Electronic radiation hardening – Radiation Hardness Assurance and Technology Demonstration Activities

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Radiation Effects in electronics

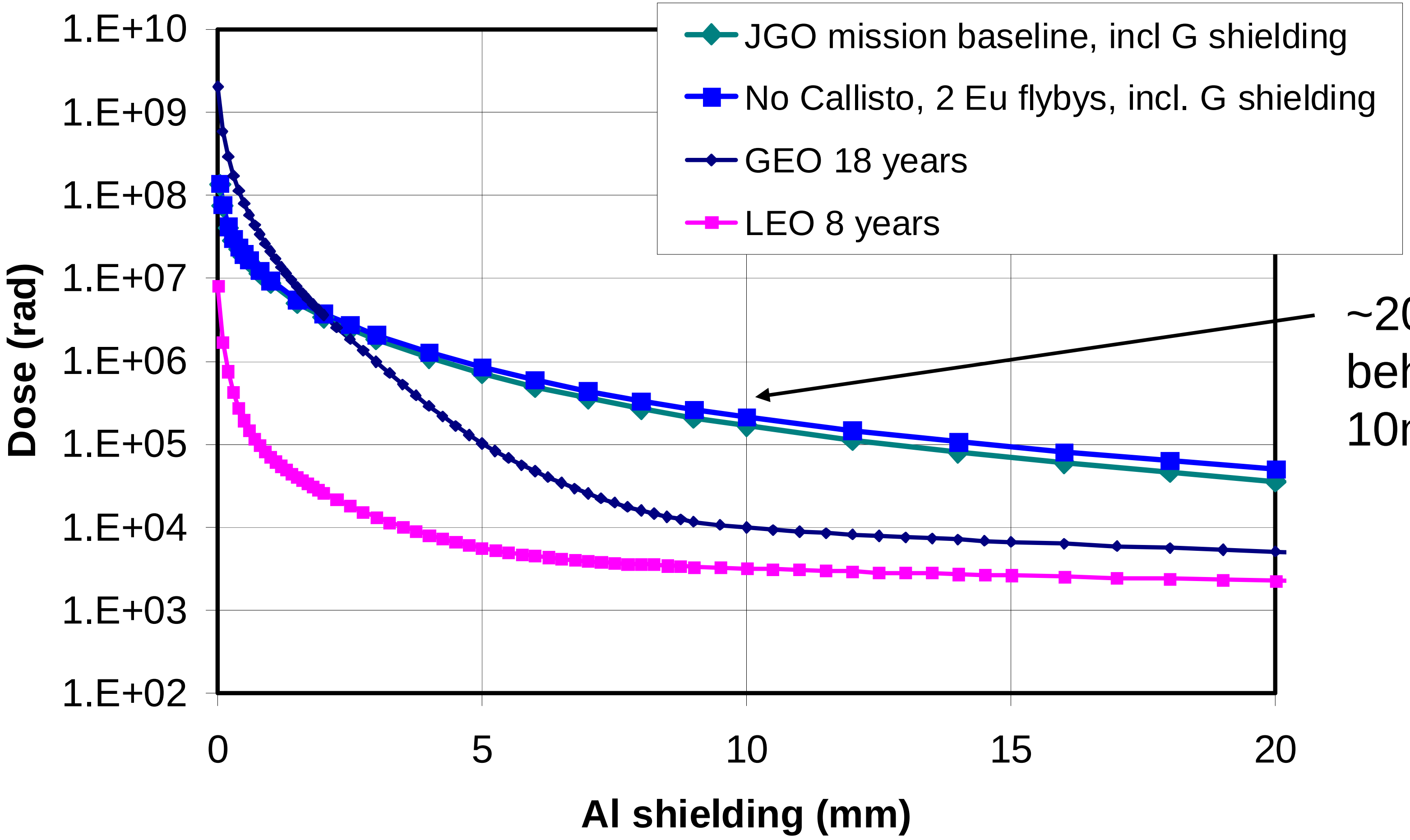
- Radiation environment is a significant constraint for any space missions
- The Jupiter environment is very demanding
  - The electron environment is particularly harsh
  - Proton and heavy ion environments similar to other interplanetary missions
- Radiation hardness assurance of electronic components and systems for Laplace instruments will require interactions between teams
  - Environment specialists
  - Radiation effects engineers
  - System designers

Outline

- Laplace radiation environment at the component level
- Radiation hardness assurance
  - **TID**
  - **TNID**

    Radiation Design Margin (RDM)
  - SEE
- Technology Demonstration Activities
  - Critical components for power systems
  - Optocouplers, sensors and detectors
  - Radiation testing of candidate memory devices for Laplace mission
  - Characterisation of front end and mixed signal ASICs (to be initiated)

Laplace Radiation Environment - TID

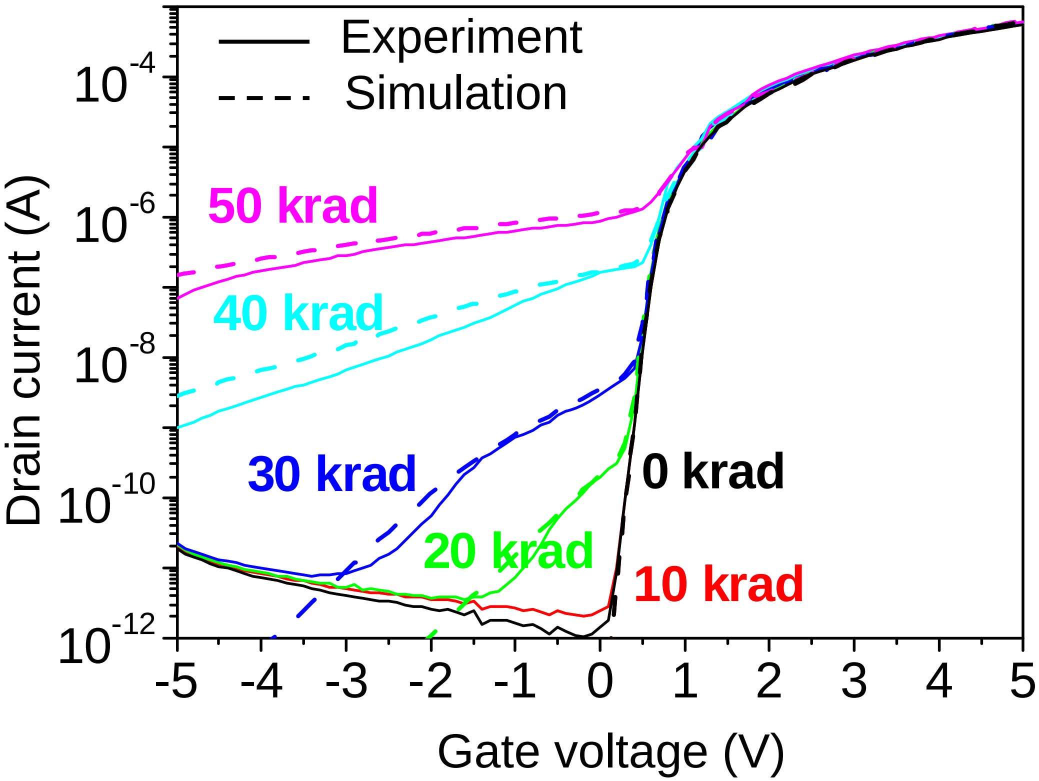


~200 krad behind 10mm Al

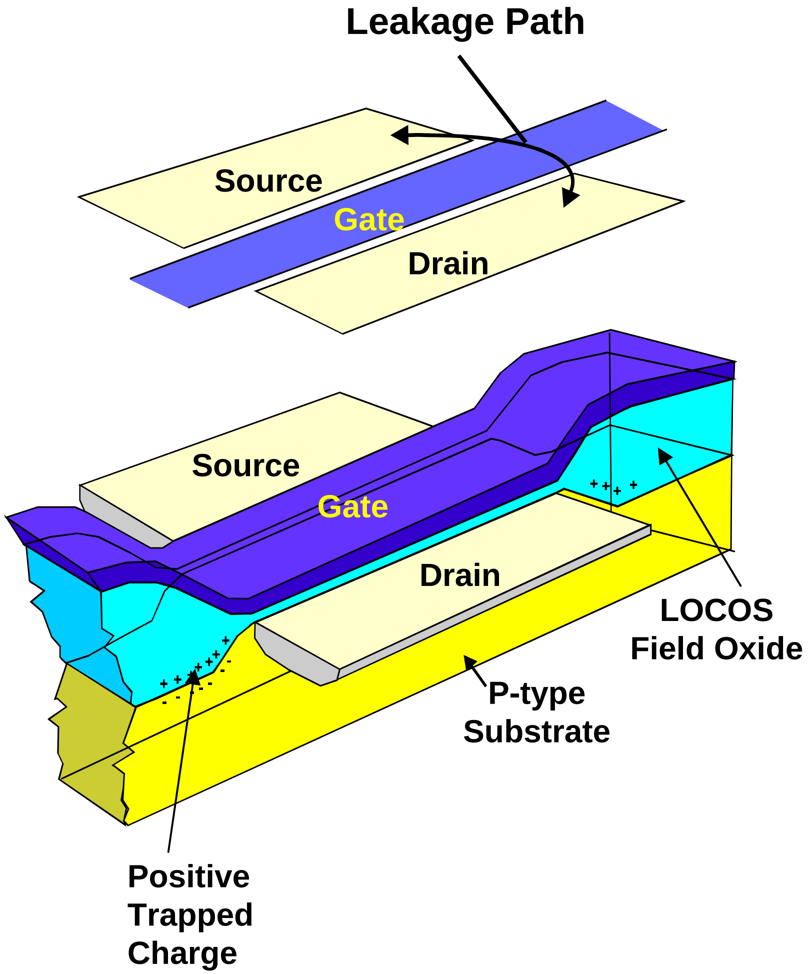
After [Ch. Erd, "Laplace environment specification, 14 June 2011]

Typical TID effect in CMOS: charge buildup in gate and field oxides induces leakage currents

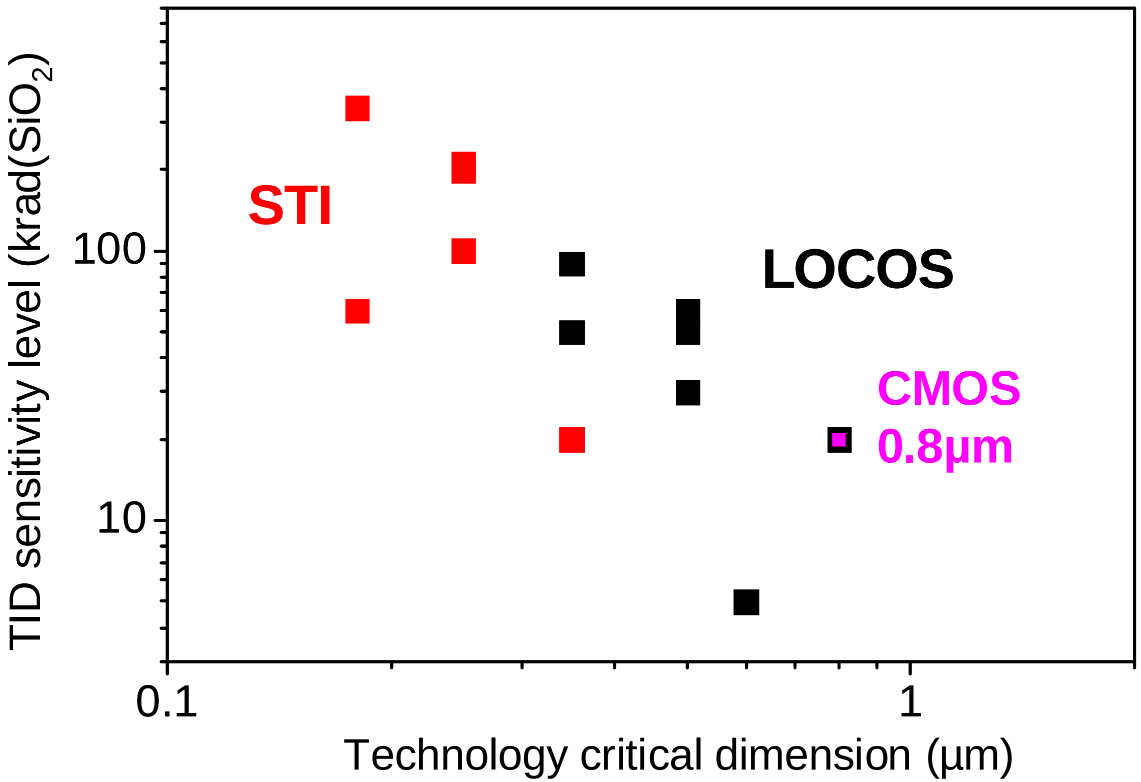
CMOS technology 0.8um,
LOCOS isolation



[Ferlet HDR05]



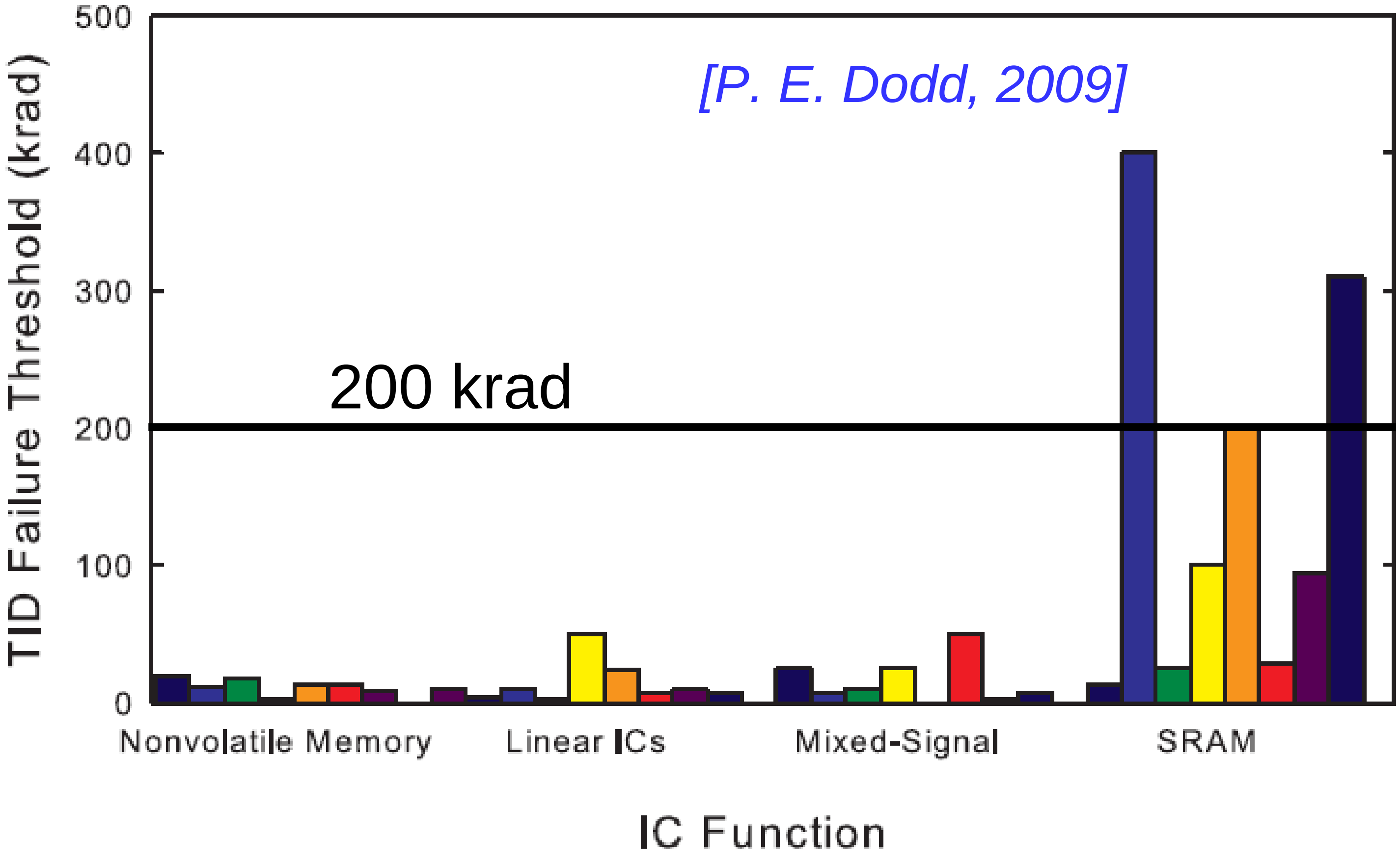
Highly scaled CMOS technologies, with standard design, are less sensitive to TID



Design with rad-hard libraries, like DARE, improves TID hardness, compared to standard designs

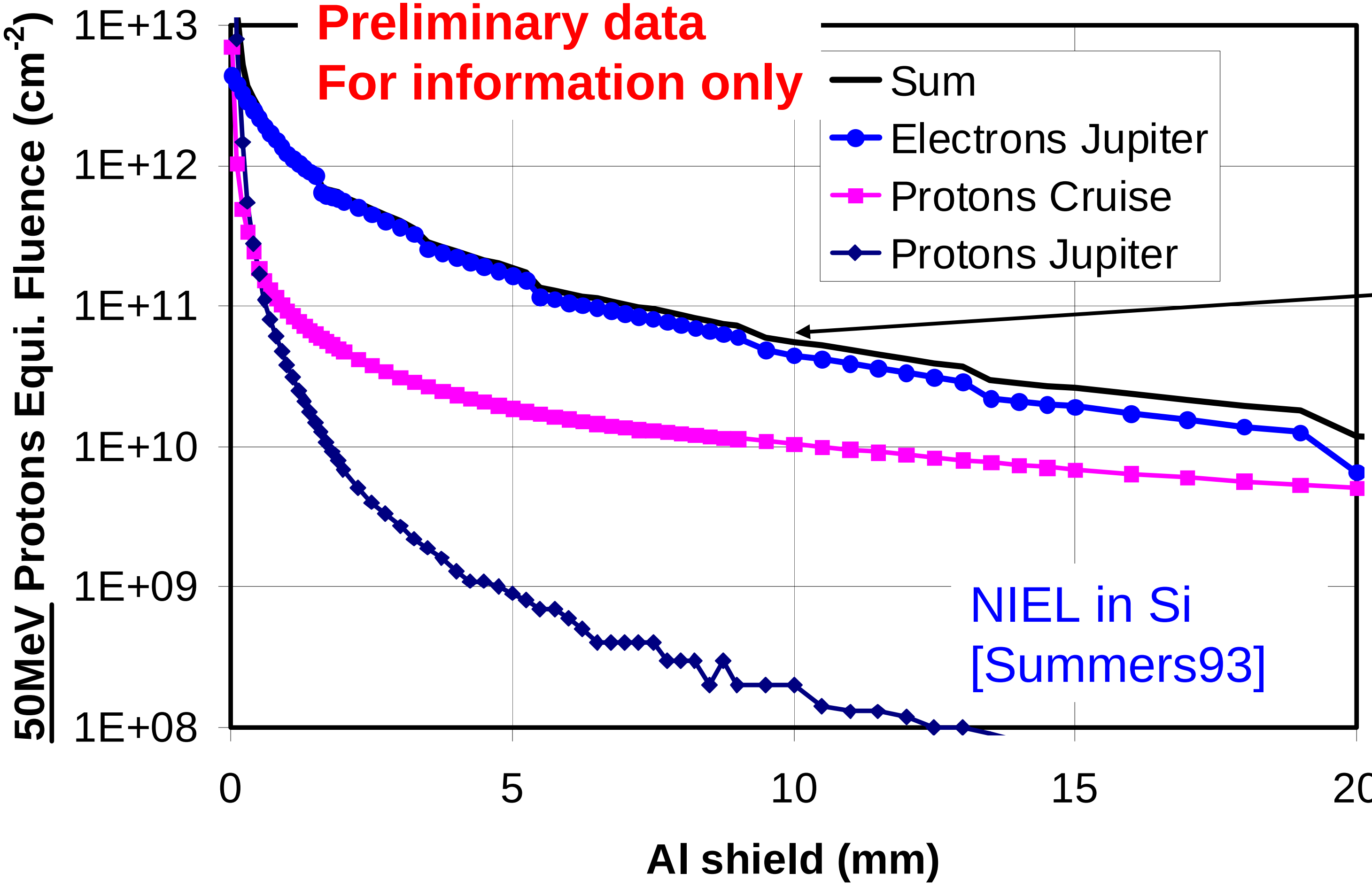
Compilation from [Lacoe03, Anel97, Kerwin98, Shaneyfelt98, Brady99, Lacoe99, Lacoe00, Lacoe01, Nowlin04]

However, real systems use a wide variety of IC technology generations, for which TID hardening is not granted



Compilation from Radiation Effect data workshops between 2002 and 2004

Laplace Radiation Environment - TNID



Preliminary data
For information only

~5.5E10 p/cm^2 50 MeV eq. behind 10mm Al

NIEL in Si [Summers93]

Simulations with OMERE (solid-sphere) from data in [Ch. Erd, “Laplace env. spec.”, 14 June 2011]

Because of displacement damage, some circuits fail at much lower equivalent total dose levels compared to gamma rays

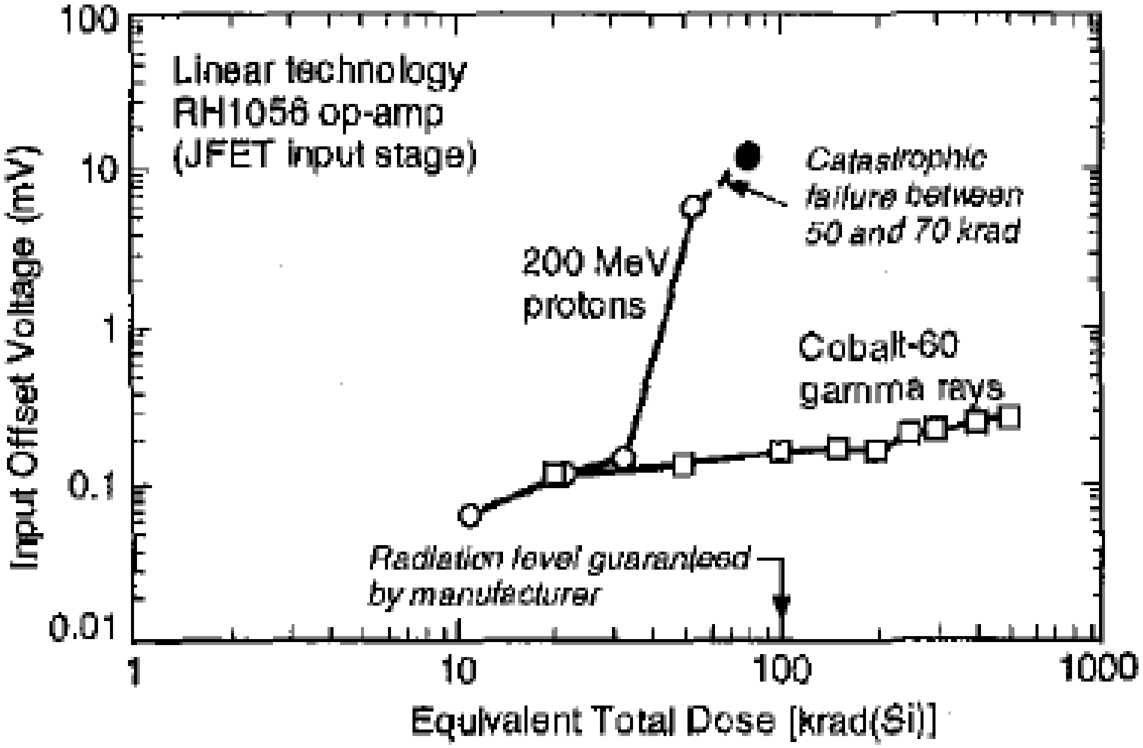
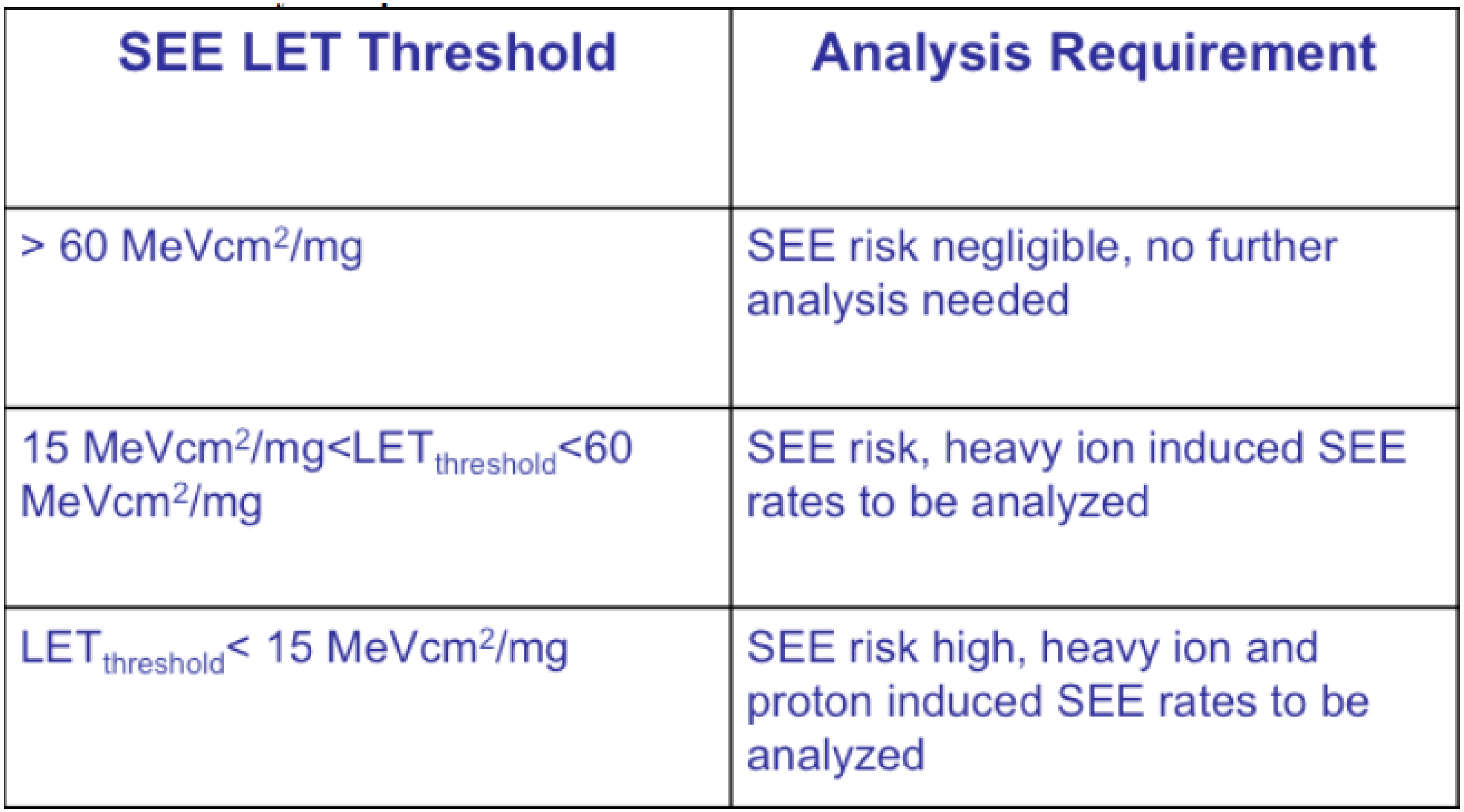


Figure 1. Degradation of the RH1056 op-amp from protons and gamma rays.

50-70 krad corresponds to **2E10 cm^{-2} 50MeV protons**

[B. G. Rax et al. TNS Dec. 1999]

The SEE requirements for Laplace are similar to other space missions



SEE LET Threshold	Analysis Requirement
> 60 MeVcm^2/mg	SEE risk negligible, no further analysis needed
15 MeVcm^2/mg<LET$_{\text{threshold}}$<60 MeVcm^2/mg	SEE risk, heavy ion induced SEE rates to be analyzed
LET$_{\text{threshold}}$< 15 MeVcm^2/mg	SEE risk high, heavy ion and proton induced SEE rates to be analyzed

[ECSS-Q-ST-60-15C, draft]

What is Radiation Hardness Assurance (RHA) ?

- RHA consists of all activities undertaken to ensure that the electronics and materials of a space system perform to their design specifications after exposure to the space radiation environment

- Deals with environment definition, part selection, part testing, spacecraft layout, radiation tolerant design, mission/system/subsystems requirements, mitigation techniques, etc.

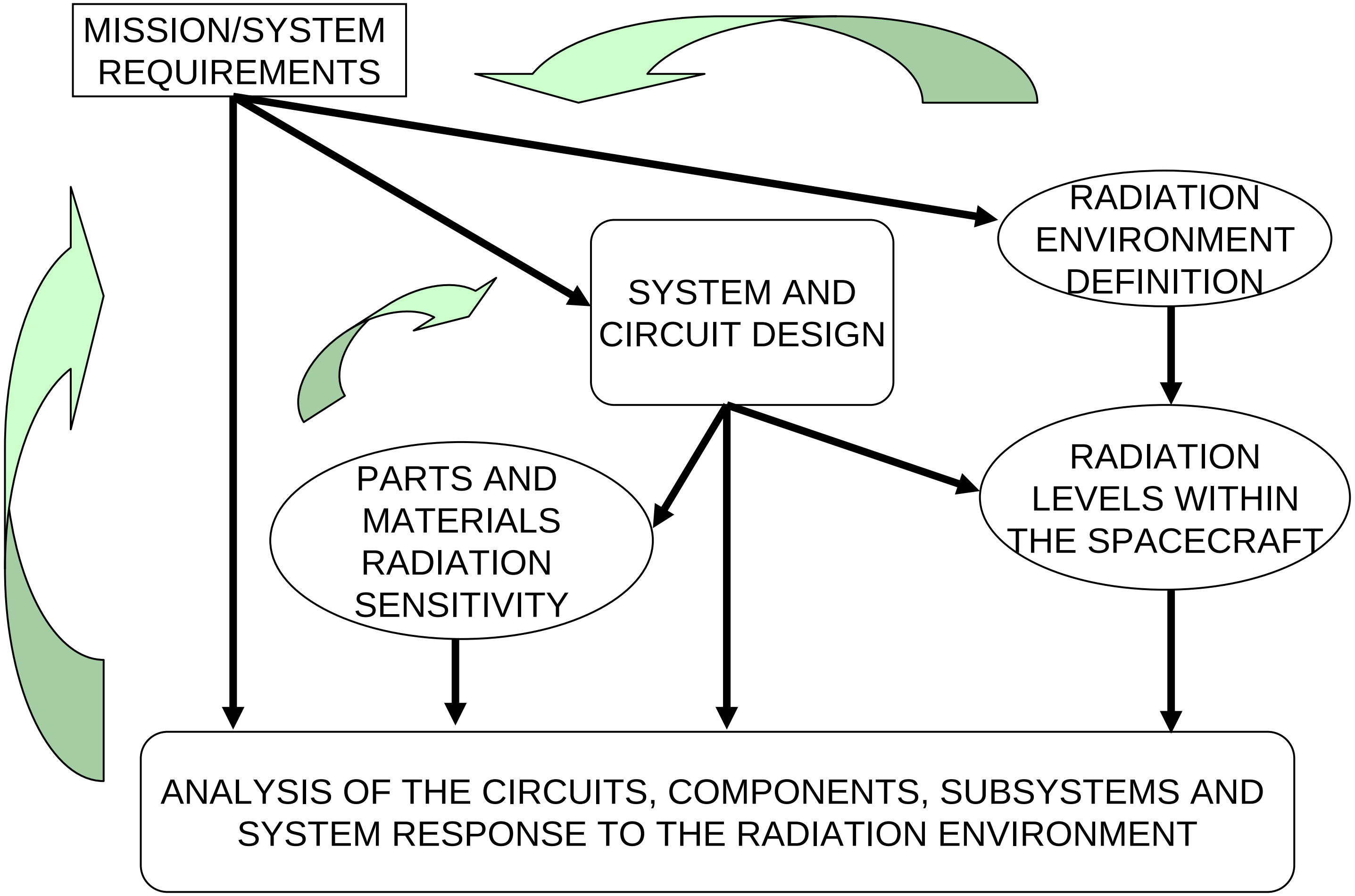
- Radiation Hardness Assurance goes beyond the piece part level

RHA Requirements and TID test standard

- European standard for RHA
  - *ECSS-Q-ST-60-15C* draft
  - 2 years discussions with space agencies and industrials
- Test standards:
  - *ESCC 22900*
  - *US MIL-STD1019.7*

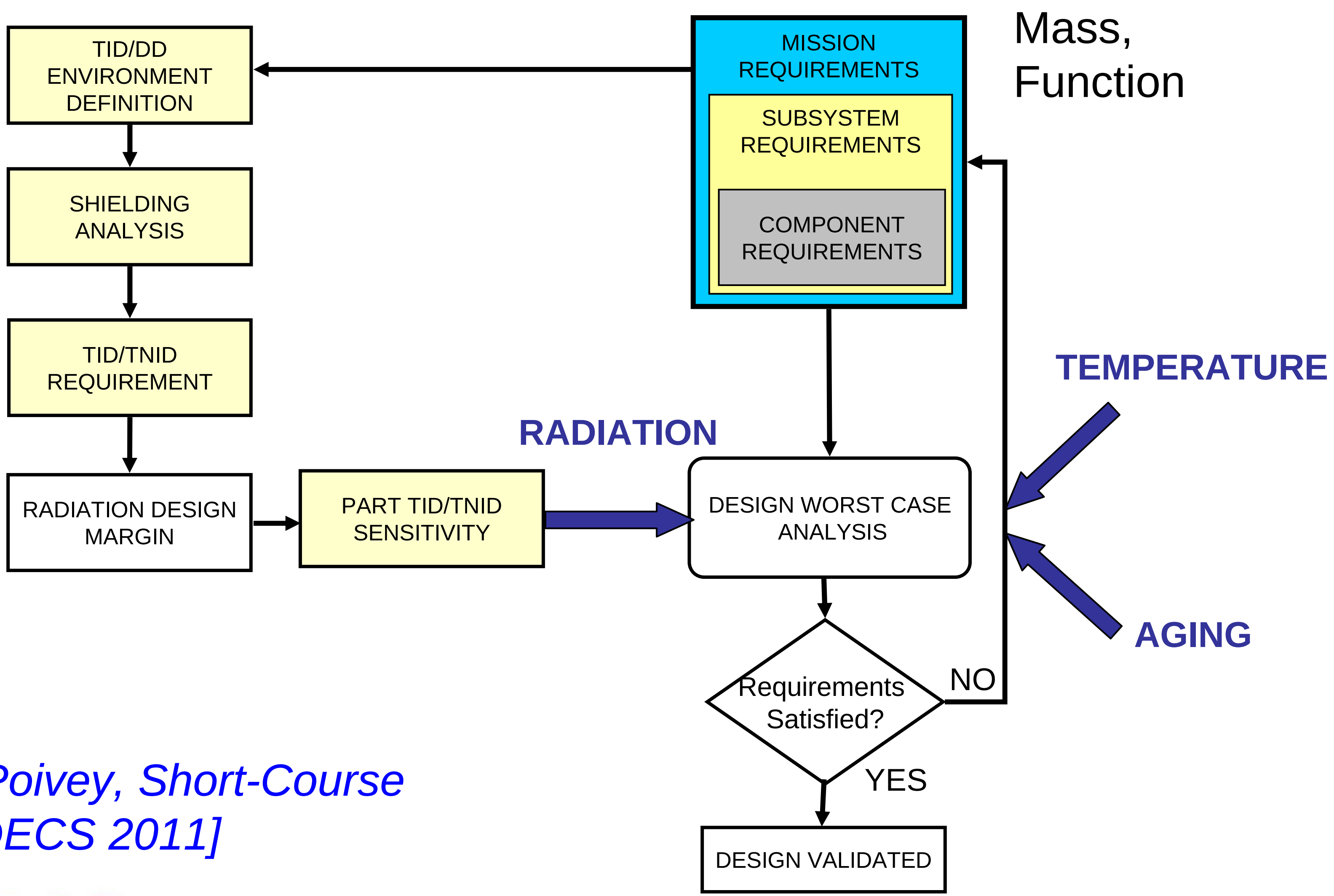
- Test Guidelines:
  - *ASTM F1892*

RHA Overview



[C. Poivey, Short-Course RADECS 2011]

TID / TNID - Analysis Flow



[C. Poivey, Short-Course RADECS 2011]

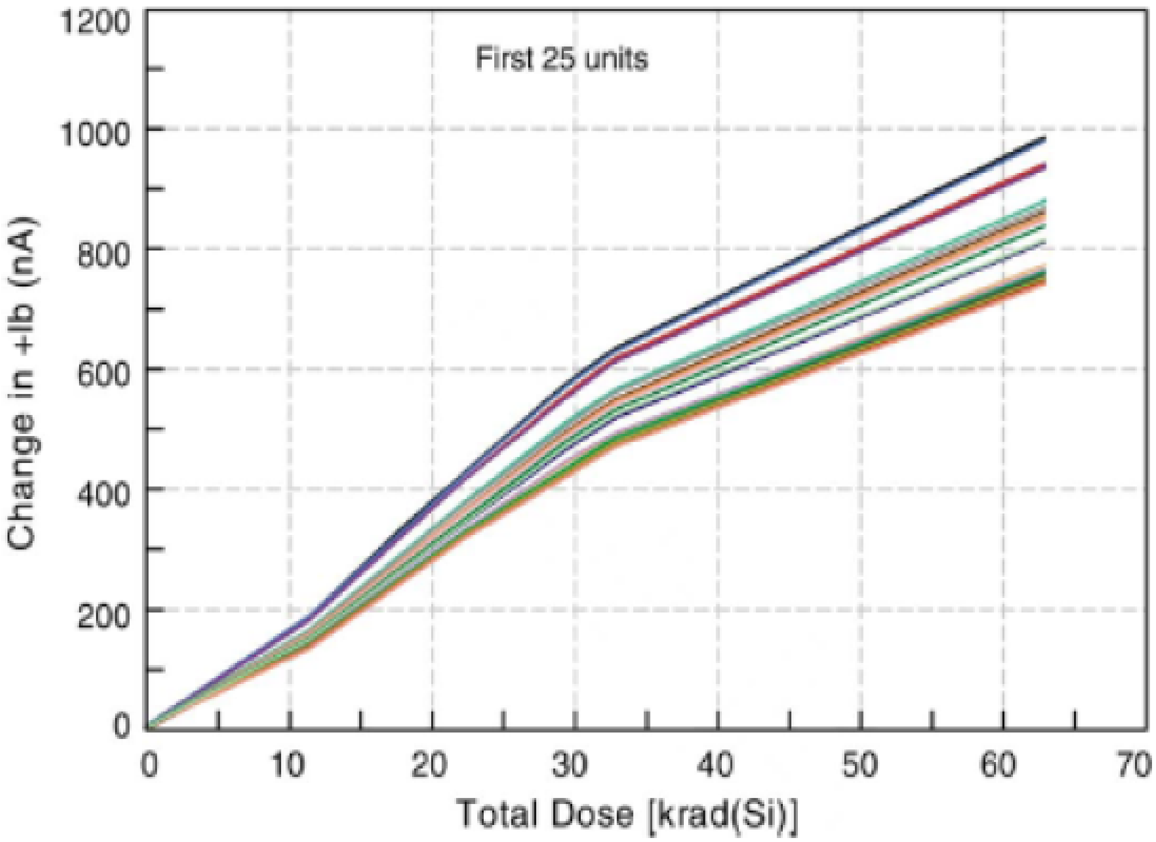
TID RHA, Scope

EEE part family	Sub family	TIDL
Diodes	Voltage reference	all
	Switching, rectifier, schottky	> 300 Krad-Si
Diodes microwave		> 300 Krad-Si
Integrated Circuits		all
Integrated Circuits microwave		> 300 Krad-Si
Oscillators (hybrids)		all
Charge Coupled devices (CCD)		all
Opto discrete devices, Photodiodes, LED, Phototransistors, Opto couplers		all
Transistors		all
Transistors microwave		> 300 Krad-Si
Hybrids		all

TNID RHA Scope

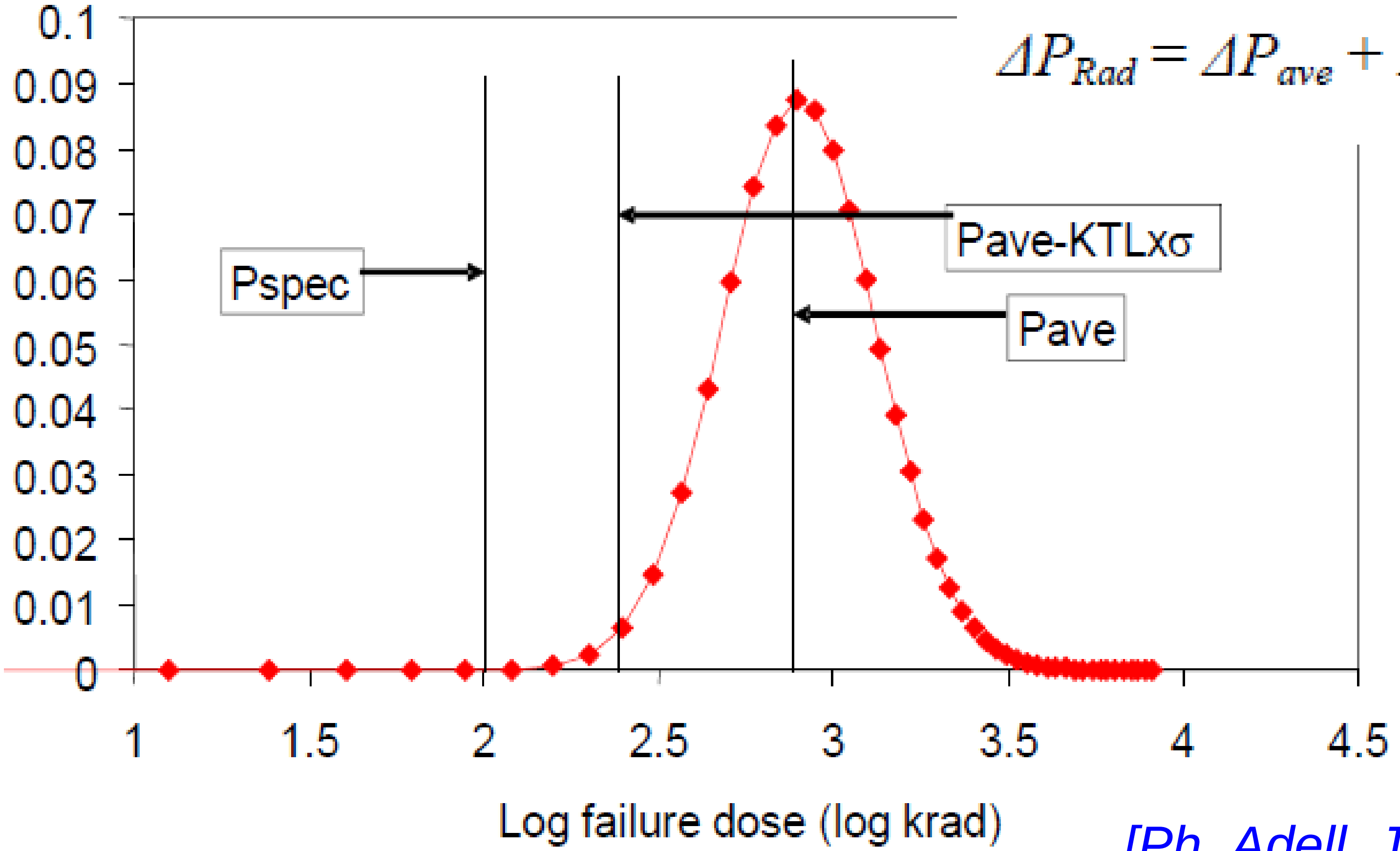
Family	**Sub-Family**	**TNIDL**
CCD, CMOS APS, opto discrete devices	all	all
Integrated circuits	Silicon monolithic bipolar or BiCMOS	> 2×10^{11} p/cm^2 50 MeV equivalent proton fluence
Diodes	Zener Low leakage Voltage reference	> 2×10^{11} p/cm^2 50 MeV equivalent proton fluence
Transistor	Low power NPN Low power PNP High power NPN High power PNP	> 2×10^{11} p/cm^2 50 MeV equivalent proton fluence

Example of part-to-part variation in the same lot – 25 DUTs OP484



[Ph. Adell, JPL Short-Course RADECS 2011]

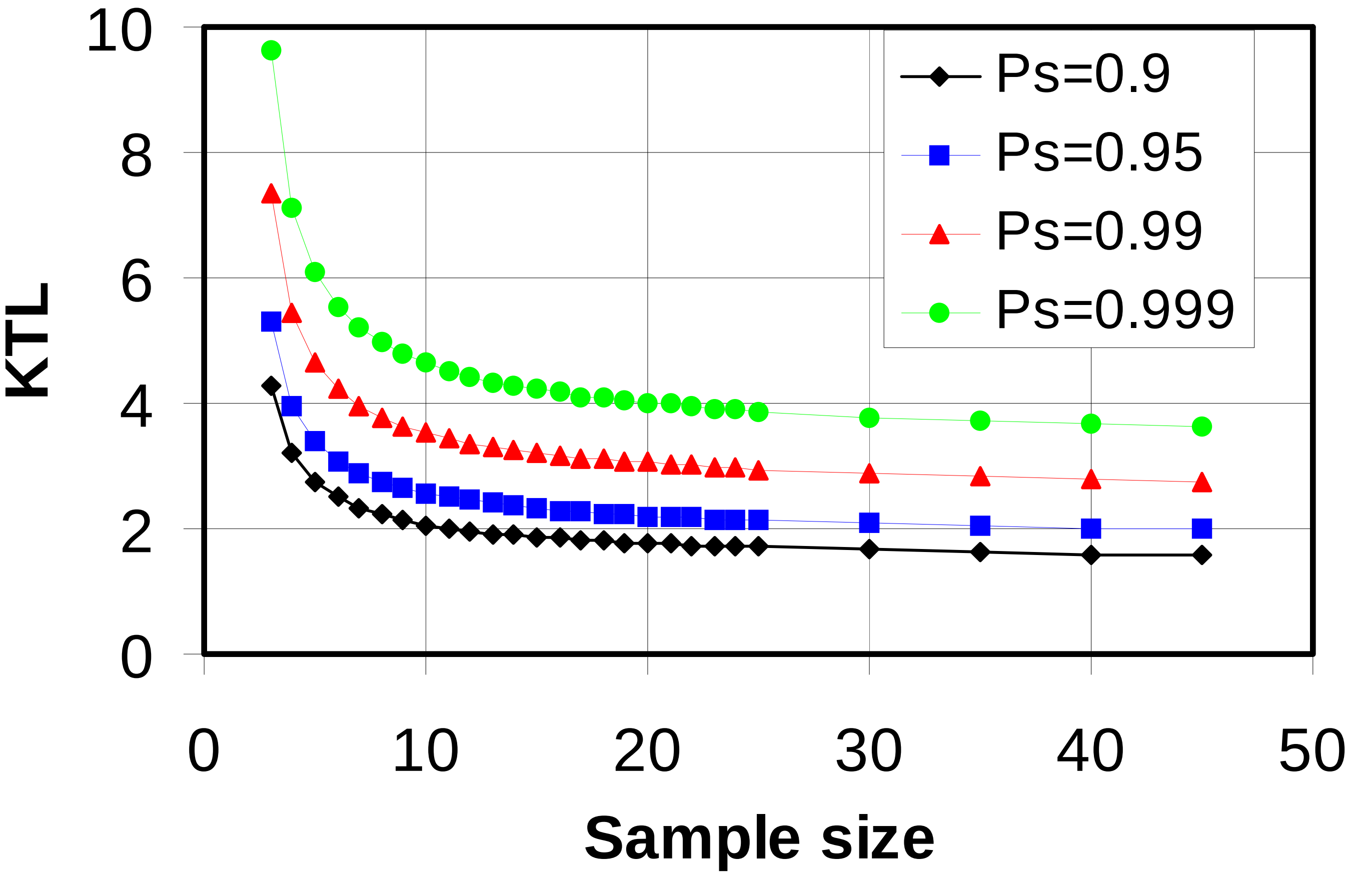
Assumption: The degradation of electrical parameters induced by radiation follows a Log-normal distribution



$$\Delta P_{Rad} = \Delta P_{ave} + K_{TL} * \sigma$$

[Ph. Adell, JPL Short-Course RADECS 2011]

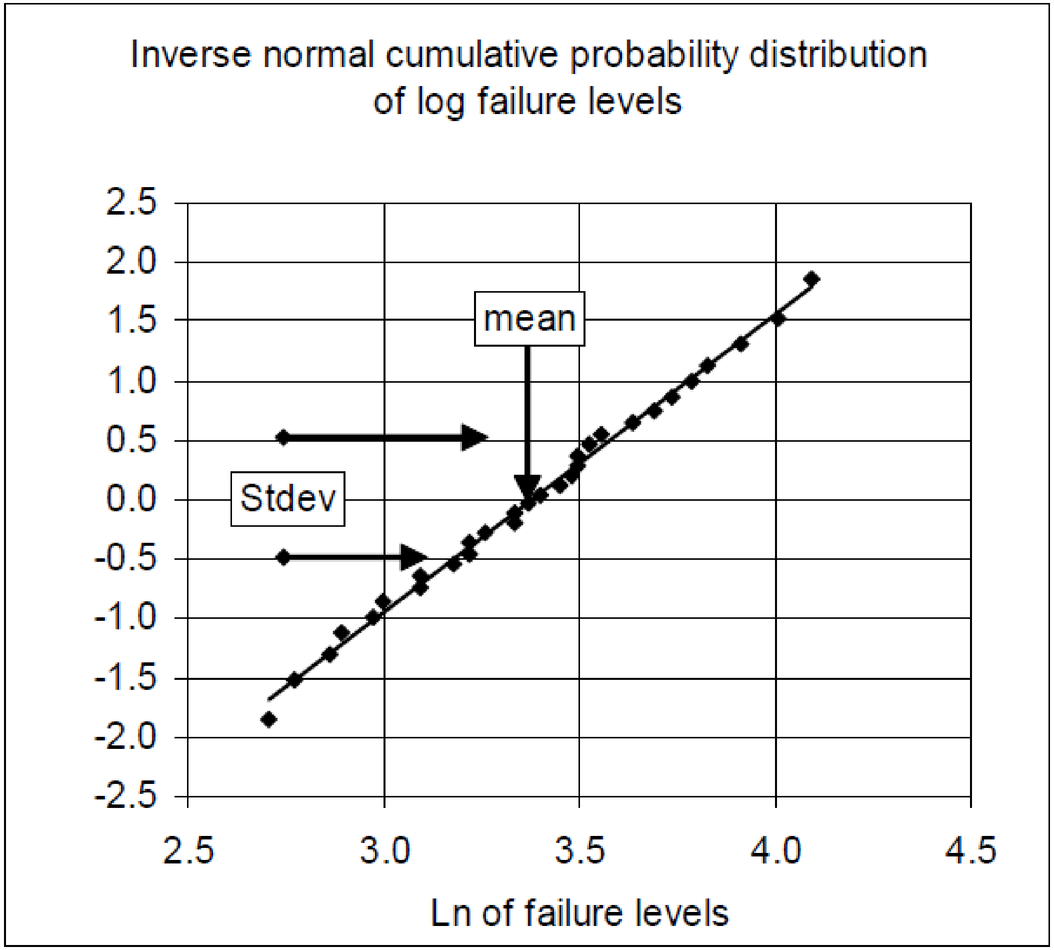
One-Sided Tolerance Limits, K_{TL}, for 90% Confidence



Confidence Limit (CL) and Probability of survival (Ps) are defined by the mission

After R Pease, Rad Phys Chem 43, 1994

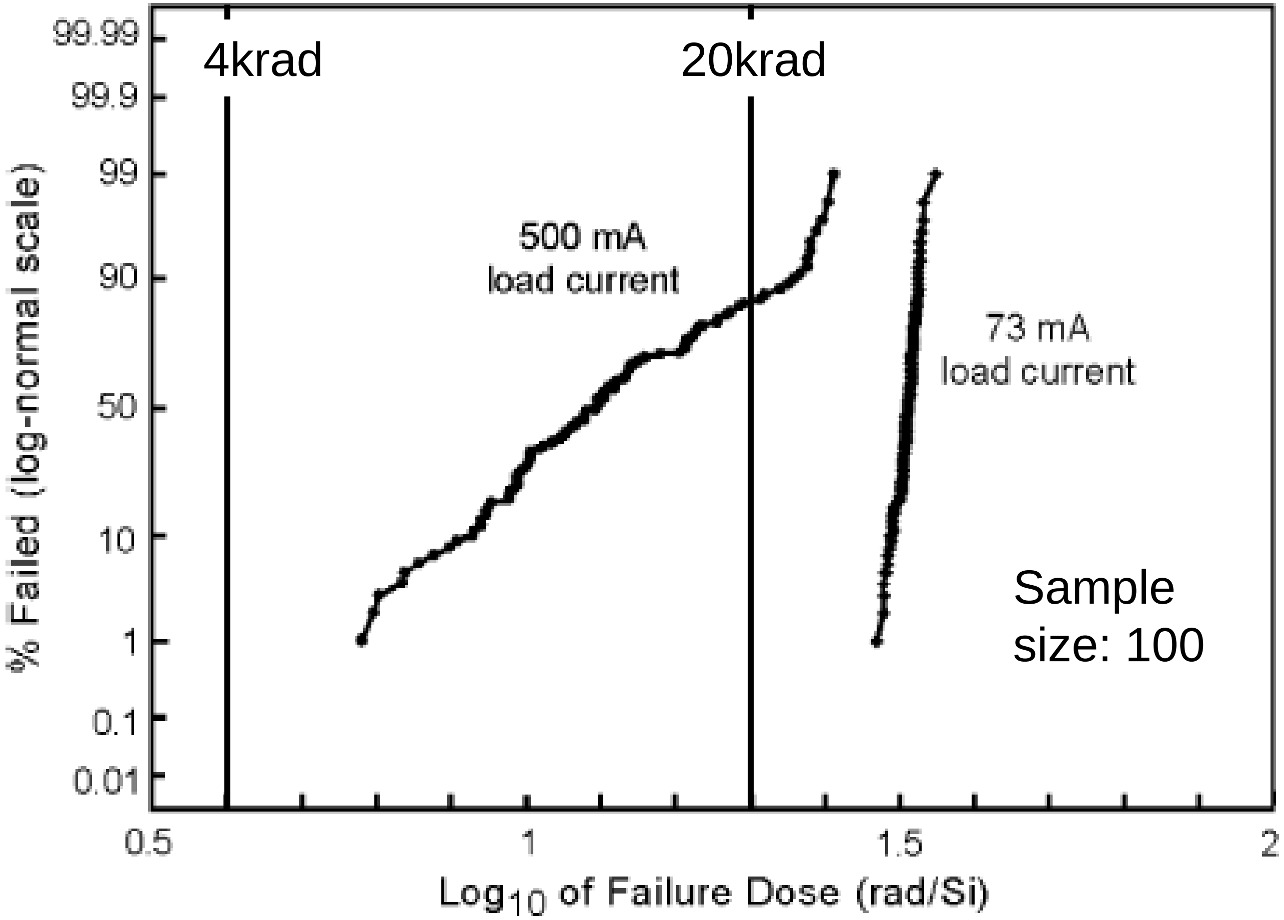
Statistical analysis of TID results: extraction of the normal distribution parameters: mean – standard deviation



Statistical analysis: determination of worst-case parameter deltas for Worst-Case-Analysis

[R. L. Pease, Short-Course NSREC 2004]

Example of statistical TID analysis: LM117 voltage regulator Large distributions of output voltage failure doses



- The operating conditions have a strong impact on the radiation response
- System designers will have to work closely with radiation effects engineers

[Johnston and Rax, TNS Aug. 2010]

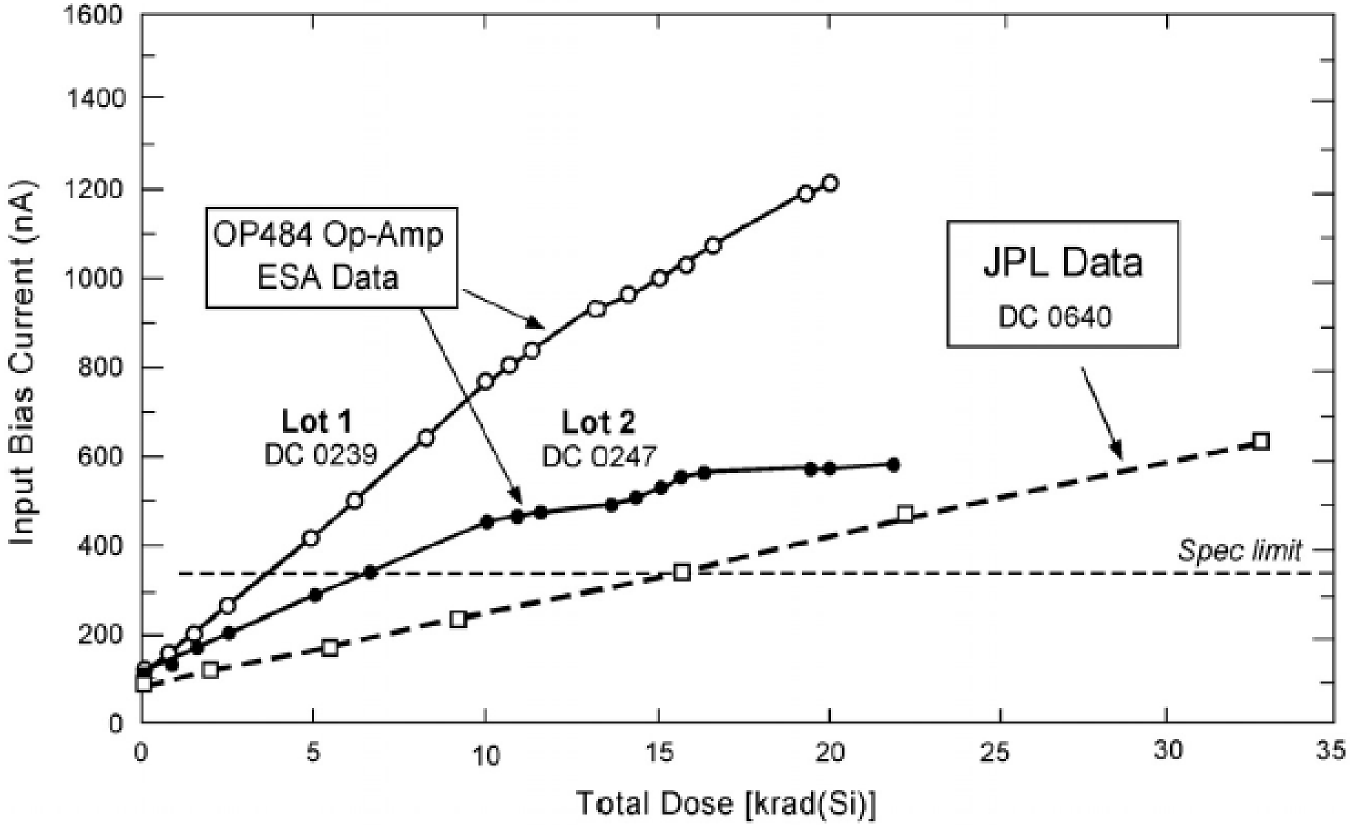
Radiation Design Margin

- RDM is the ratio of device radiation tolerance TIDS out of device radiation requirement TIDL
  - Uncertainties, variability in radiation environment
  - Part to part variations
  - Lot to Lot variations
- Applies also to TNID

[C. Poivey, Short-Course RADECS 2011]

Example of Lot-to-lot variability
The test of the flight lot is mandatory for accurate statistical analysis

Figure 43. Linear regulator I_{out} degradation as a function of total dose @ 50 mrad/s.



- •Average input bias current degradation for 3 Date Codes (lots)
- •TID/TNID irradiation tests to be performed on same lot as FM lot

[Ph. Adell, JPL Short-Course RADECS 2011]

Typical RDMs and RADLAT policy used in programs

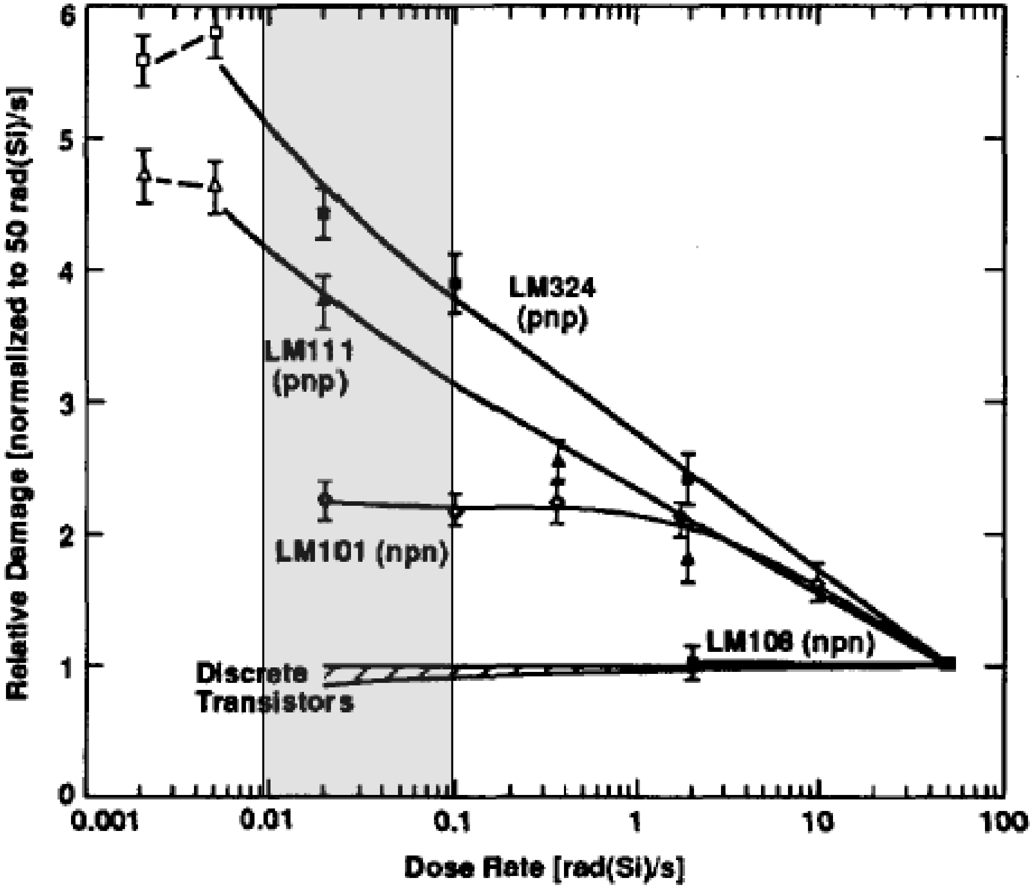
- ESA internal RHA
  - DM > 2 on the WC failure level + systematic lot testing policy
  - Part categorization criteria defined to guarantee a Ps of 90% with a CL of 90% + systematic lot testing policy
- The RDM of 2 can be reduced to 1 if
  - Statistical radiation analysis performed on large sample size
  - Test of the Flight lot
  - In the flight operating conditions or worst-case
- ESA internal RHA are tailored to project requirements

ELDRS in Linear - bipolar based – components: Enhanced Low Dose Rate Sensitivity

Laplace mission receives most of its TID in the vicinity of Jupiter’s moons.

For example, 200krad received within ~40 days results in an average dose rate of ~**200rad/h**

The low dose rate window in ESCC22900: **36-360 rad/h (10-100mrad/s)** is well adapted to the Laplace environment



[A. H. Johnston, et al. TNS Dec. 1994]

Technology Demonstration Activities

Components for Power Systems

Components for Power Systems

- MOS, CMOS
  - CMOS Logic
  - Power MOSFET (60,10, 200V; N channel, P channel)

☺

- Bipolar – BiCMOS
  - Voltage reference (bandgap and Zener)
  - Operational amplifier
  - Voltage Comparator
  - PWM (Pulse Width Modulator) controller
  - Analog Multiplexer
  - MOSFET driver
  - Bipolar transistor (NPN, PNP, small signal, medium power)
  - Schottky diode (small signal, power)

ELDRS
and
DD

?

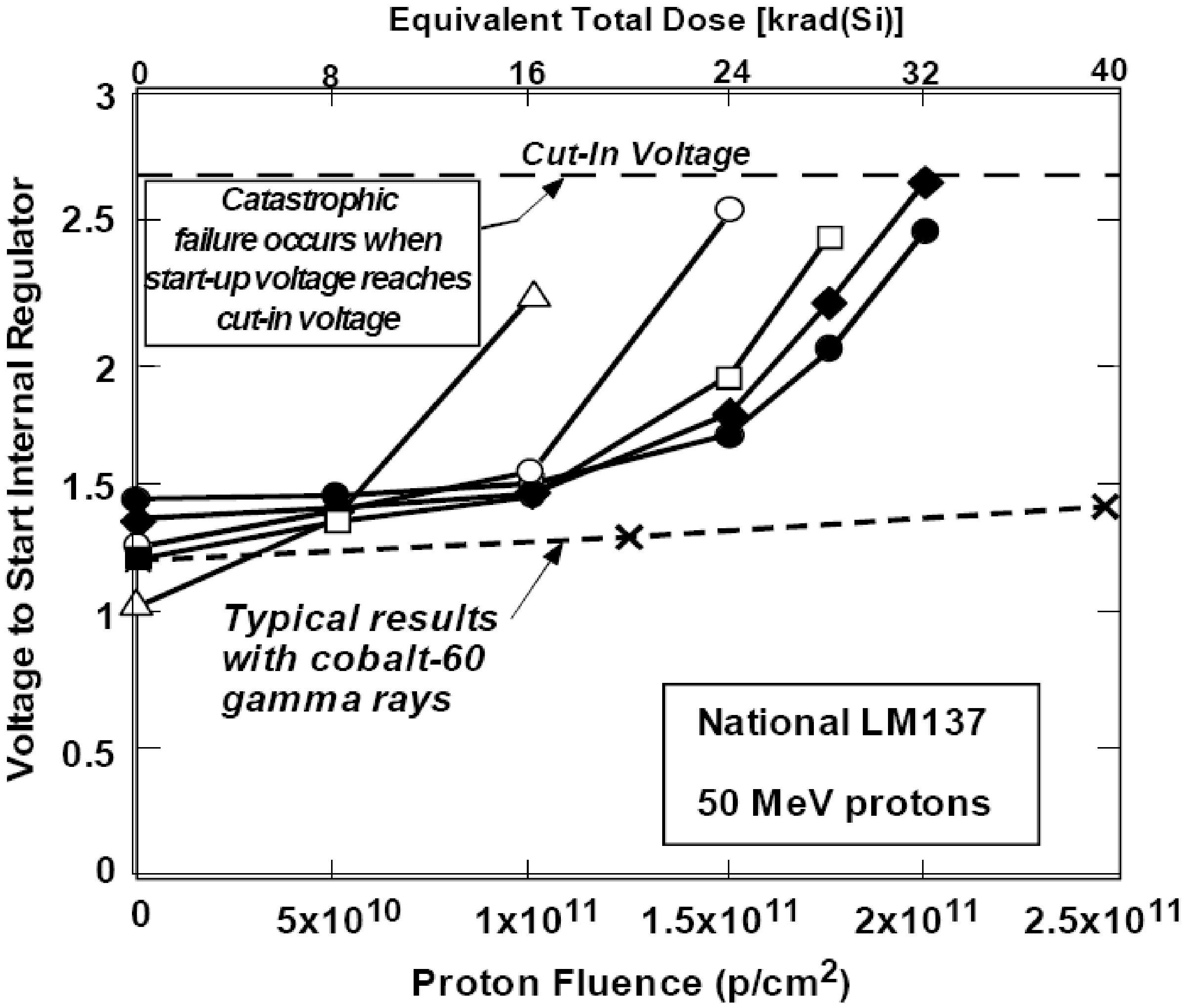
- Optoelectronics
  - Optocoupler

Displacement Damage in bipolar technologies

Voltage Regulator

5 DUTs: large variability

[B. G. Rax et al. TNS Dec. 1999]



Objectives of the Study

- Survey the components required to meet Laplace power requirements
- If radiation data is not available on selected components, they shall be characterized to the **combined effects** of TID up 400krad - and TNID up to a 60 MeV protons fluence of $2*10^{11}$ #/cm^2
- The results of the study are used as inputs to a subsequent activity to design power systems for the Laplace mission. Can we design power systems employing component that may degrade significantly when exposed to Laplace radiation levels?

Final List of Tested Parts

DESCRIPTION	PART-TYPE	MFR	FOR TESTING	TECHNOLOGY	TID	ELDRS	PROTONS
NPN POWER SILICON SWITCHING TRANSISTOR	2N5154	MSC	JANSF2N5154	BIPOLAR	N	Y	Y
NPN SILICON SWITCHING TRANSISTOR	SOC2222A	STM	SOC2222AK2	BIPOLAR	N	Y	Y
DUAL-TRANSISTOR, NPN, SILICON	2N2920A	STM	SOC2N2920AK2	BIPOLAR	N	Y	Y
PNP SILICON AMPLIFIER TRANSISTOR	2N3637	MSC	JANSR2N3637	BIPOLAR	N	Y	Y
PNP SMALL SIGNAL SILICON TRANSISTOR	SOC2907A	STM	SOC2907AK2	BIPOLAR	N	Y	Y
DUAL-TRANSISTOR, PNP, SILICON	2N3810	STM	SOC2N3810AK2	BIPOLAR	N	Y	Y
LOW POWER, NPN (< 2WATTS)	2N3700	STM	SO3700SW	BIPOLAR	N	Y	Y
RAD HARD HIGH FREQUENCY HALF BRIDGE DRIVER	HS-2100RH	INTERSIL	IS9-2100ARH/PROTO	DI RSG	N	Y	Y
DUAL, NON INVERTING POWER MOSFET DRIVERS	HS-4424BRH	INTERSIL	HS9-4424BRH/PROTO	DI RSG BICMOS	N	Y	Y
LOW POWER QUAD BIPOLAR OPERATIONAL AMPLIFIER	LM124AW	NATIONAL	5962R9950402V**	BIPOLAR	N	Y	Y
LOW POWER QUAD BIPOLAR OPERATIONAL AMPLIFIER	RHF43	STM	RHF43K2	BIPOLAR	N	Y	Y
RAD TOLERANT VERSION OF 4N49	OLS449	ISOLINK	OLS449	-	N	Y	Y
LINEAR OPTOCOUPLER	OLH7000	ISOLINK	OLH7000-0011	-	Y (1)	N	Y
SEE HARD HIGH SPEED, CURRENT MODE PWM	IS-1845ASRH	INTERSIL	IS7-1845ASRH/PROTO	DI RSG	N	Y	Y
SEE HARD HIGH SPEED, DUAL OUTPUT PWM	IS-1825ASRH	INTERSIL	IS1-1825ASRH/PROTO	DI RSG	N	Y	Y
SEE HARD QUAD VOLTAGE COMPARATOR	IS-139ASRH	INTERSIL	IS9-139ASRH/PROTO	DI RSG	N	Y	Y
RAD HARD 2.5V REFERENCE	IS-1009RH	INTERSIL	IS2-1009RH/PROTO	DI EBHF	N	Y	Y

Technology Demonstration Activities

Optocouplers, sensors and detectors

- 10 differents types of « slow »and « fast » optocouplers from Micropac, Isolink, Avago.

- TID/TNID tests:
  - Dose (Co60), 36-360 rad/h until 200krad.
  - DD proton, 3 energies (30, 60 et 200MeV).
  - DD neutron 1MeV; separate contributions from TID and TNID

- SEE tests:
  - Three « fast » optocoplers
    - Isolink OLH7000
    - Micropac 66193 et
    - Avago HCPL5431)
  - 3 different proton energies (100, 175 et 250MeV).

- Combined effects: SEE tests of previously TID/TNID irradiated optocouplers

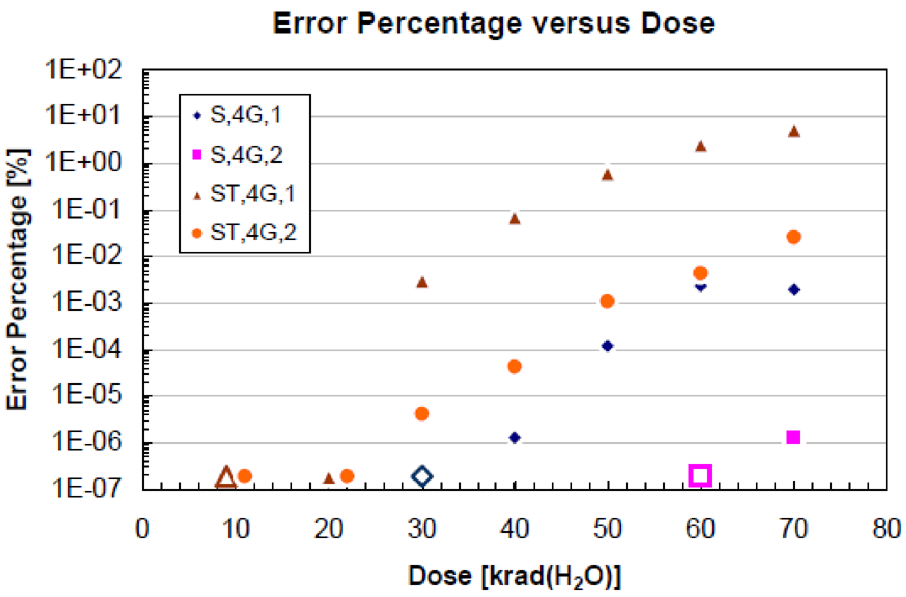
- Are these technologies capable of surviving the Laplace radiation environment?

Technology Demonstration Activities

Radiation testing of candidate memories for Laplace mission

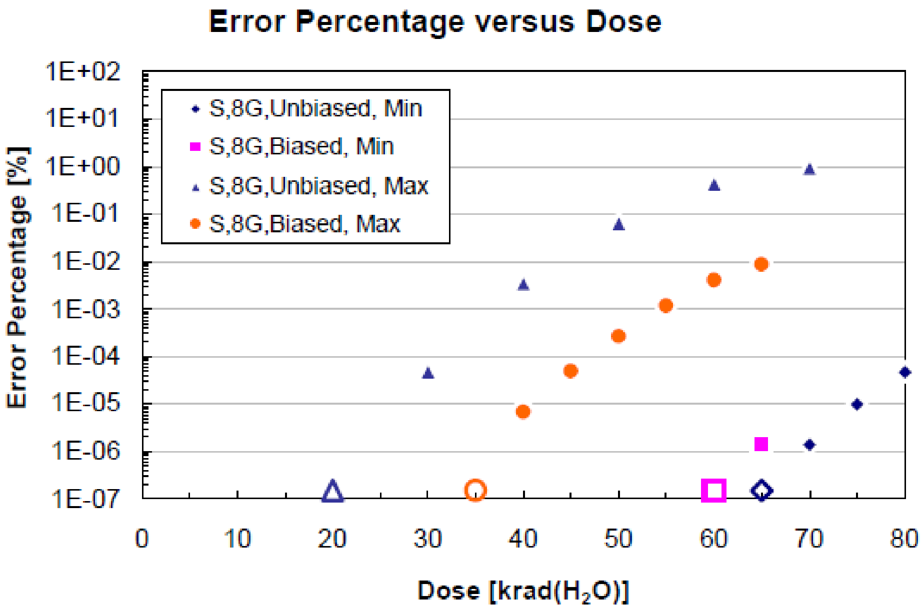
50nm technologies 8-Gbits NAND-Flash TID tolerance ~ 20 krad

8-Gbits NAND-Flash, Samsung & ST



Significant variation, even for same “date code” parts

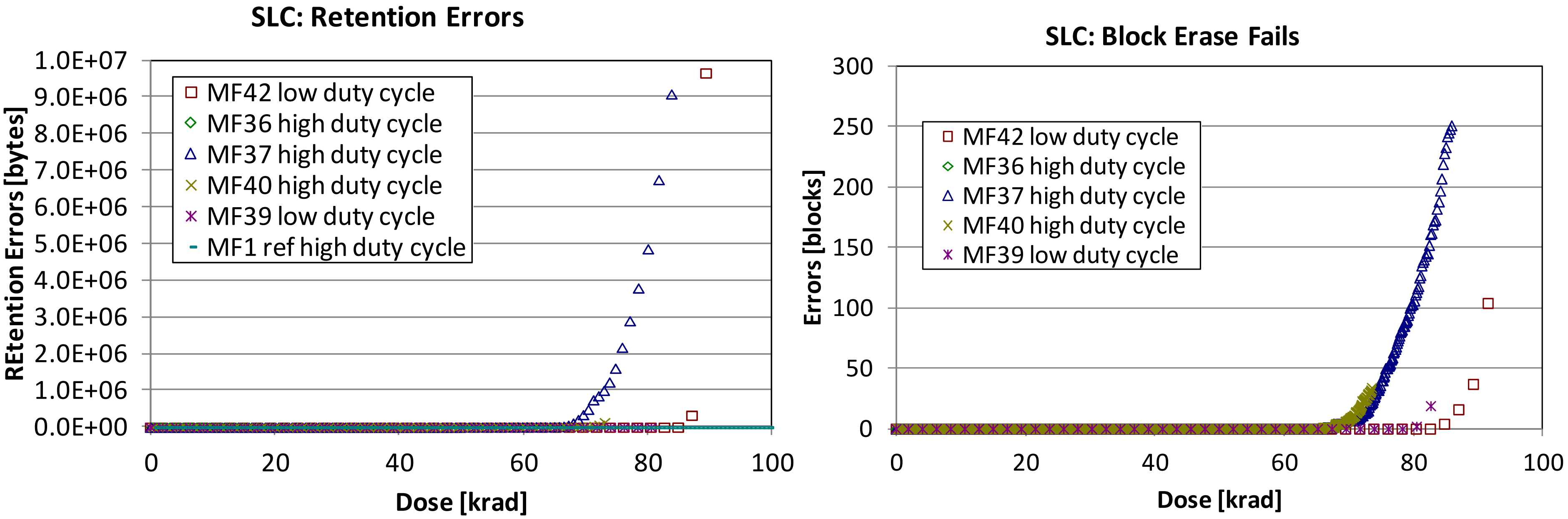
8-Gbits NAND-Flash, Samsung



Biased vs unbiased tests:
10 + 8 samples

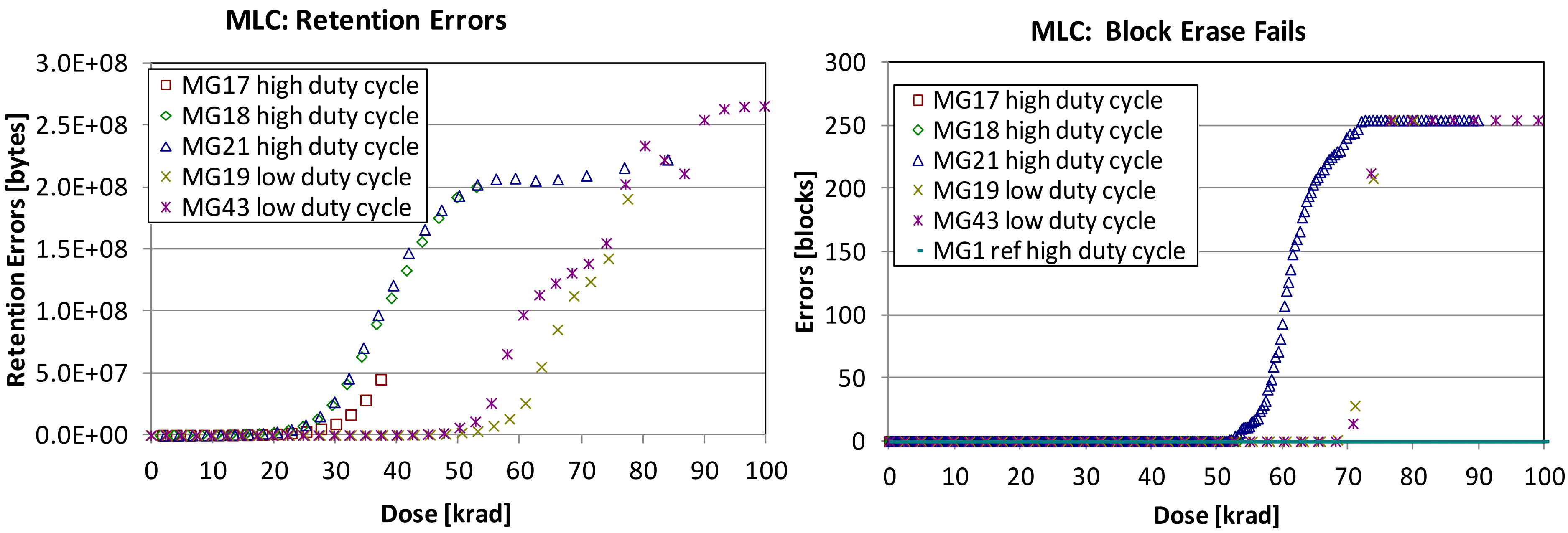
[Schmidt, IDA, 2008] under ESA contract

New generation, 34-nm technology, 16-Gbit Single-Level-Cell Flash Memories : Micron MT29F16G08ABABA Preliminary TID tolerance ~65krad



ESA Contract 2011-2012 RFQ3-13074/10/NL/PA
M. Bagatin, S. Gerardin, A. Paccagnella, Università di Padova

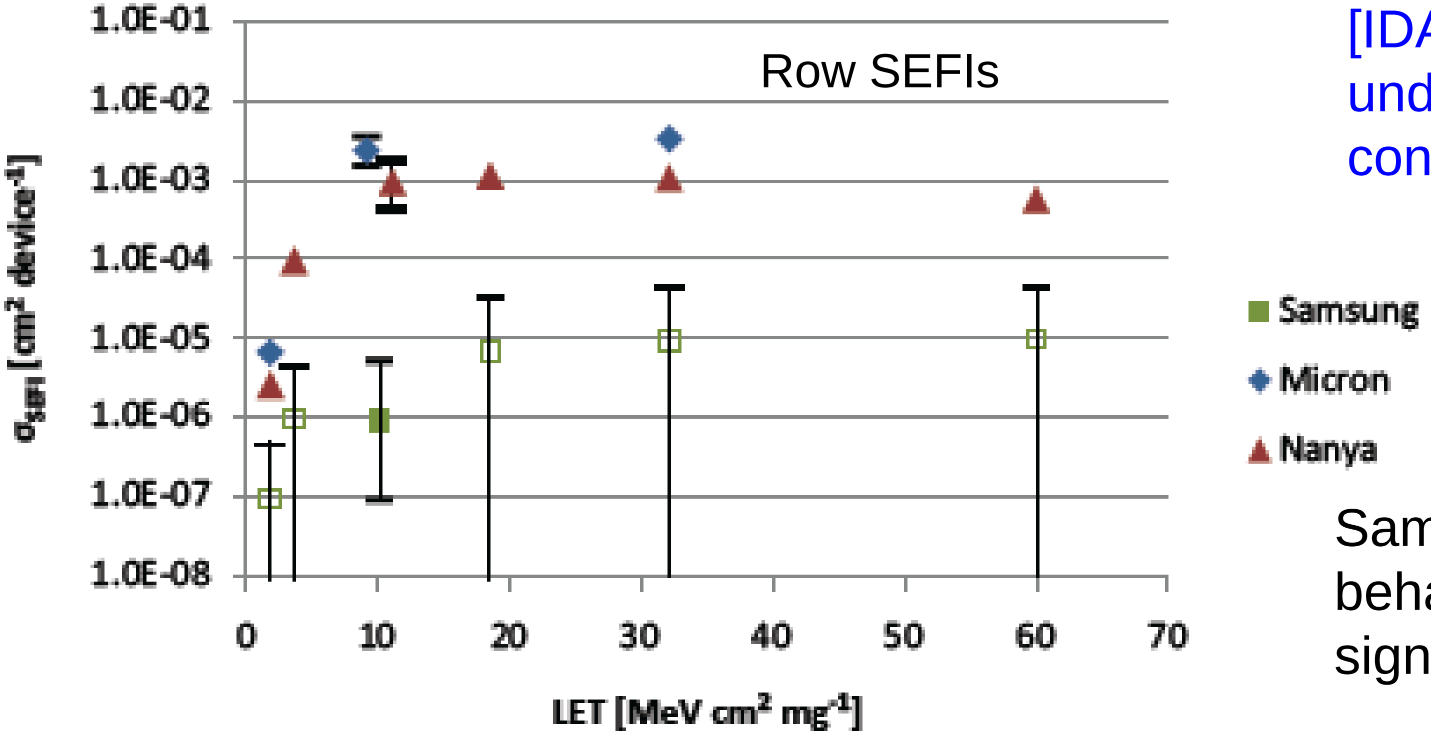
But Multi-Level-Cell (two-bit-per-cell) Flash Memories 25-nm technology, 32-Gbit: Micron MT29F32G08CBACA do not behave as well: TID tolerance ~ 20 krad



ESA Contract 2011-2012 RFQ3-13074/10/NL/PA
M. Bagatin, S. Gerardin, A. Paccagnella, Università di Padova

Some SEE results on DDR3 memories: SEFIs are the dominant source of errors

Micron MT41J256M8 (2 samples, date code 0949)
Samsung K4B2G0846D (3 samples, date code 1006)
Nanya NT5CB256M8BN (3 samples, date code 1026)



[IDA, Radecs2011, under Laplace contract]

Samsung behaves significantly better

Conclusion

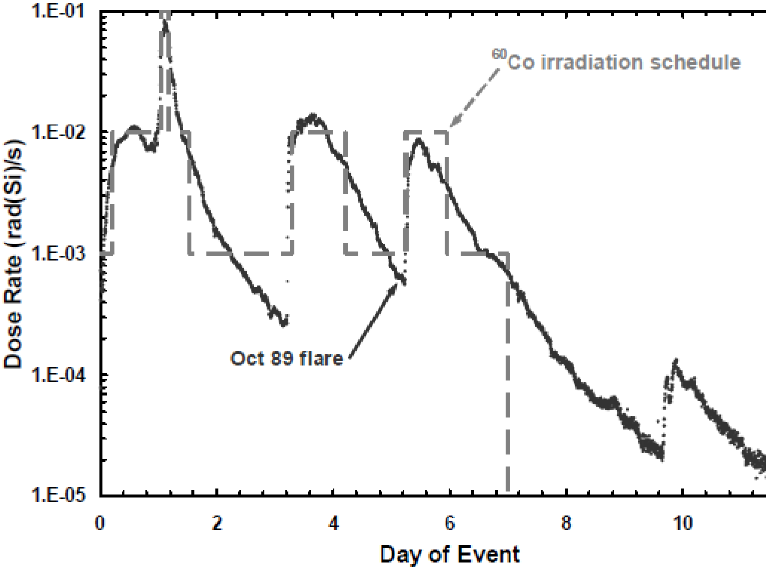
- Radiation environment is severe, but nothing impossible
- Will require careful part selection and RHA process at all levels (systems – components)
  - Radiation tests of electronic components
    - Statistical radiation analysis, to reduce the RDM
    - Tests of the Flight lots
    - in the application conditions (or worst)
  - System Worst-case analysis
    - Robust designs
  - RHA process to be started in early project phases
- Compromises between shielding mass & radiation tolerance

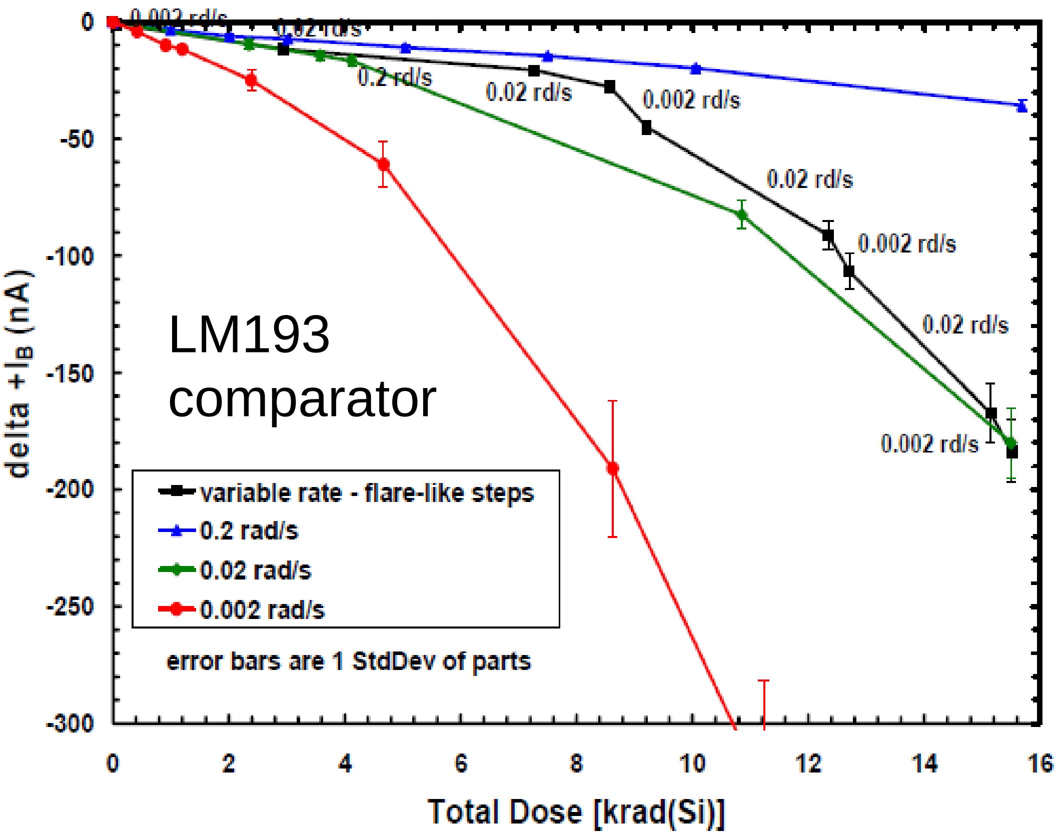
Links to

- ESCC web site
  - https://spacecomponents.org/
  - EPPL
- ESCIES web site
  - https://escies.org/
  - Test facilities
  - Standards and handbooks
  - Radiation database

Back-up slides

Example of the Oct. 89 solar flare: applicable to variable dose rate missions





low dose rate window in the ESCC22900:

36-360 rad/h = 10-100mrad/s

[R. D. Harris, TNS Dec. 2008]