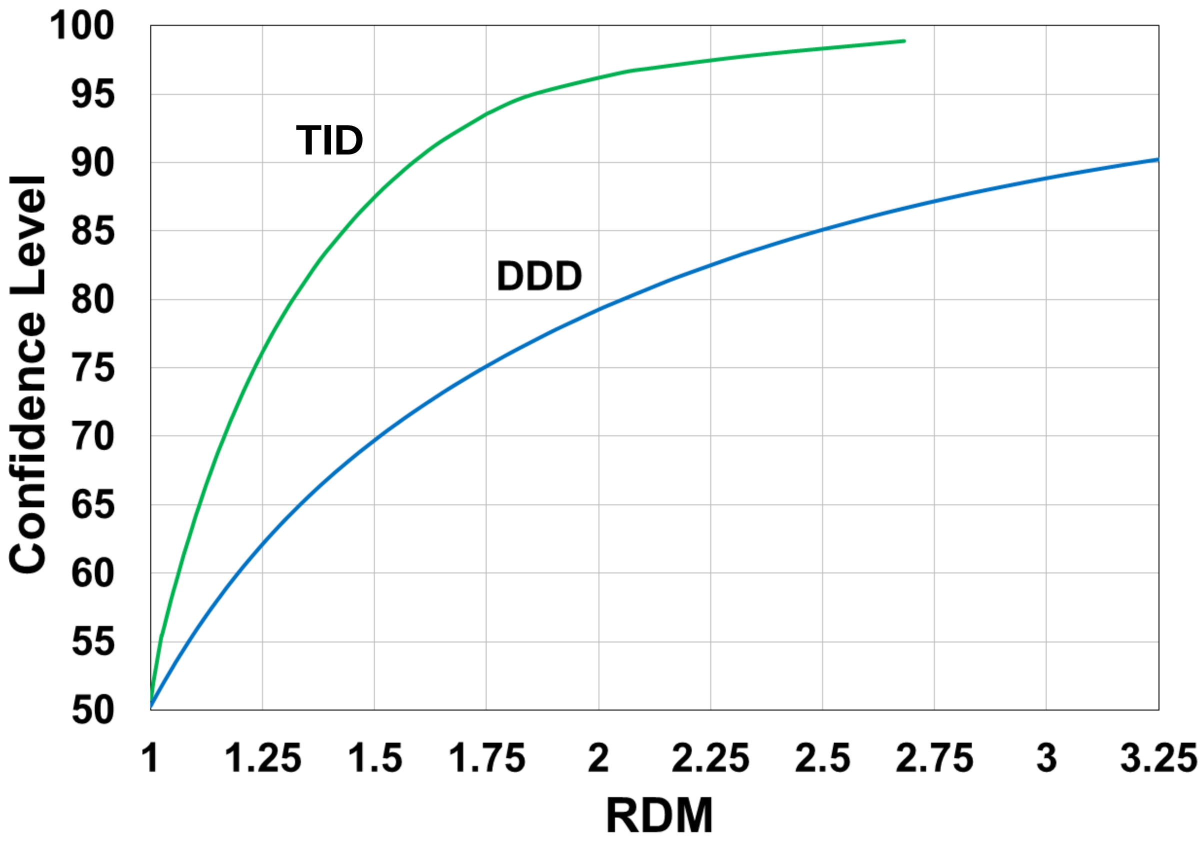
$$P_{fail} = \int [1 - H(x)] \cdot g(x)dx$$

H(x) = CDF for environment dose
g(x) = PDF for device failure

Failure probability (P_{fail}) is the probability of a total dose failure during a mission



Confidence Level vs. RDM for 10 years in GEO 200 mils Al shield



Conclusions

- An approach to total dose radiation hardness assurance was developed that includes variability of the space radiation environment.
- Examples showed radiation environment variability is at least as significant as variability of total dose failures in devices measured in the laboratory.
  - New approach is more complete
  - Uses consistent evaluation of each radiation in the space environment through use of confidence levels
- Advantages of using P_{fail} instead of RDM are:
  - P_{fail} is an objectively determined parameter because complete probability distributions are used to calculate it
  - Better characterization of device radiation performance
  - Allows direct comparison of the total dose threats for different devices and missions, regardless of whether degradation is due to TID or DDD
  - More amenable to circuit, system and spacecraft reliability analysis