Part-to-part and lot-to-lot variability study of TID effects in bipolar linear devices

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The definition of Radiation Design Margin requirements and criteria to waive Radiation Verification Testing on flight lots is a controversial aspect of **Radiation Hardness Assurance** for **Total Ionizing Dose**. These discussions are critical for **linear bipolar devices** as they are likely to show part-to-part and lot-to-lot variation in TID sensitivity. The work presented here investigates the **within-one-lot** and **inter-lot variability** on three different references. Experimental characterizations and data analysis have been performed by TRAD and supported by the ESA. The one-sided tolerance limit (K_{TL}) method is usually considered for TID testing. It is compared to the **Maximum Likelihood Ratio method** which is investigated and provides an interesting accuracy.

Devices Under Test

Three different references were irradiated and for each reference **three lots** were tested for parametric TID characterization. **30 devices** were irradiated for each lot. The references were irradiated under **Cobalt 60**. The irradiations were done at **210 rad/h**, at the **GAMRAY** facility (TRAD, Tests & radiations – Labège, France).

Device	Part number	Manufacturer	Lots
LM124AWG	5962R9950401VZA	Texas Instruments	0539A 1136A 1306A
AD584SH	5962R3812801VGA	Analog Devices	0125A 0226A
AD584SH	5962-3812801VGA	Analog Devices	1052A
TL1431ACZ	-	ST Microelectronics	GE245074 GE334152 GE337030

Methodology for statistical analysis

First Level Analysis: ***3-sigma approach***

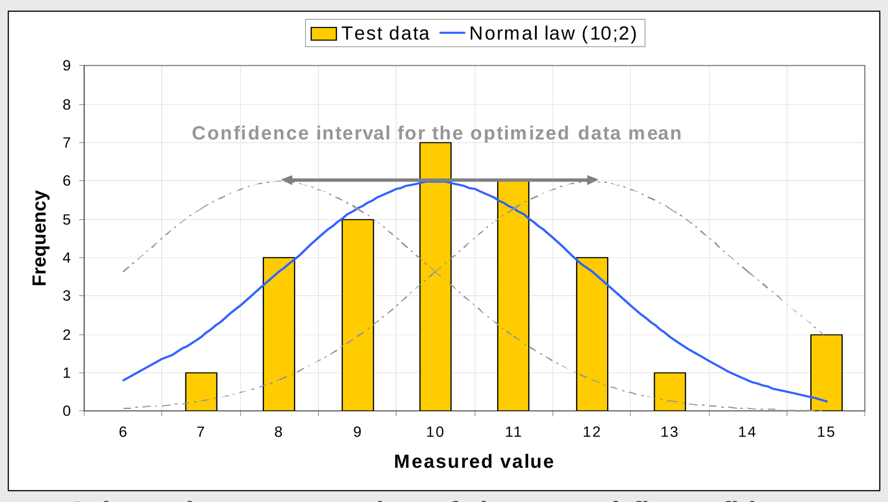
$$m = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - m)^2}$$

K_{TL} = 2.742 for n = 5 (C=90, P=90) [1]

Second Level Analysis: ***Maximum Likelihood Ratio***

$$f_{nm}(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$$

$$L = \prod_{i=1}^{n} f(x_i,\mu,\sigma) \qquad L_{max} = \max(L) \qquad \ln\left(\frac{L}{L_{max}}\right) \geq -\frac{1}{2}\chi^2(1-\alpha,2)$$

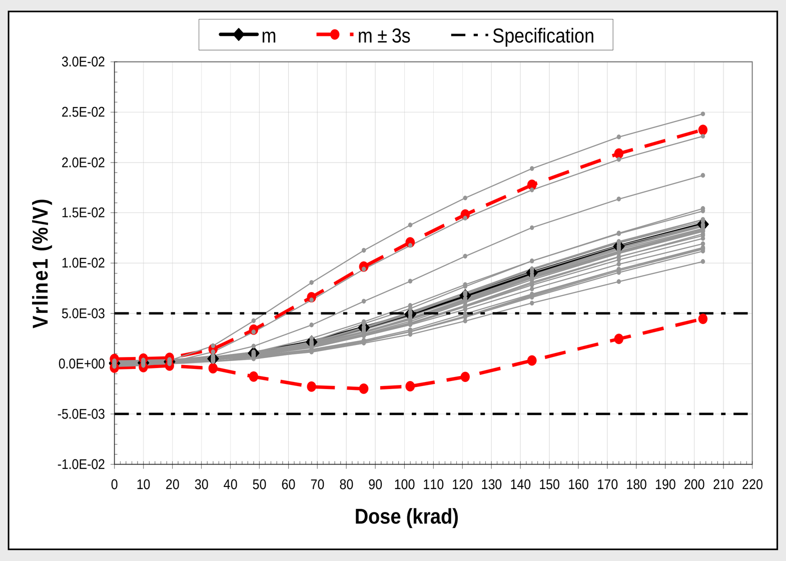


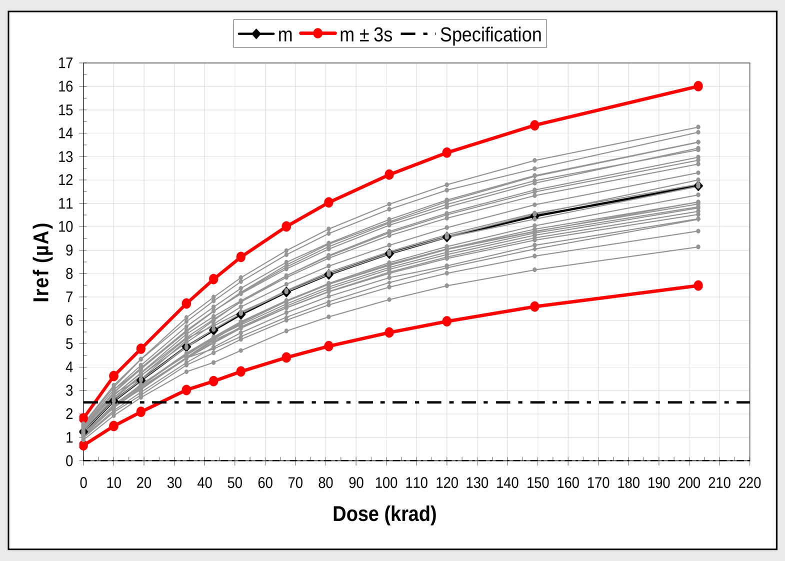
Schematic representation of the normal fit confidence interval calculation. The frequency is plotted as a function of the measured value for the electrical parameter, and a normal law is fitted to the test data.

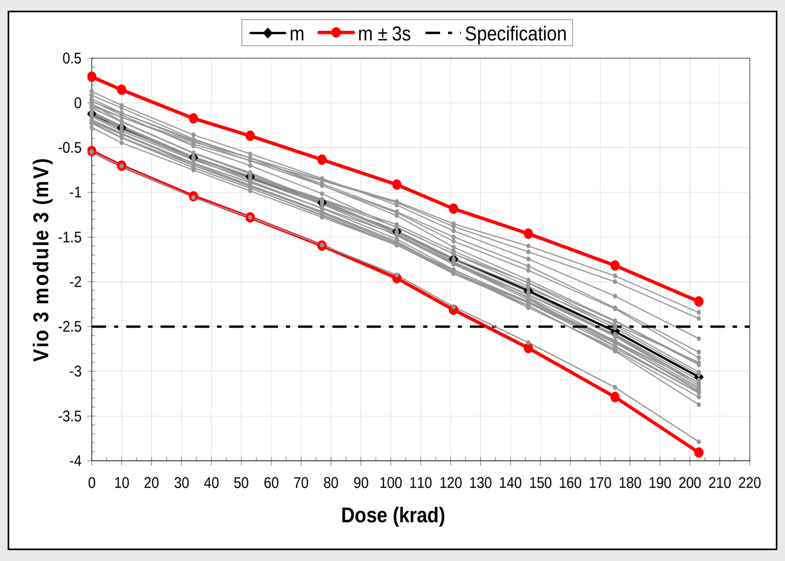
AD584SH
Vrline1 (%/V) lot 0226A

TL1431ACZ
Iref (µA) lot GE334152

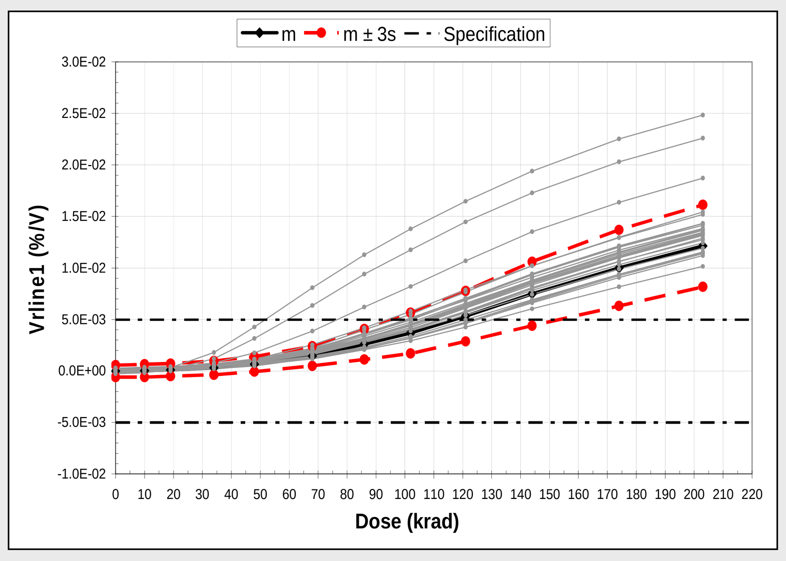
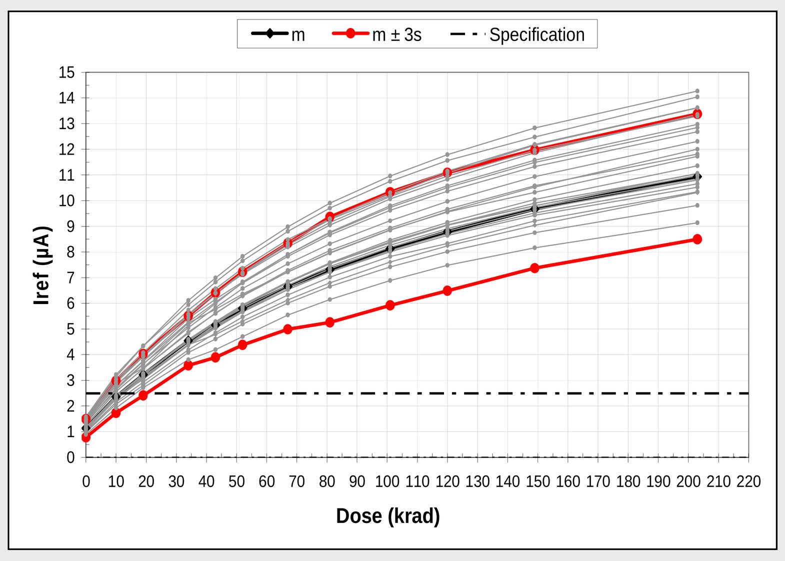
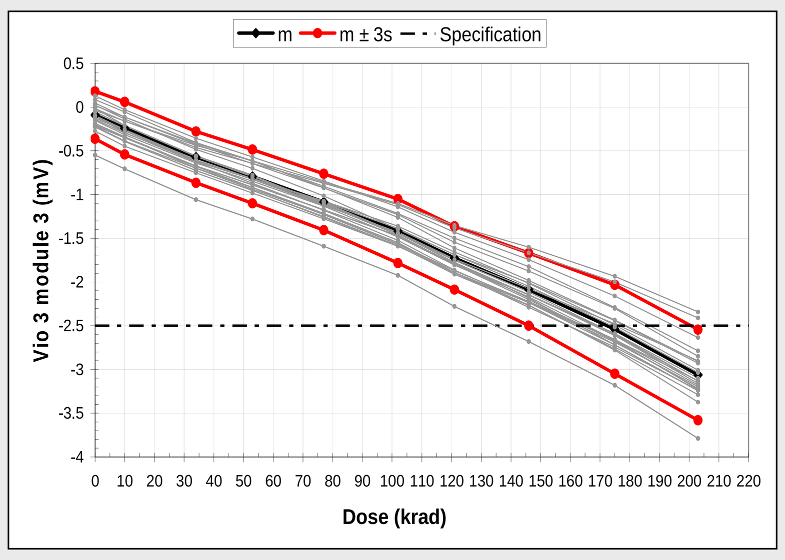
LM124AWG
Vio3 module 3 (mV) lot 1136A



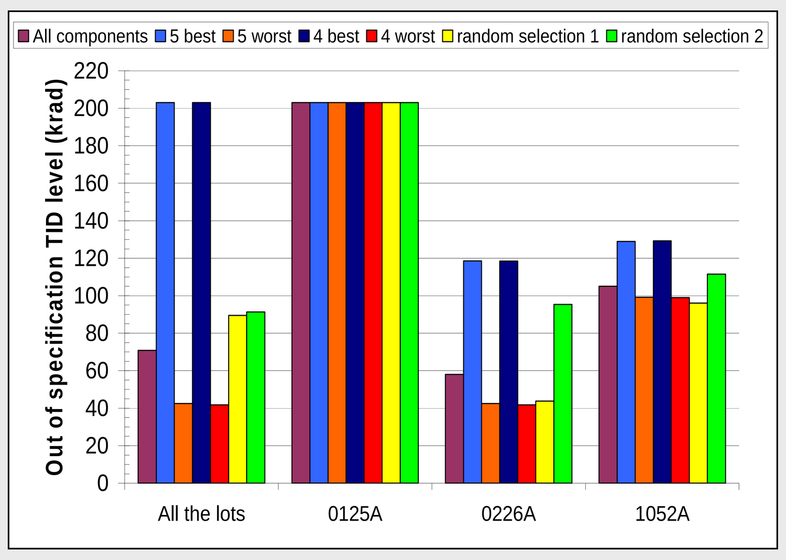




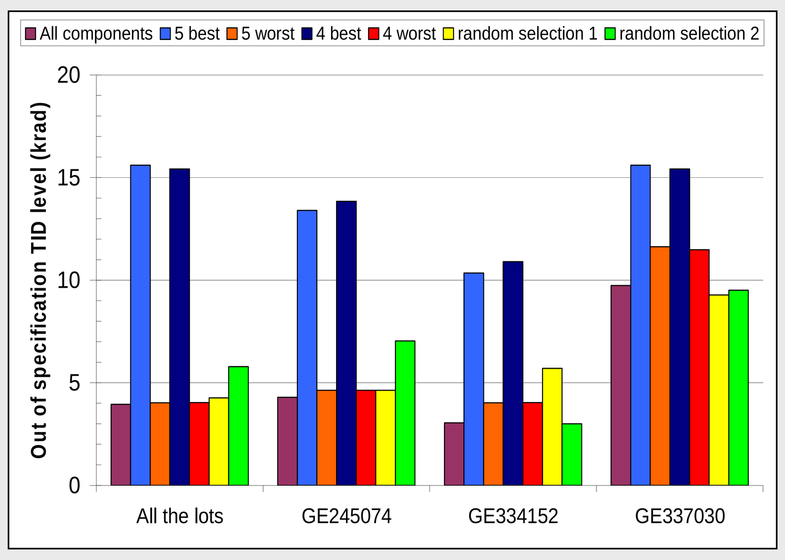
3-sigma approach, selection of 30 devices, 1 lot

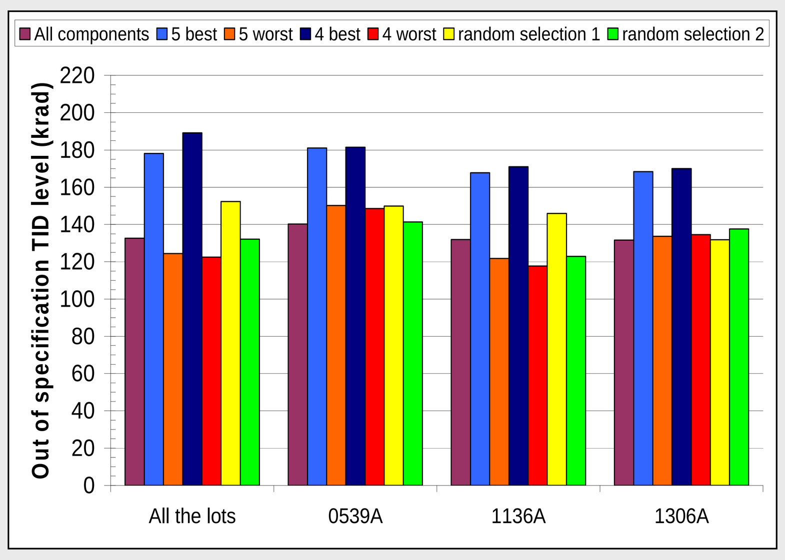
3-sigma approach, 5 random devices among 1 lot



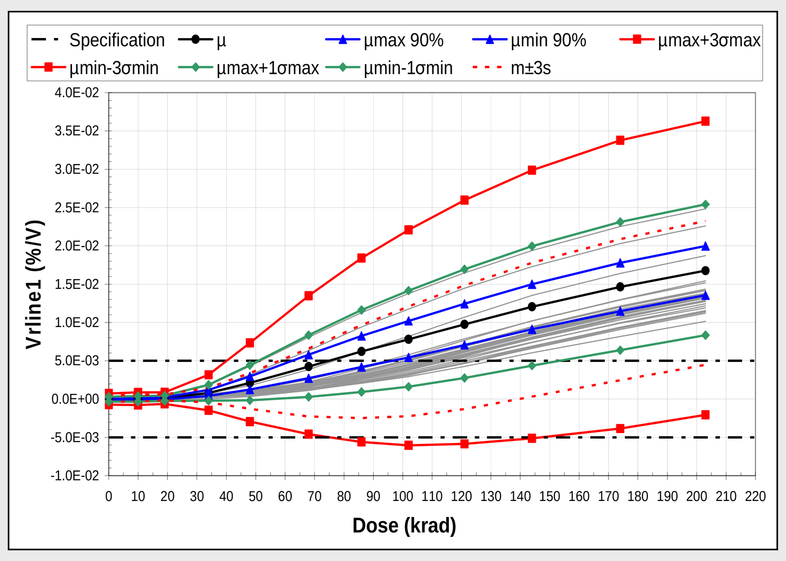
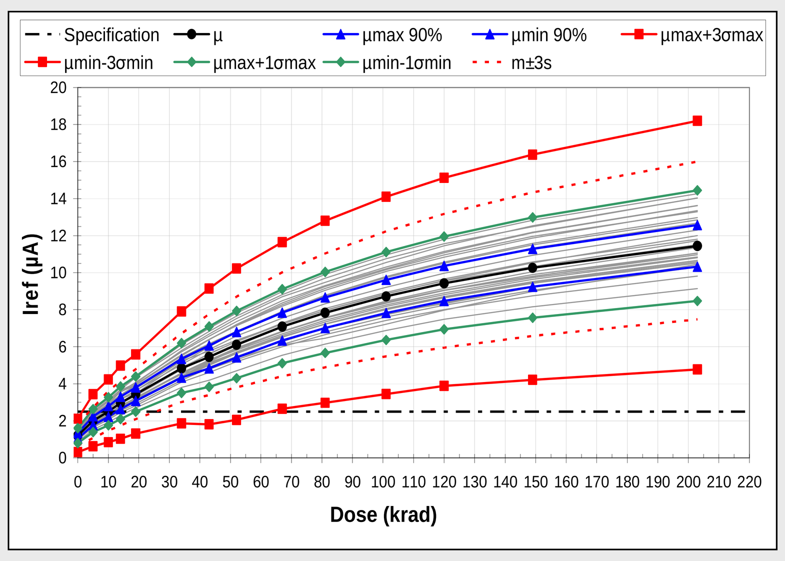
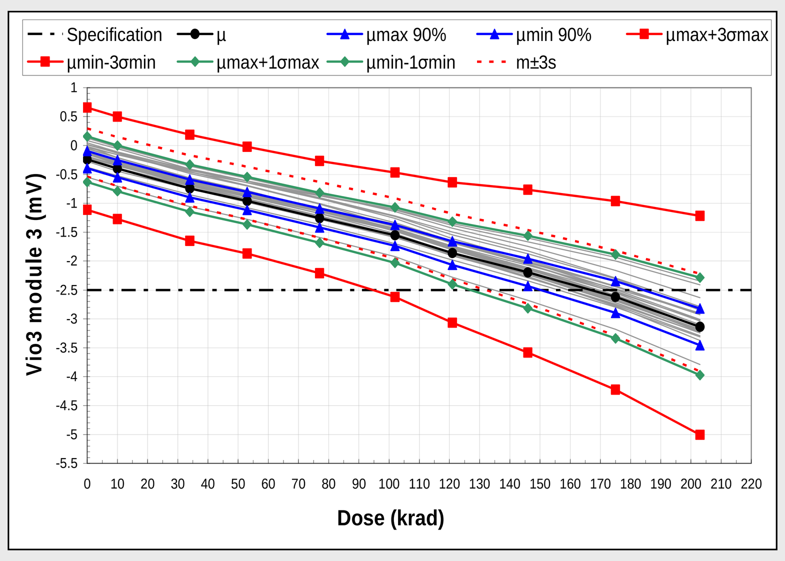
Out-of-specification TID level for *m* + 3s limit



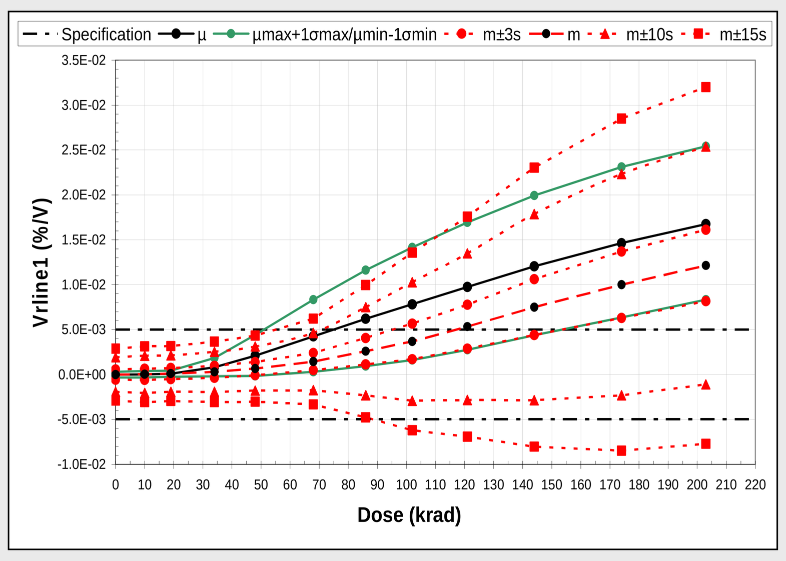
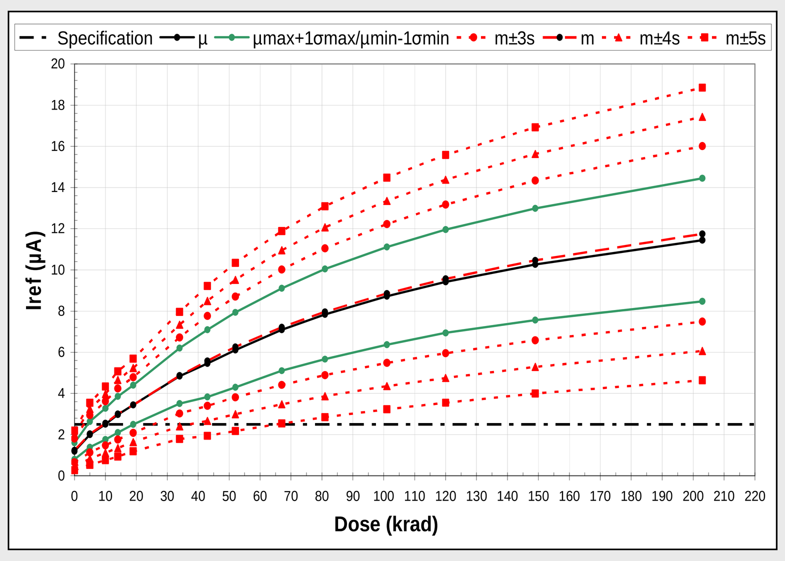
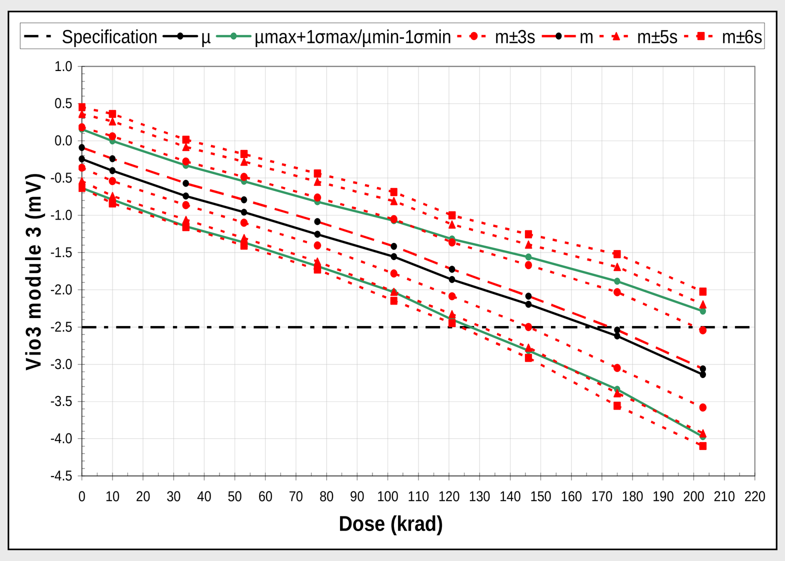
Out-of-specification TID level for *m* + 3s limit



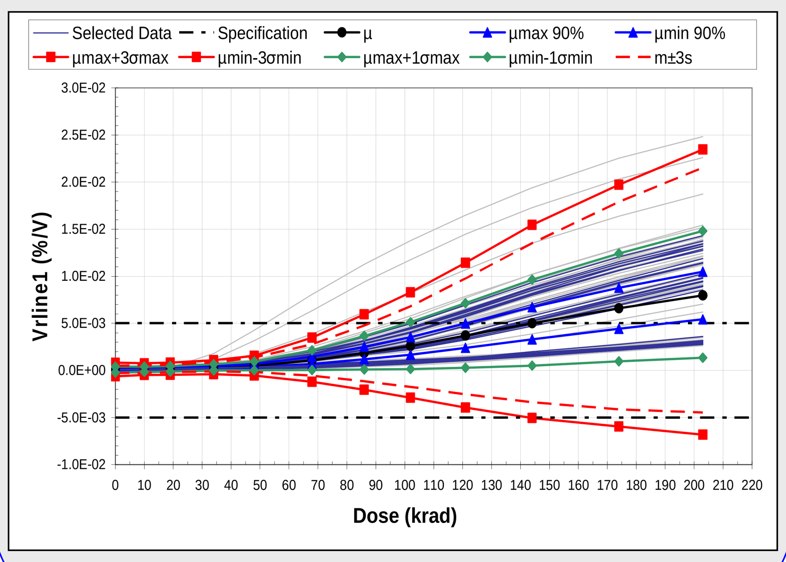
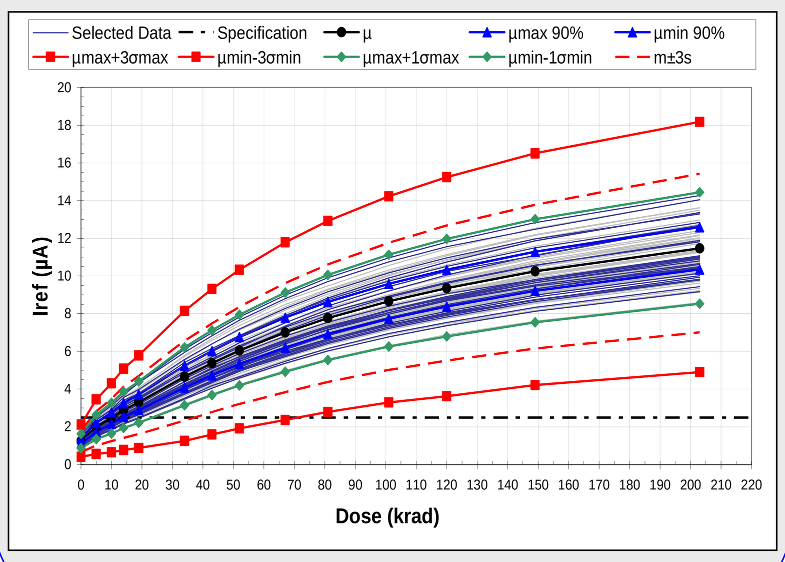
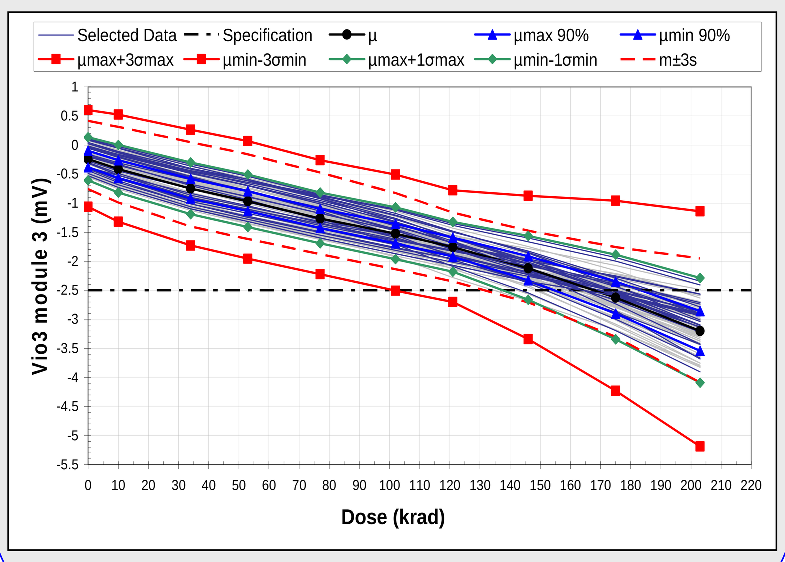
Out-of-specification TID level for *m* - 3s limit

Max Likelihood Ratio method, 30 devices, 1 lot

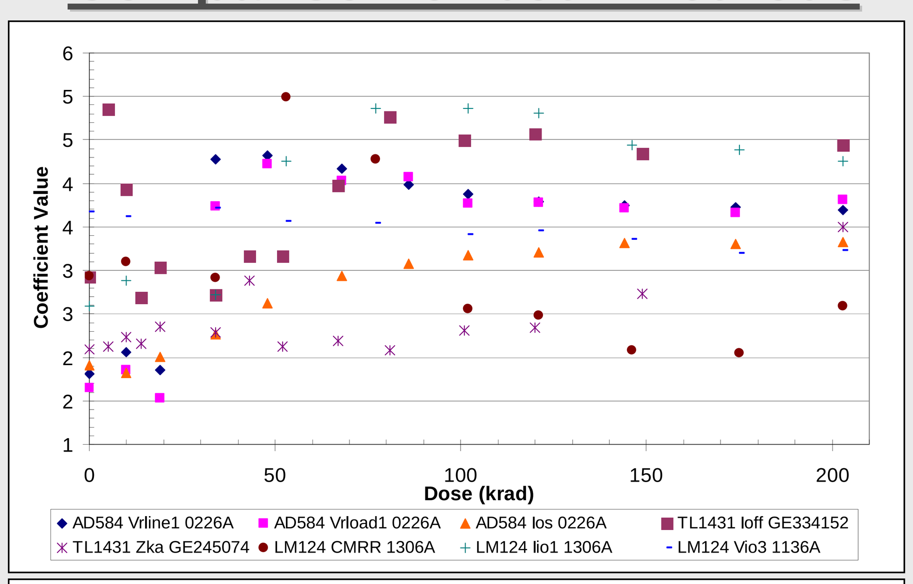
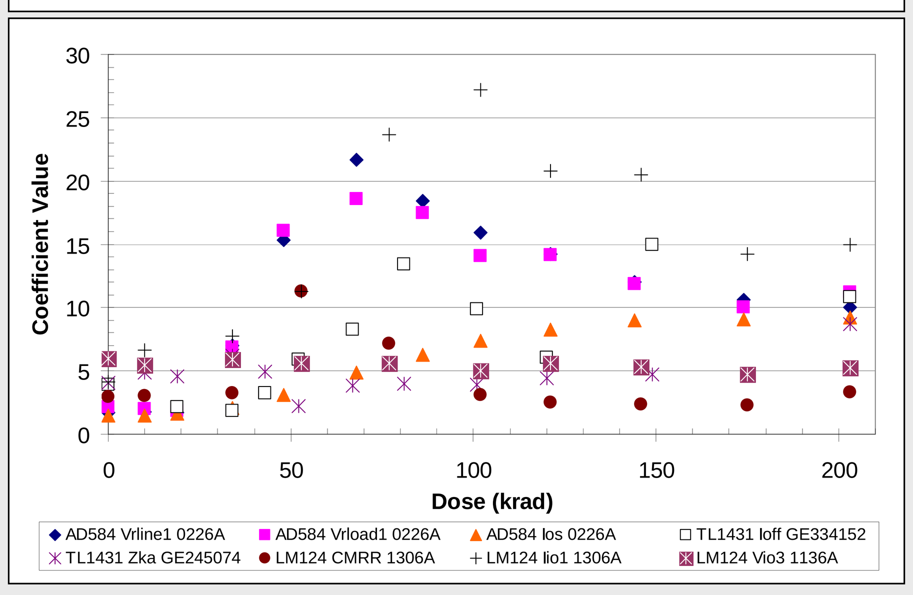




Comparison of both methods, 5 devices among 1 lot

MLR method, 10 devices selected per lot, 3 lots plotted (30 devices)

Comparison of both methods

Multiplication factor applied to sigma *s* at each TID step to replicate the Maximum Likelihood Ratio method results. This gives an indication of the precision achieved with the proposed method (P > 0.999 for C = 90). The impact of the degradation curve shape of the selection can be observed. 30 devices are considered at the top and 5 devices at the bottom.

Conclusion & perspectives

TID testing was performed on three lots for three different **bipolar** references. The aim was to analyse the **lot-to-lot** and **within-one-lot variability**. The data analysis objectives were to characterise the lot coverage based on 5-device sample size for testing, and to propose and **evaluate the Maximum Likelihood Ratio method** based on the use of confidence intervals. All the results are presented in reference [10].

An interesting accuracy in the test data behaviour representation was observed with this proposed method. This has to be related to the **large sample size** (30 devices) taken into account for the calculations and to the use of a **confidence interval** on the mean µ of the electrical parameter measurement. The possibility of selecting **data from different lots** was also explored and led to interesting results.

This work present an **accurate way** to estimate the **lot behaviour**, and the method was evaluated through different examples. However, the required sample size is too large for space applications and further investigations have to be performed in order to adapt this interesting methodology.

References

[1] MILITARY HANDBOOK, Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuits and Semiconductor Devices, MIL-HDBK-814, 08 February 1994.
[2] R. L. Pease, 'Total ionizing dose effects in bipolar devices and circuits', IEEE Transactions on Nuclear Science, vol. 50, no. 3, pp. 539–551, Jun. 2003.
[3] A. Namenson and I. Arimura, 'A Logical Methodology for Determining Electrical End Points for Multi-Lot and Multi-Parameter Data', IEEE Transactions on Nuclear Science, vol. 34, no. 6, pp. 1726–1729, Dec. 1987.
[4] I. Arimura and A. I. Namenson, 'Hardness Assurance Statistical Methodology for Semiconductor Devices', IEEE Transactions on Nuclear Science, vol. 30, no. 6, pp. 4322–4325, Dec. 1983.
[5] R. Ladbury, J. L. Gorelick, and S. S. McClure, 'Statistical Model Selection for TID Hardness Assurance', IEEE Transactions on Nuclear Science, vol. 56, no. 6, pp. 3354–3360, Dec. 2009.
[6] R. Ladbury and J. L. Gorelick, 'Statistical methods for large flight lots and ultra-high reliability applications', IEEE Transactions on Nuclear Science, vol. 52, no. 6, pp. 2630–2637, Dec. 2005.
[7] R. Ladbury, 'Statistical Techniques for Analyzing Process or "Similarity" Data in TID Hardness Assurance', IEEE Transactions on Nuclear Science, vol. 57, no. 6, pp. 3432–3437, Dec. 2010.
[8] R. Ladbury and B. Triggs, 'A Bayesian Approach for Total Ionizing Dose Hardness Assurance', IEEE Transactions on Nuclear Science, vol. 58, no. 6, pp. 3004–3010, Dec. 2011.
[9] R. L. Ladbury and M. J. Campola, 'Bayesian Methods for Bounding Single-Event Related Risk in Low-Cost Satellite Missions', IEEE Transactions on Nuclear Science, vol. 60, no. 6, pp. 4464–4469, Dec. 2013.
[10] 'Part-to-part and lot-to-lot variability study of TID effects in bipolar linear devices' ESA study report ref. TRAD/ESA/IR/VAR/NS/241115 of 29/11/2015.

[PC-2] RADECS, September 18th to 23rd 2016 (Bremen, Germany)