European Space Agency EEE Component Radiation Hardness Assurance related R&D activities

Cesar Boatella Polo
Ali Zadeh
Véronique Ferlet Cavrois
Christian Poivey

Introduction

- ESA spacecraft are designed to carry out a variety of missions covering Space Science, Earth Observation, Telecommunication, Navigation, Human Spaceflight and technology demonstration type programmes. Launcher development is also part of the ESA mandate.

- The space environment for which ESA spacecraft operate is in many aspects different from the terrestrial environment. We are concerned about environments such as:
    - vacuum
    - thermal environment
    - Atomic oxygen
    - UV radiation
    - high energy particle radiation environment.
    - Etc.

Introduction

- The space radiation environment detrimentally affects EEE components flown on ESA space missions. The impact on electronic components vary from slow degradation of electrical parameters, due to cumulative effects to sudden unwanted events due to transient effects.

- The interplay between energetic particles impinging components in space, the particular radiation effect(s) induced and the subsequent electronic component response is complex.

- The manner for which a EEE component behaves in its application depends on a number of factors such as:
    - Spacecraft orbit
    - The location of the component in the spacecraft (shielding conditions)
    - Thermal environment
    - Application conditions

Introduction

- **To ensure that EEE components are suitable for flight in their applications on ESA space missions, strict RHA processes are followed.**

What is Radiation Hardness Assurance

- 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.
- RHA deals with:
    - environment definition,
    - part selection,
    - part testing,
    - spacecraft layout,
    - radiation tolerant design,
    - and mission/system/subsystems requirements.

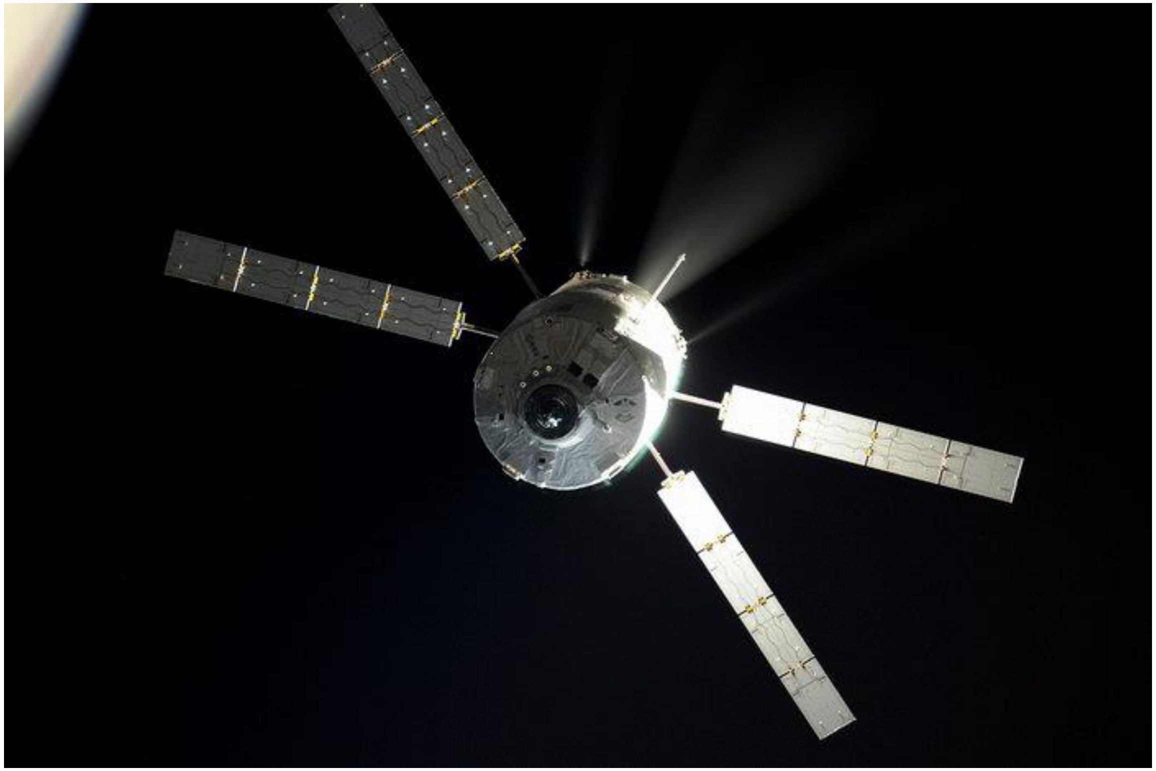
OUTLINE

This presentation is divided in two parts

1. Description of ESA's RHA requirements

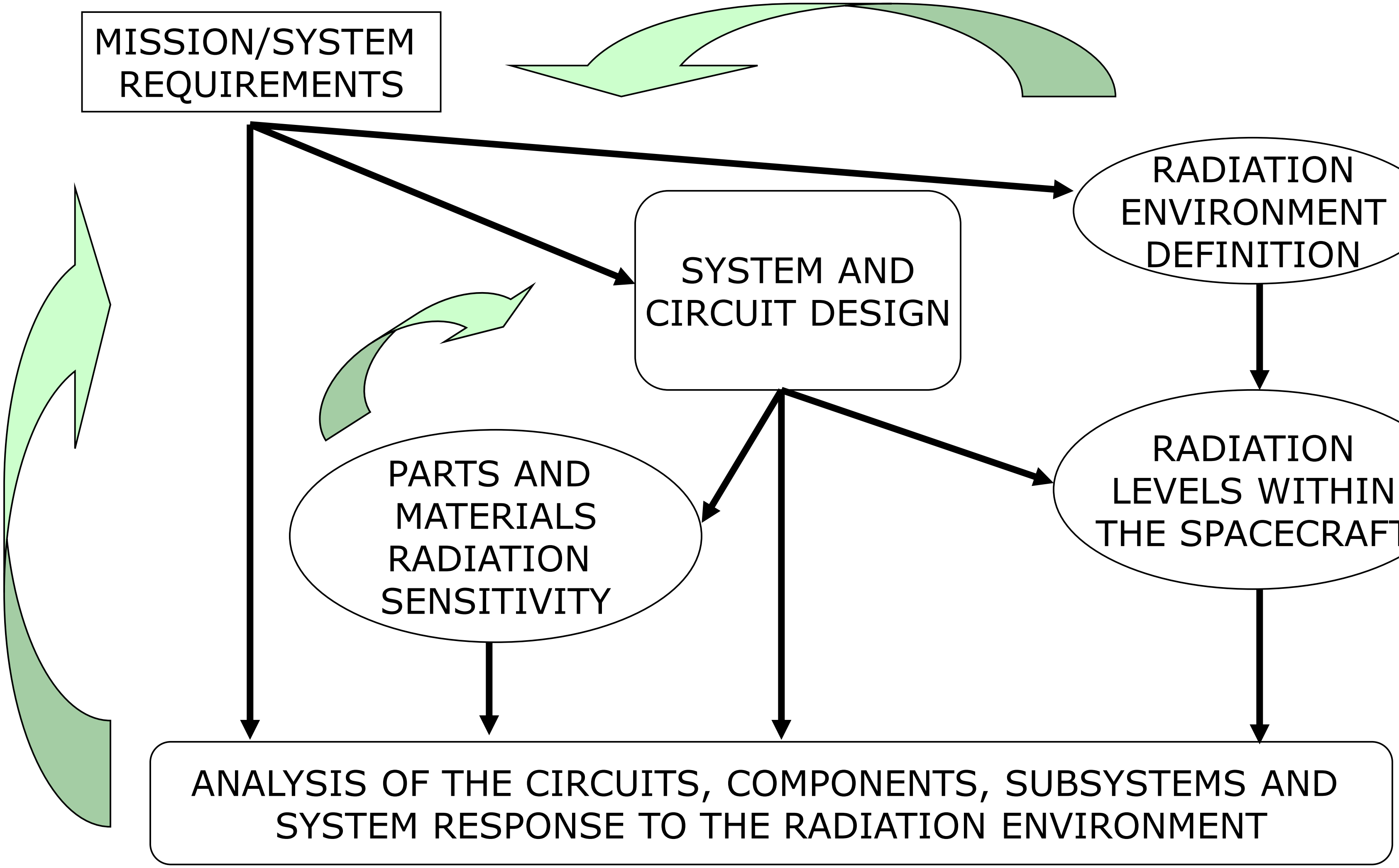
2. Radiation related R&D activities in the frame of ESA's JUICE mission

Radiation Harness Assurance

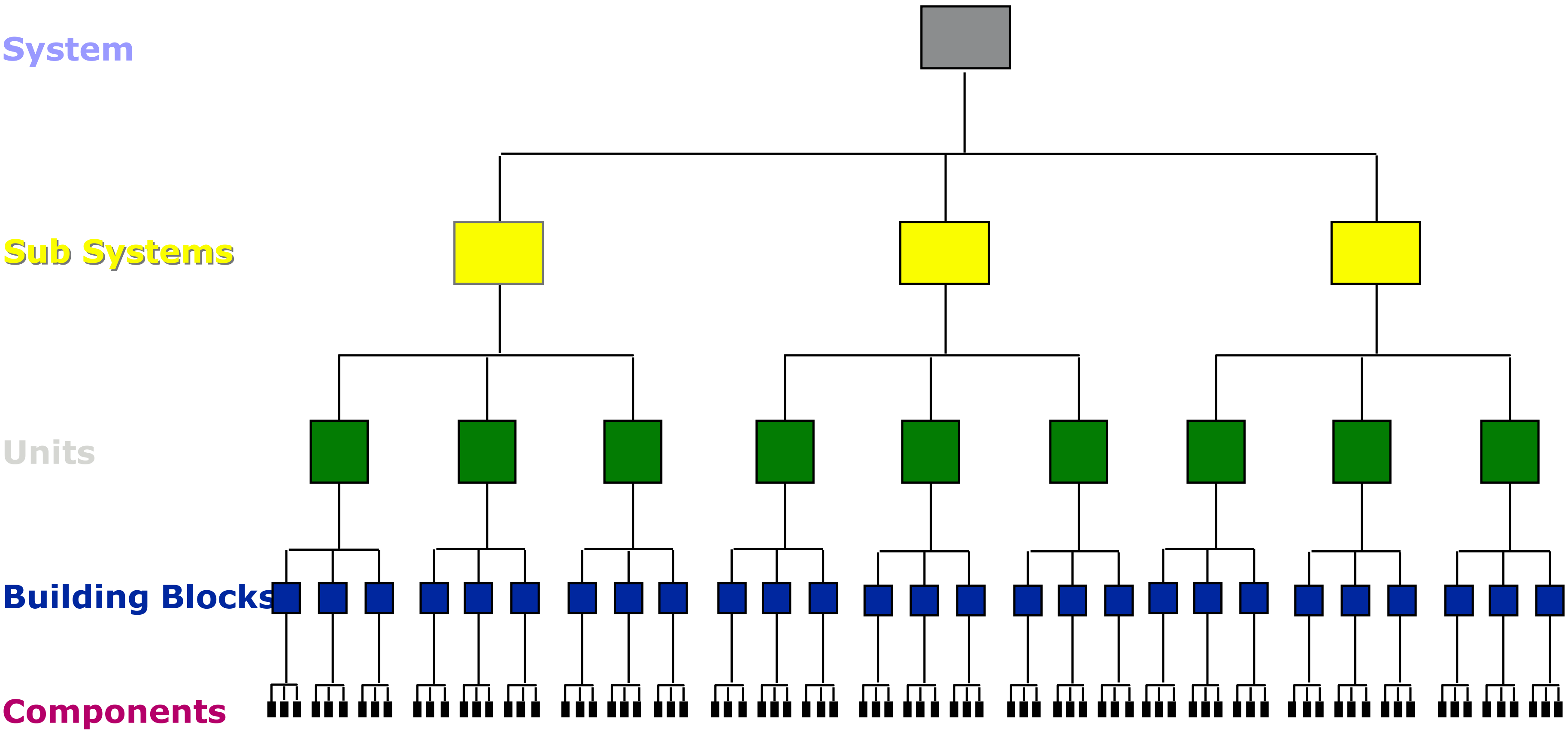


Automated Transfer Vehicle (ATV) approaching the International Space Station (ISS)

RHA Overview

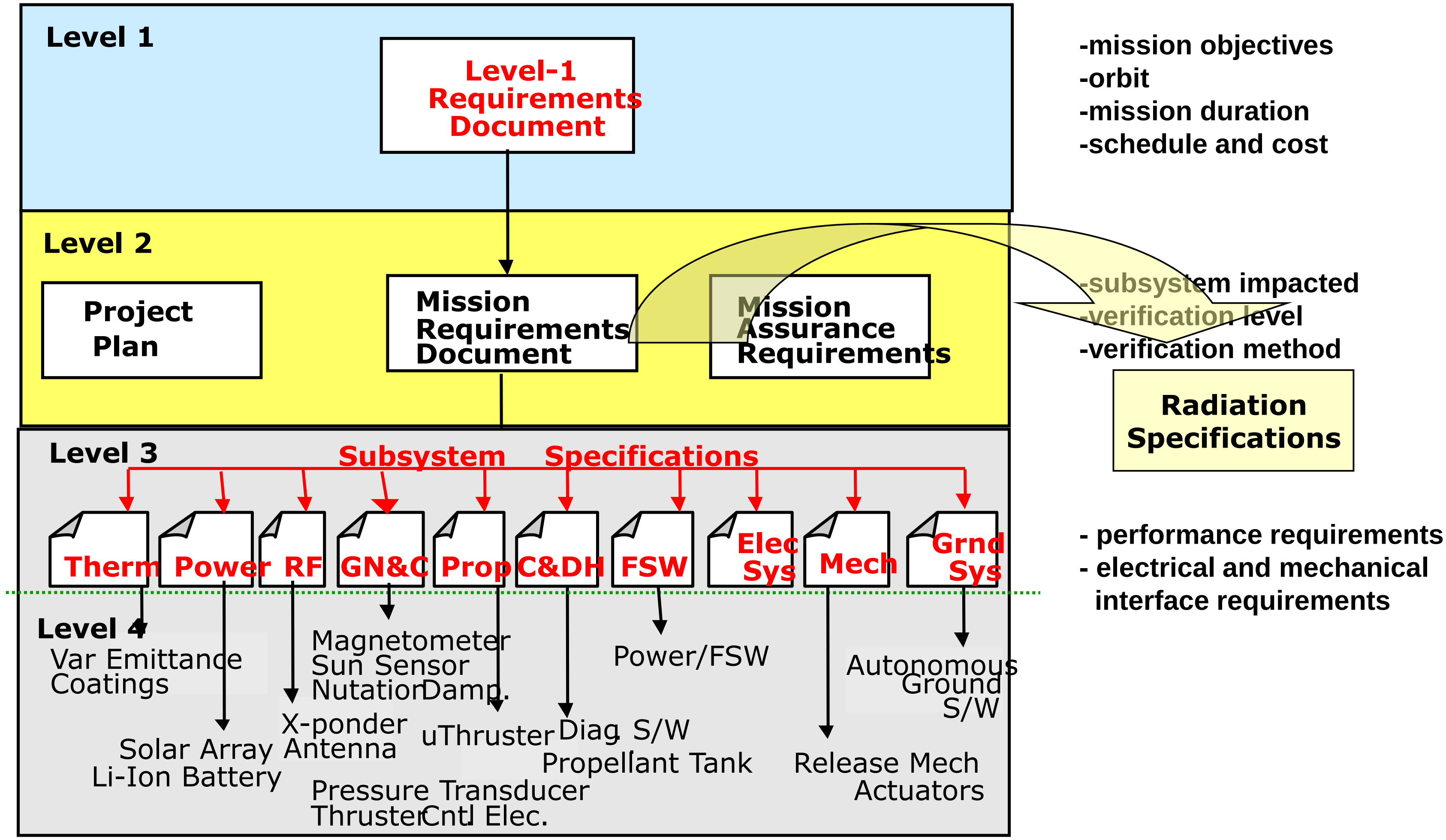


System Hierarchy



The smallest System shown is at 'Building Block' level (e.g. a circuit board), made up from 'Components'

Project Requirements Flow-Down



Hardness Assurance Requirements/standards

1. European Component Space Standardisation (ECSS)
    a. ECSS-Q-ST-60-15C, Issue 1, October 2012

2. Examples of ESA tailoring
    a. ESSB-AS-Q-008, Issue 1, October, 2013
        – Adoption notice of ECSS-Q-ST-60-15C
    b. The standard has also been tailored for projects such as:
        – MTG (Earth Observation Mission)
        – JUICE (Jupiter Mission)

- Used as stand alone applicable documents or included in systems/ Subsystems or Payload Requirement document:
    - Product Assurance Requirement Documents (PARD)
    - User Requirement Document (URD)
    - Experiment Interface Document – Part A (EIDA)

Mission Radiation Environment Specification

1. Depends on orbit and mission duration
    a. Particle fluxes, incident and shielded
    b. Dose versus depth curve
    c. Displacement Damage versus depth curve
    d. LET spectra (used for SEE rate prediction)
2. ECSS-E-ST-10-04

- Used as stand alone applicable documents or included in systems/ Requirement document:
    - Satellite Environment and Test Specification (EDTRS)

Other requirements related to RHA

1. **ECSS-E-ST-10-12C**, Methods for the calculation of radiation received and its effects, and a policy for design margin

- **US MIL-HDBK814**, Ionizing Dose and Neutron HA Guidelines for Microcircuits and Semiconductor Devices, 1994.

2. **ECSS-Q-ST-60**, EEE components [AD-Q60]
3. **ECSS-Q-ST-30**, Dependability [RD-Q30]
4. **ECSS-Q-ST-30-11**, EEE components, derating [AD-Q30-11]
5. **ESCC22900**, TID test method
6. **ESCC25100**, SEE test method
7. **MIL-STD-750 method 1080**, SEB/SEGR testing

ESA Radiation Hardness Assurance requirements.

ESA applies a tailored version of the ECSS-Q-ST-60-15C on its space projects

ESA regularly develops one-off type space missions operating in highly varying environments, shielding configurations and applications.

Although the basic RHA standard applied is the same. In some cases the RHA standard requires further tailoring due to the uniqueness of the ESA space missions.

The RHA standards covers Total Ionising Dose (TID), Total Non-Ionising Dose (TNID) and Single Event Effects (SEE)

RHA for TID and TNID

- **TID and TNID are cumulative effects**
- **TID:**
  - Ionizing Radiation Creates Oxide- And Interface-Trap
  - Energy deposited by photons or ions: uniformed or localized
  - Leads to gradual electrical parameter changes
- **TNID:**
  - Defect creation via elastic or inelastic collision of particles with semiconductor lattice atoms.
  - concentration of defects depends only on Non Ionising Enery Loss and not on the type and initial energy of the particle
  - Defects lead to gradual electrical parameter changes

Radiation Design Margin

To account for uncertainties in parameters such as part-to-part variations, environment definition and models, Radiation Design Margins are applied. RDM is associated with cost and shall be selected to ensure the components function within required specification for the duration of the spacecraft lifetime.

Philae separation from Rosetta. Rosetta is an long duration interplanetary mission and had an RDM requirement of 2.

Radiation Design Margin for TID and TNID

- **Radiation Design Margin is an important part of RHA**
- **TID and TNID RDMs are defined already in the initial RHA requirements.**
- **To prove that EEE components are compliant with the RDM requirement two parameters are required:**
    - **TIDL and TNIDL** calculated TID and TNID level received by the part at the end of the mission
    - **TIDS and TNIDS** level at which the part exceeds its parametric/functional requirements
- **RDM is calculated by**
    - TIDS/TIDL and TNIDS/TNIDL

TID RHA, Scope

Generic table of the TID level (TIDL) for which TID analysis of EEE components is required

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

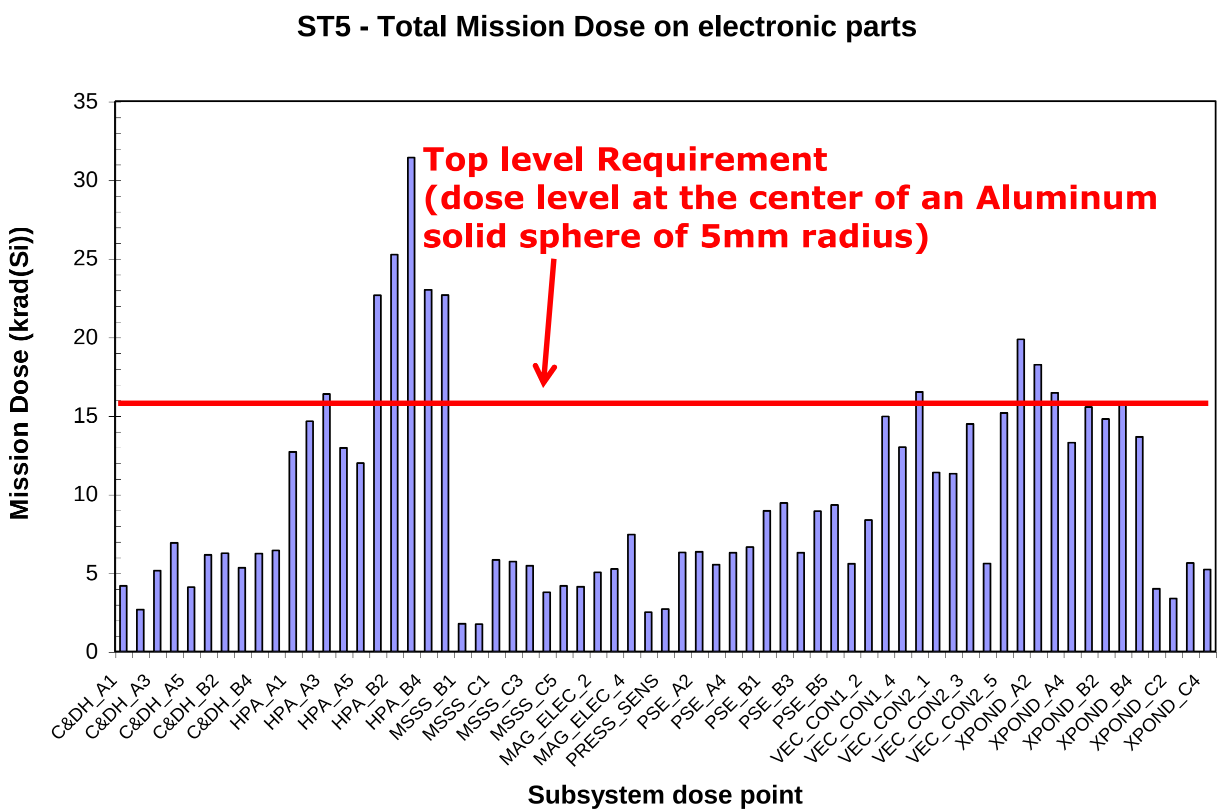
TNID RHA, Scope

Generic table of the TNID level (TNIDL) for which DD analysis of EEE components is required

Family	Sub-Family	TNIDL
CCD, CMOS APS, opto discrete devices	all	all
Integrated circuits	Silicon monolithic bipolar or BiCMOS	> $2x10^{11}$ p/cm^2 50 MeV equivalent proton fluence
Diodes	Zener Low leakage Voltage reference	> $2x10^{11}$ p/cm^2 50 MeV equivalent proton fluence
Transistor	Low power NPN Low power PNP High power NPN High power PNP	> $2x10^{11}$ p/cm^2 50 MeV equivalent proton fluence

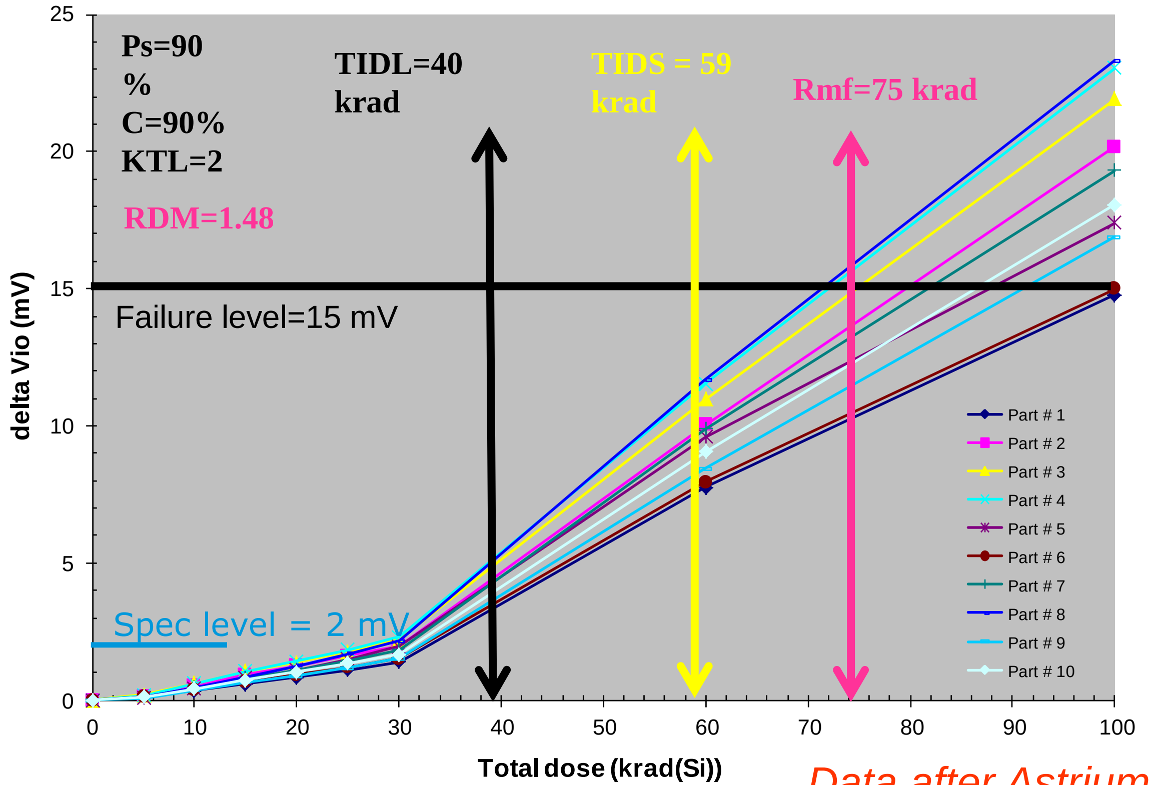
TIDL (TNIDL) Top Level Requirement versus actual dose levels

- TIDL (TNIDL) are calculated employing space radiation environment and spacecraft shielding information.
- TIDL and TNIDL vary for equipment at different locations of the spacecraft



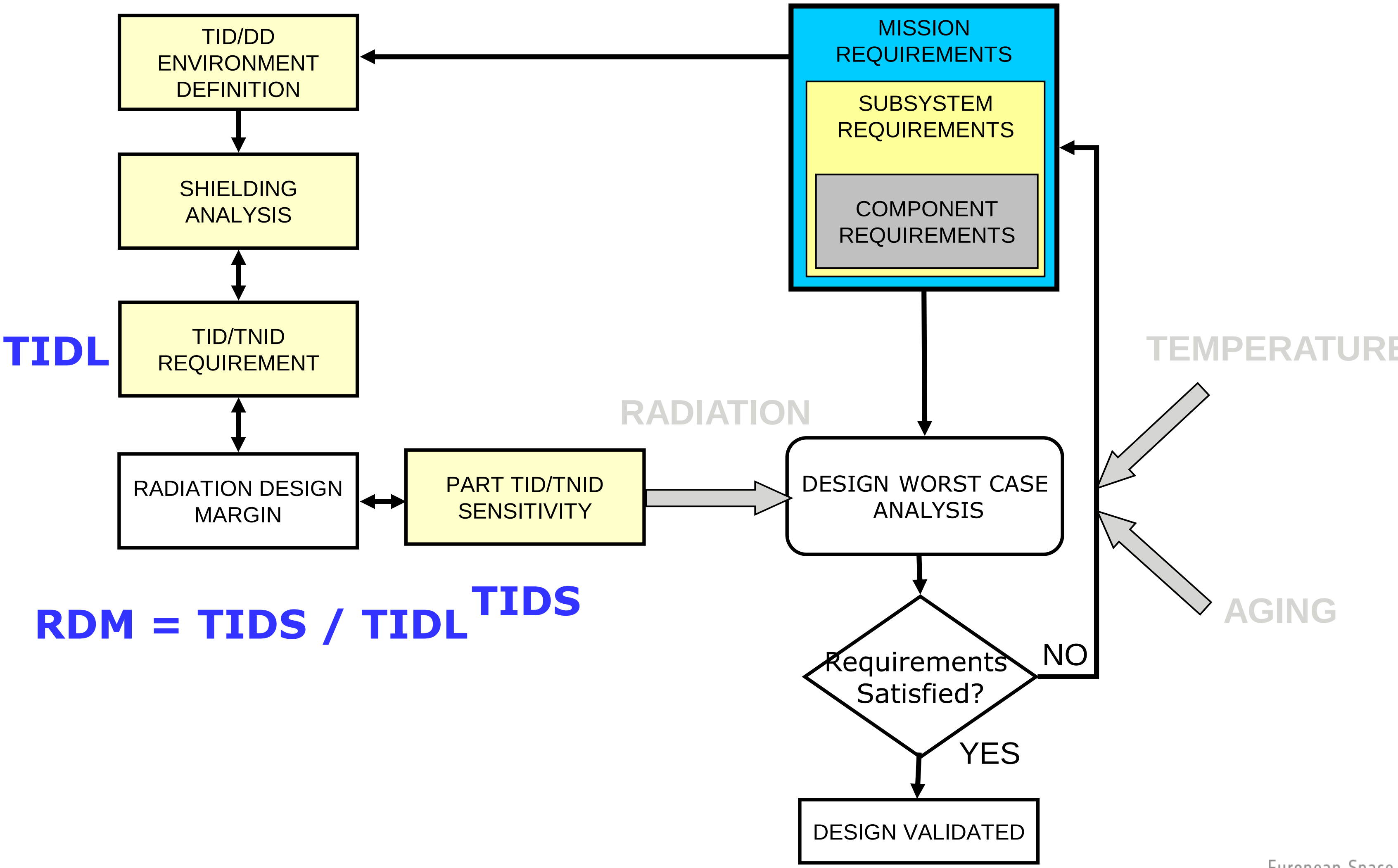
Measuring TIDS (TNIDS) and Example of Application analysis

TIDS (TNIDS) is measured by performing TID (TNID) irradiation tests on EEE components.



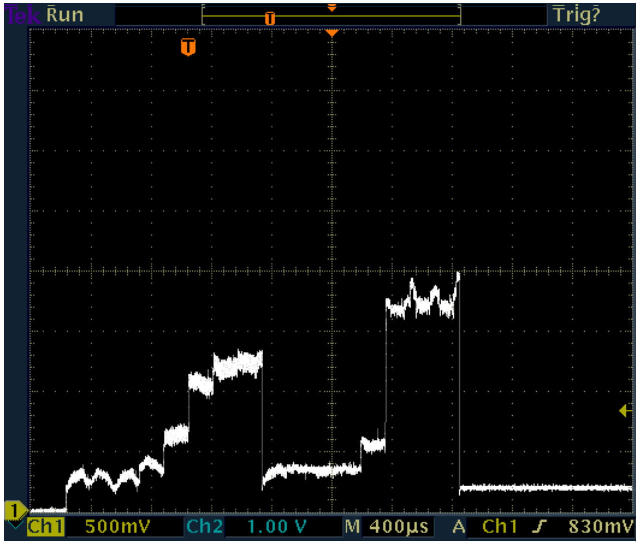
Data after Astrium test report 20

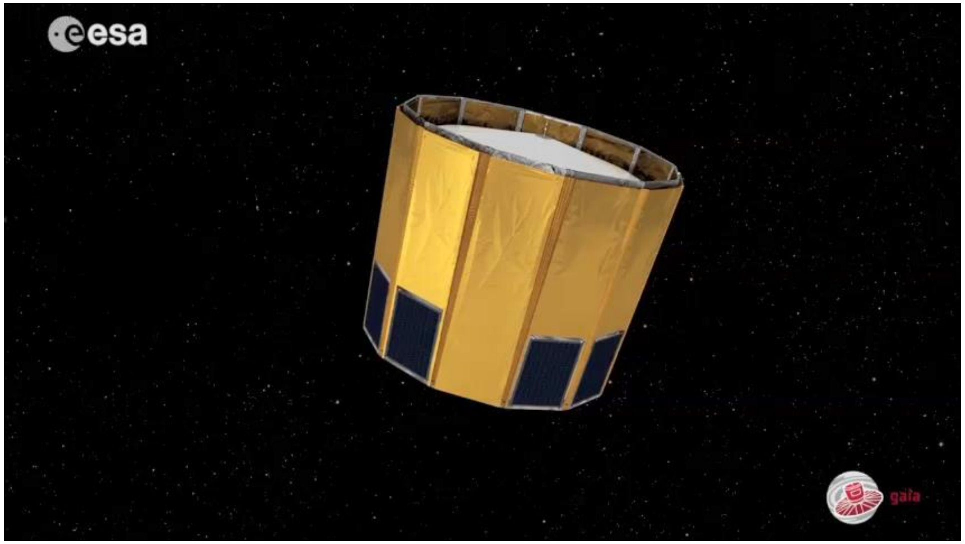
TID / TNID - Analysis Flow



TID test example of sensitive parts

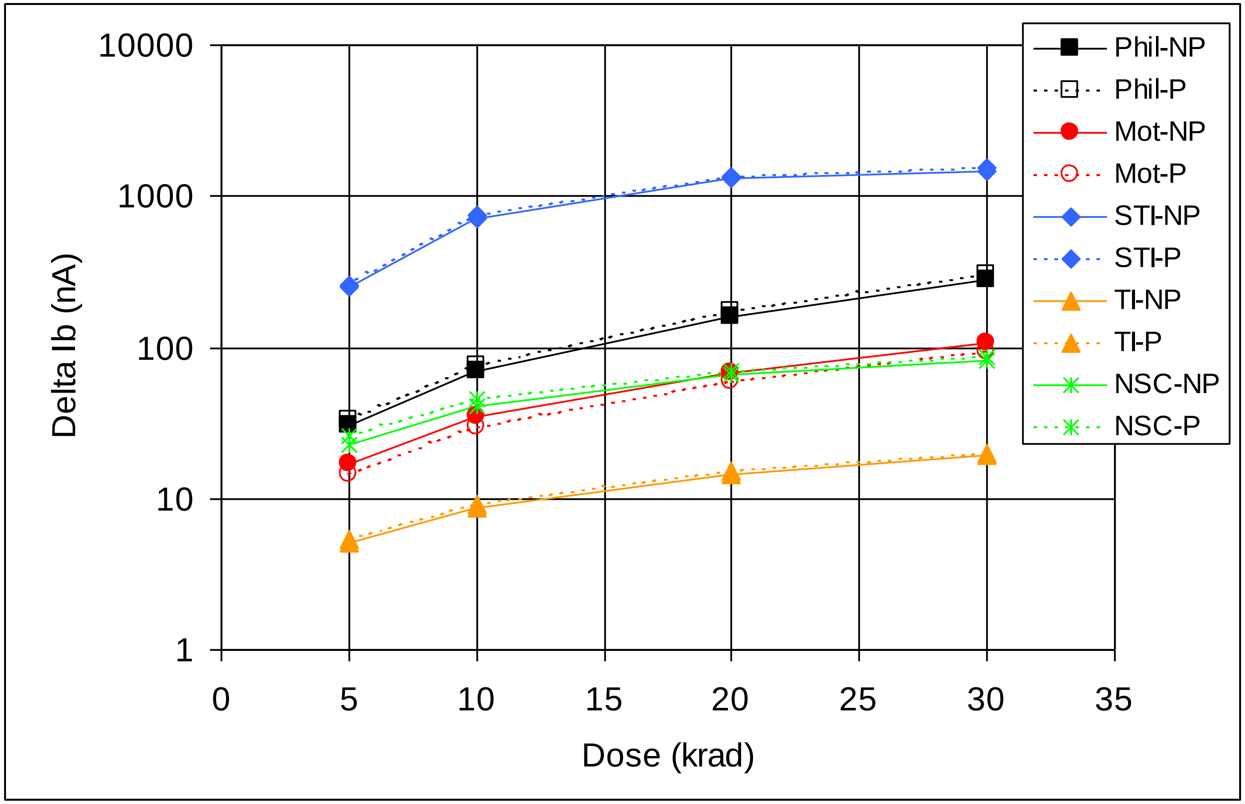
1. DAC8800 on GAIA
   - Spec Total Unadjusted Error (TUE): +/- ½ LSB
     - Out of spec limit after 2 Krad
     - TUE > 100 LSB after 5 Krad





2. OP267 on SWIFT
   a. Functional failure after 1 Krad

Variability of TID response, example LM311

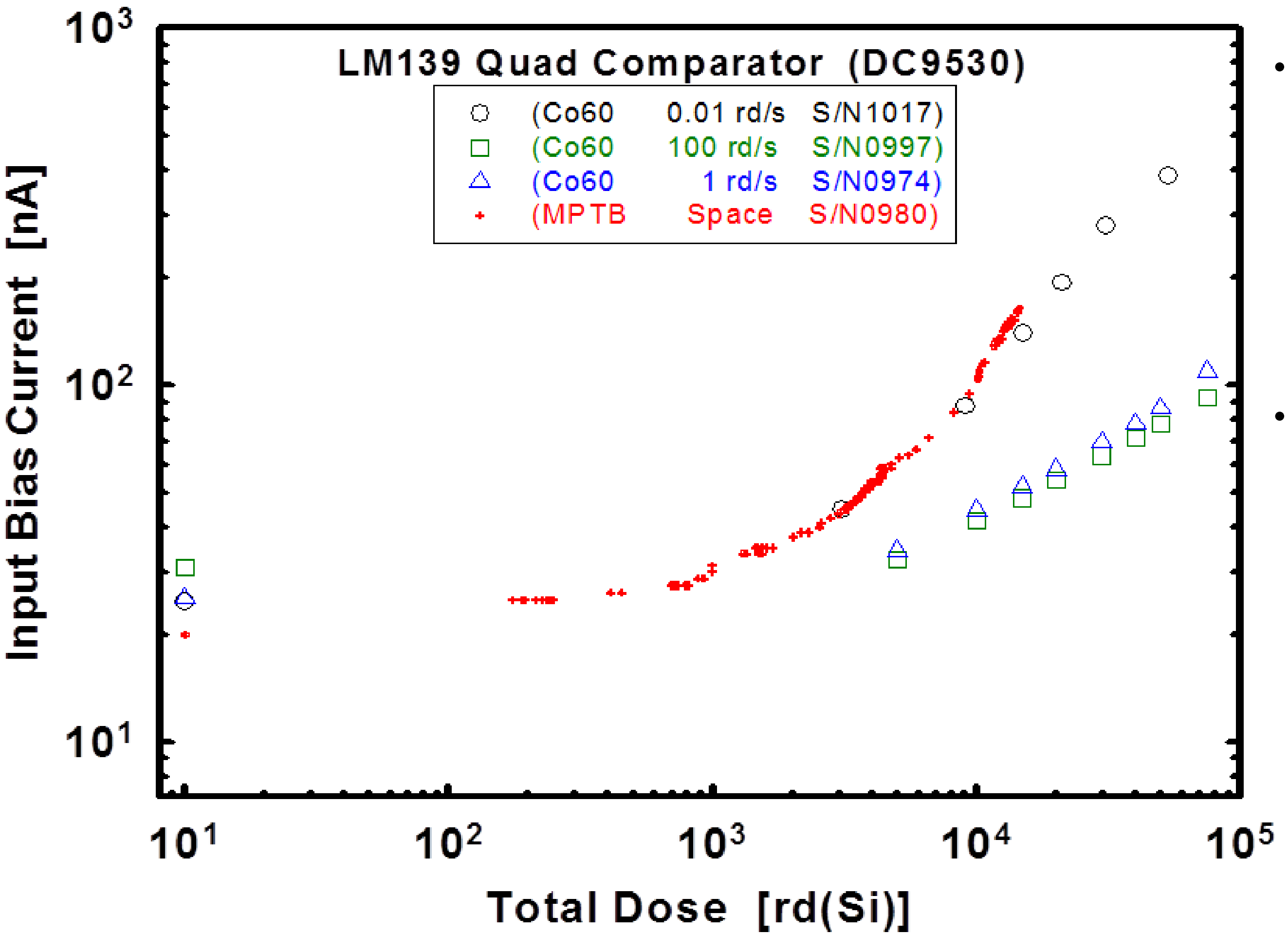


Radiation performance of LM311 from different manufacturers.

TID response may vary significantly between EEE component manufacturers even for the same component type.

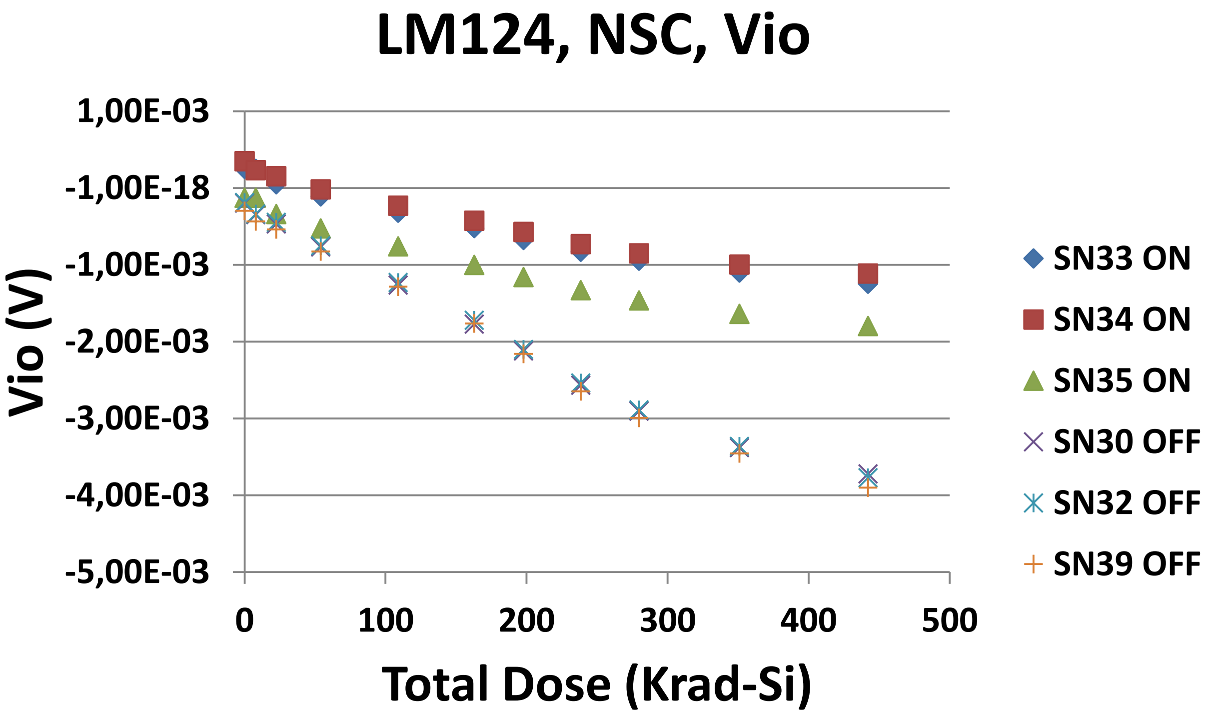
It is crucial to perform irradiation tests to identify EEE component performance when exposed to high energy particle radiation.

ELDRS of bipolar devices, Example



- devices that contain bipolar transistors are tested at a dose rate of 36 rad/h to 360 rad/h (ECSS-Q-ST-60-15C)
- ESA Tailoring states: Devices that contain bipolar transistors are tested at a dose rate of 36 rad/h unless pertinent test data from previous tests have demonstrated the worst case condition at a different dose rate

Bias effect, example

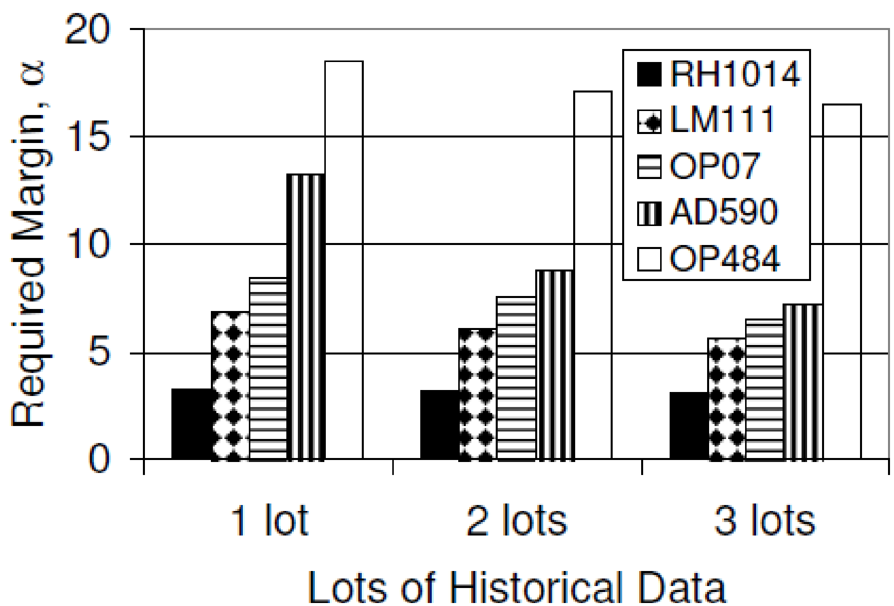


The biasing conditions of a EEE component can have significant impact on the performance of EEE components when exposed to high energy particle radiation.

Radiation performance of LM124 for biased and unbiased devices.

Lot to Lot Variability and RDM

I. Part	II. # of Lots	III. Mean Parametric Δ Ratio: SL to HL	IV. Failure Criterion	V. Mean Failure Level Ratio: HL to SL	VI. WC Failure Level Ratio: HL to SL	VII. 99/90 PL ratio HL to SL
RH1014	38	~1.9 (@100 krad(Si))	ΔIbias>50 nA	1.6	1.7	3.2
OP484	7	~9 (@100 krad(Si))	ΔIin>2 μA	~9.3	29	424
AD590	10	~10 (@15 krad(Si))	Amb. Err> 5°C	10	N/A	N/A
LM111	8	~3.4 (@60 krad(Si))	ΔIb_{in+}>300 nA	3.4	3.8	5.6
OP07	11	~3.4 (@300 krad(Si))	ΔIin>40 nA	4.2	3.8	5.5



Bipolar based ICs may show large lot-to-lot radiation performance varyation.

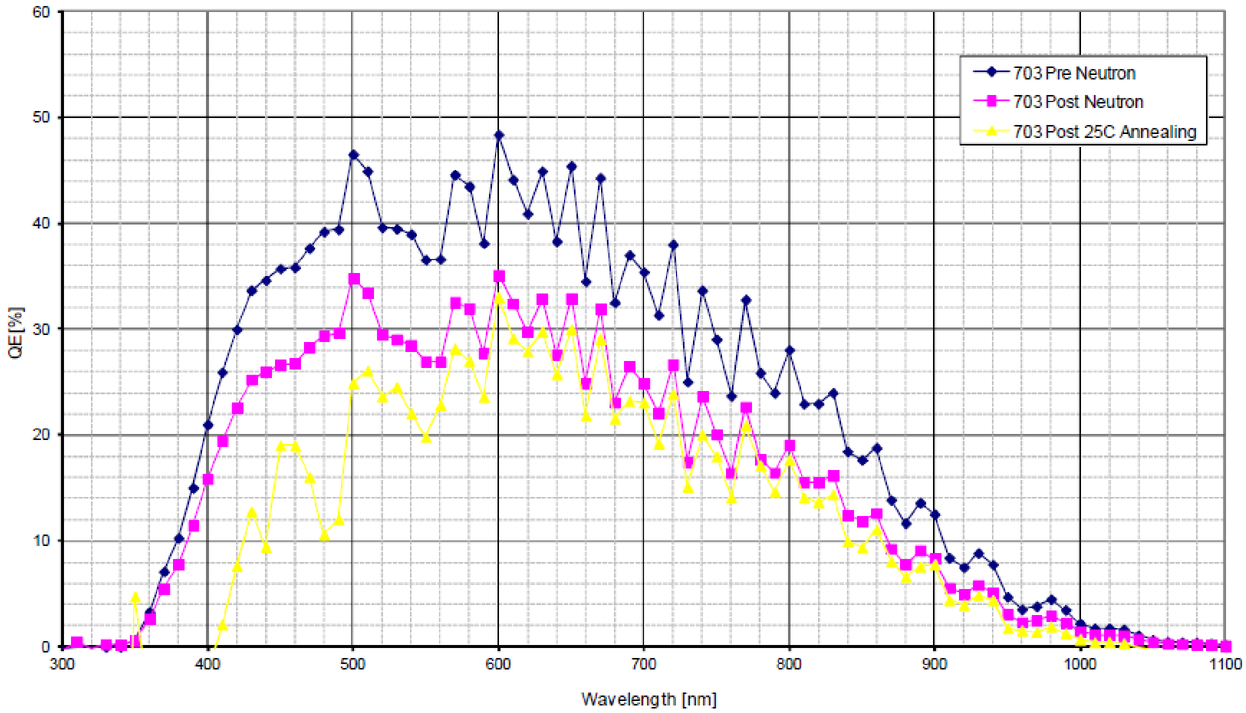
Irradiation characterisation of every lot of bipolar based ICs is therefore an ESA requirement,

After Ladbury, IEEE Trans Nuc Sci, Vol. 56, 2009

HL: Hardest Lot
SL: Softest Lot

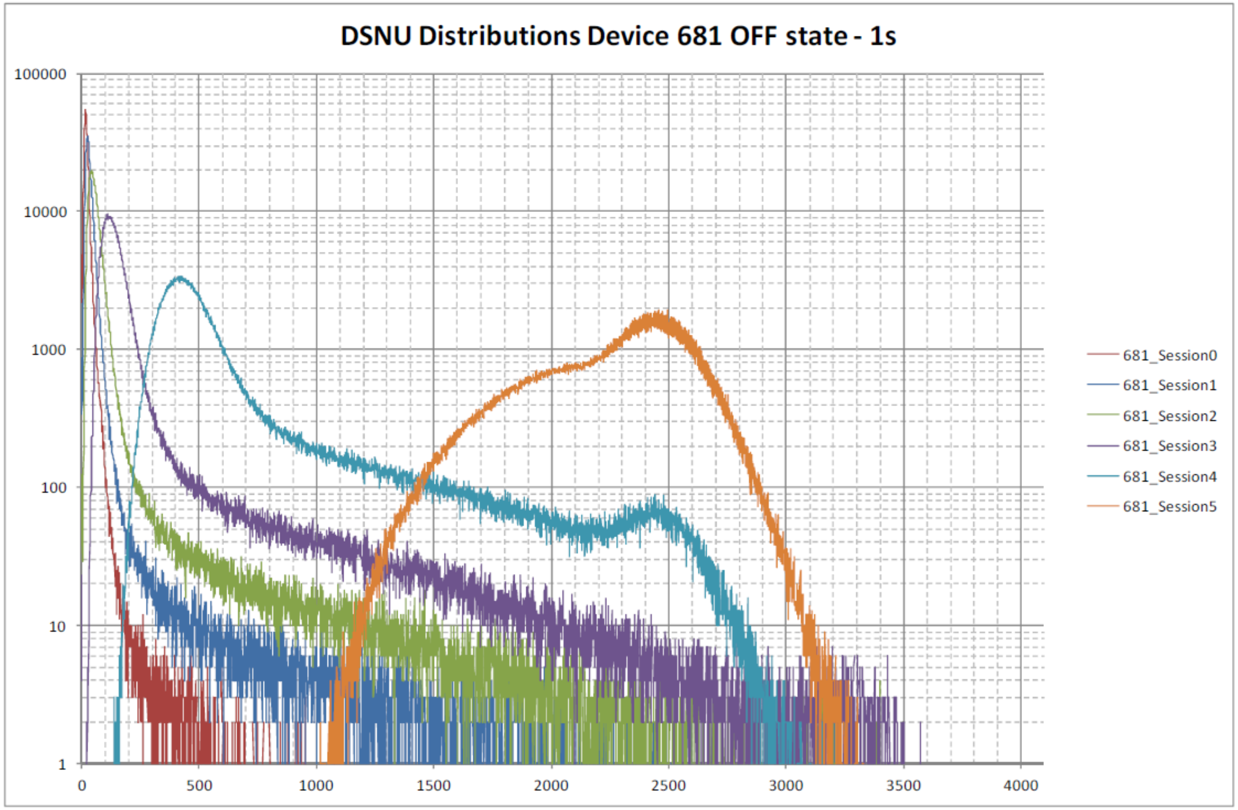
Example TNID test on optoelectronics. APS

Reduction of quantum efficiency due to Displacement Damage effects in a HAS2 CMOS image sensor



Example TNID test on optoelectronics. APS

Increase of Dark Signal Non Uniformity due to Displacement Damage effects in a HAS2 CMOS image sensor

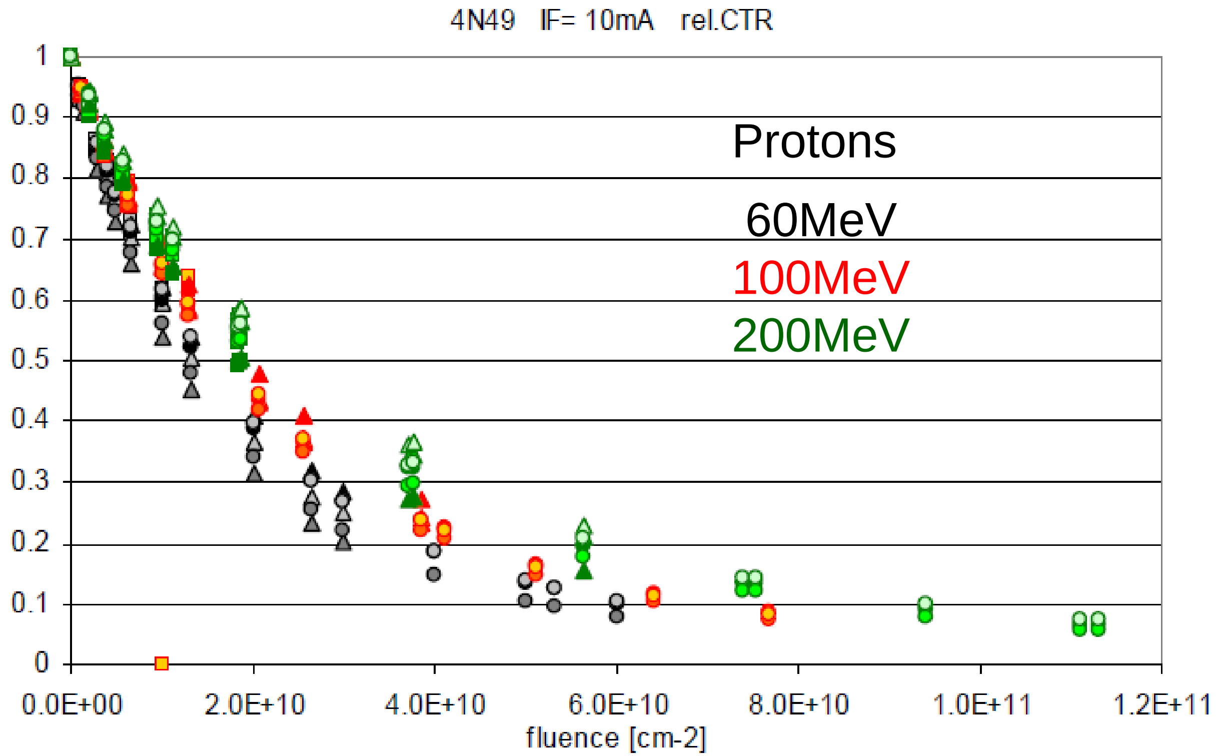


Increasing radiation levels

DSNU distribution with respect to radiation for 1 second integration time.

Optoelectronics are highly sensitive to TNID degradation of the minority carrier lifetime

Optocoupler



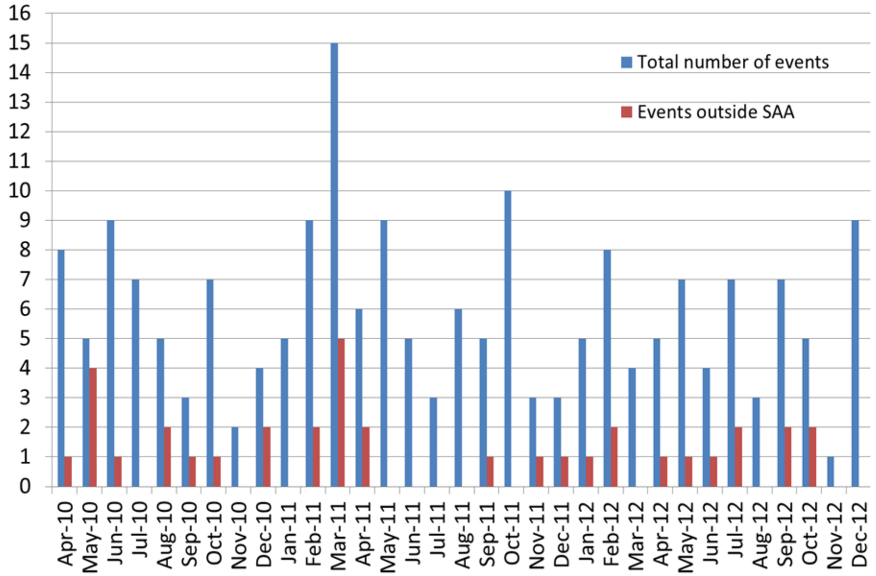
4N49 optocoupler: relative CTR with respect to fluence

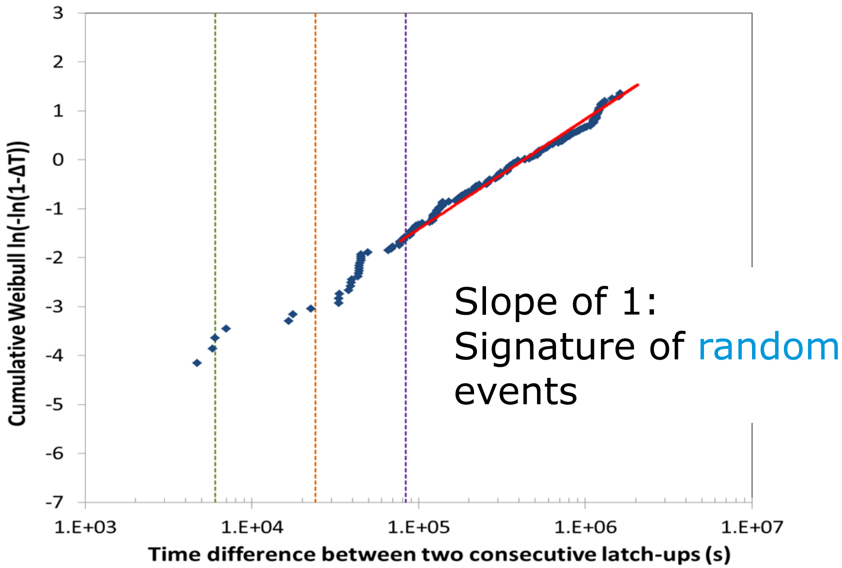
[D. Peyre, et. al. 2009] under ESA contract

RHA for SEE

- **SEE is a transient effect**
- **SEE induced by:**
  - Direct energy deposition by an ion along its track through the EEE component semiconductor material.
  - Energy deposited by fragments nuclei, from inelastic collision between a proton and a silicon nucleus in the semiconductor material of a EEE component.
- **Many different SEE types:**
  - Soft errors: SEU Single-Event Upset, MBU, MCU Multiple Bit (or Cell) Upset, ASET Analog Single Event Transient, DSET Digital Single Event Transient, SEFI Single Event Functional Interrupt
  - Destructive events: SEL Single-Event Latchup, SEHE Single-Event Hard Errors, SEDR Single-Event Dielectric Rupture, SEB Single-Event Burnout, SEGR Single-Event Gate Rupture,

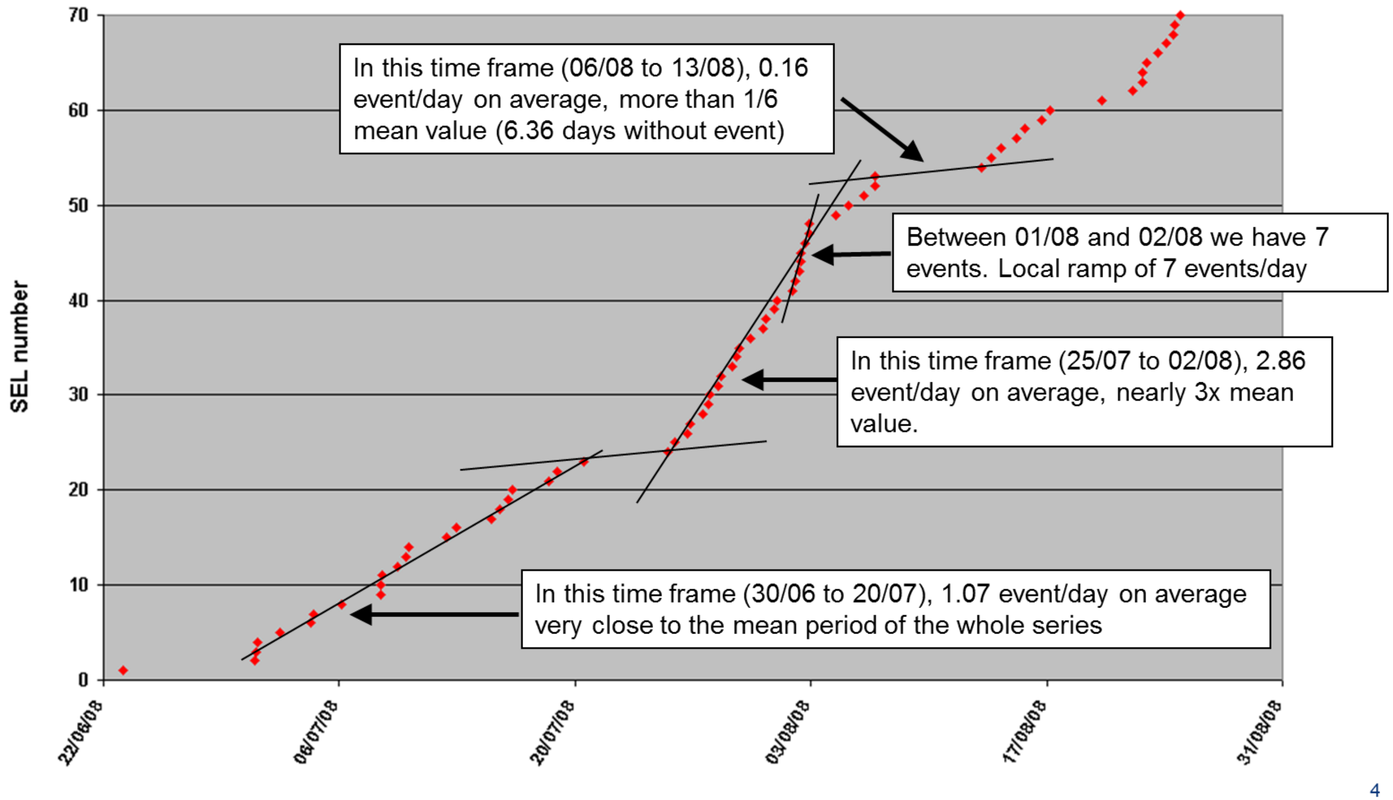
SEEs are random events PROBA2 SEL experiment, ISSI IS61LV5128AL





After d'Alessio, RADECS 2013

SEE are random events
JASON2 SEL events on Cypress CY7C1069 SRAM



SEL count during June-August 2008 period

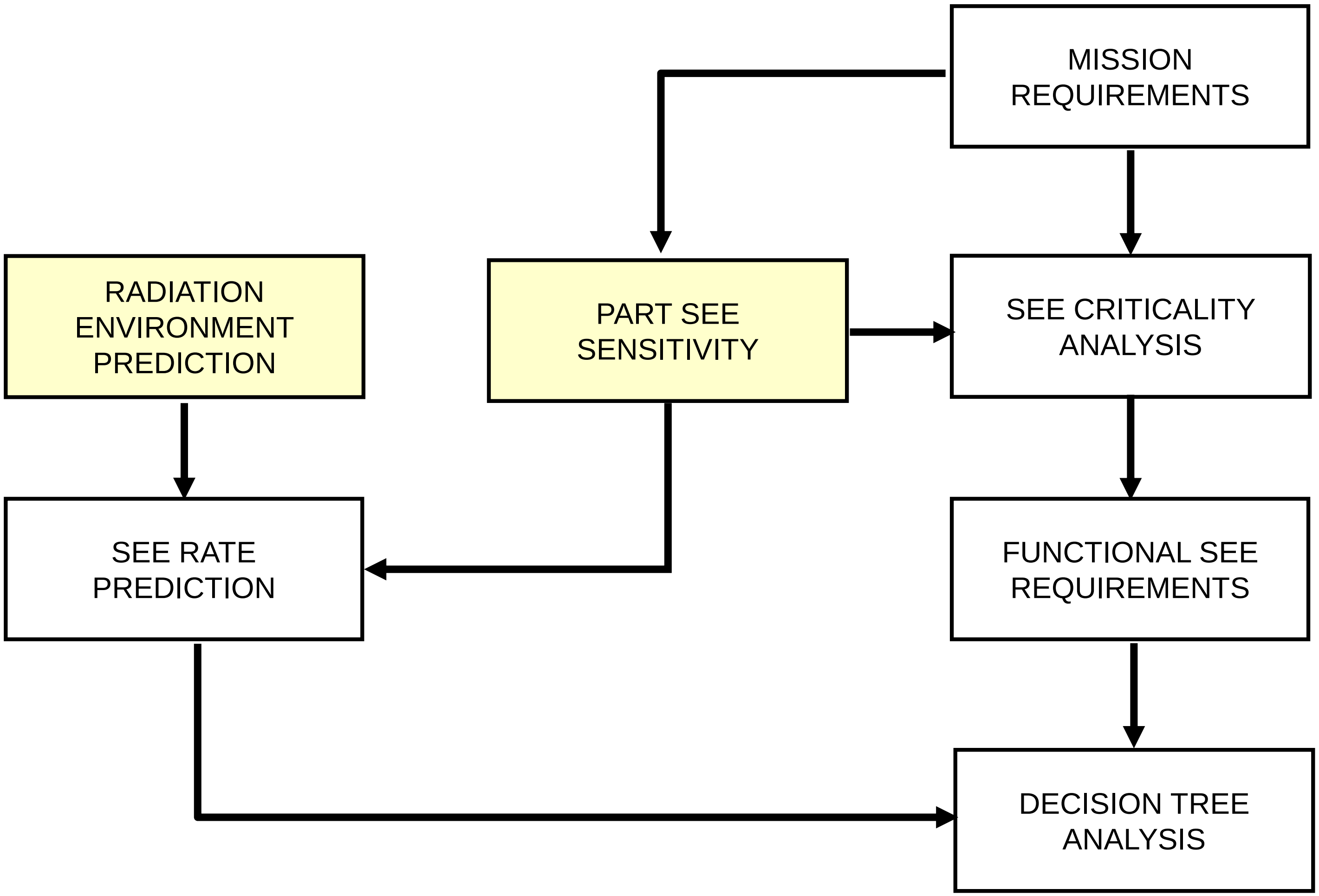
After R. Ecoffet, RWG presentation, 2009

SEE RHA Scope

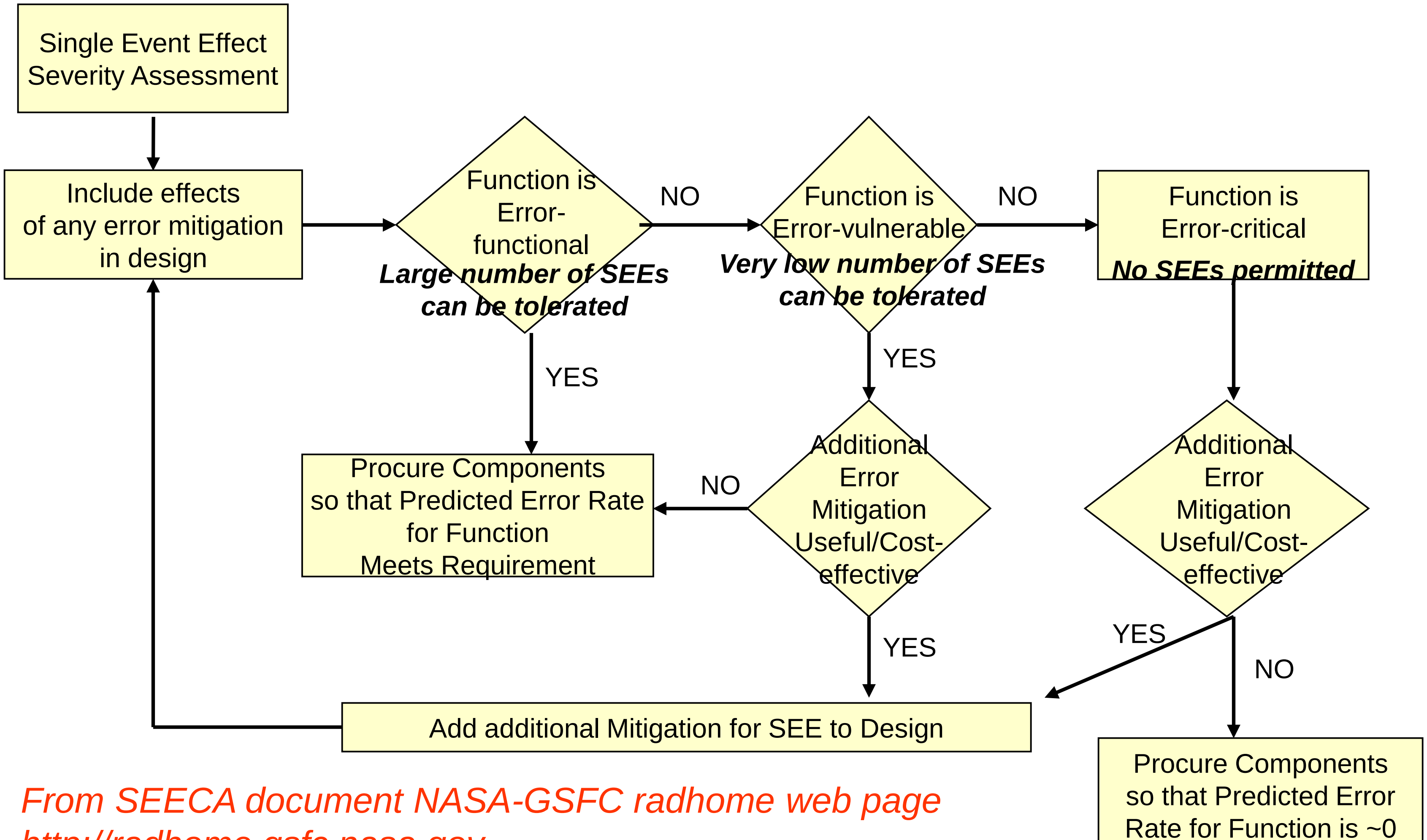
Requirement for the type of EEE components to be analysed for SEEs.

Family	Sub-family
Integrated Circuits	all
Integrated Circuits Microwave	all
Transistors	FET N channel FET P channel
Transistors Microwave	all
CCD, CMOS APS, opto discrete devices	all

SEE - Analysis Flow



SEE - Decision Tree



From SEECA document NASA-GSFC radhome web page
http://radhome.gsfc.nasa.gov

SEE - Analysis Requirement

Additional conditions for when SEE analysis shall be performed. Depends on the SEE LET threshold (the lowest LET level at which SEEs occur). SEE irradiation testing is required to identify the SEE LET threshold.

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

SEE Testing Deviations

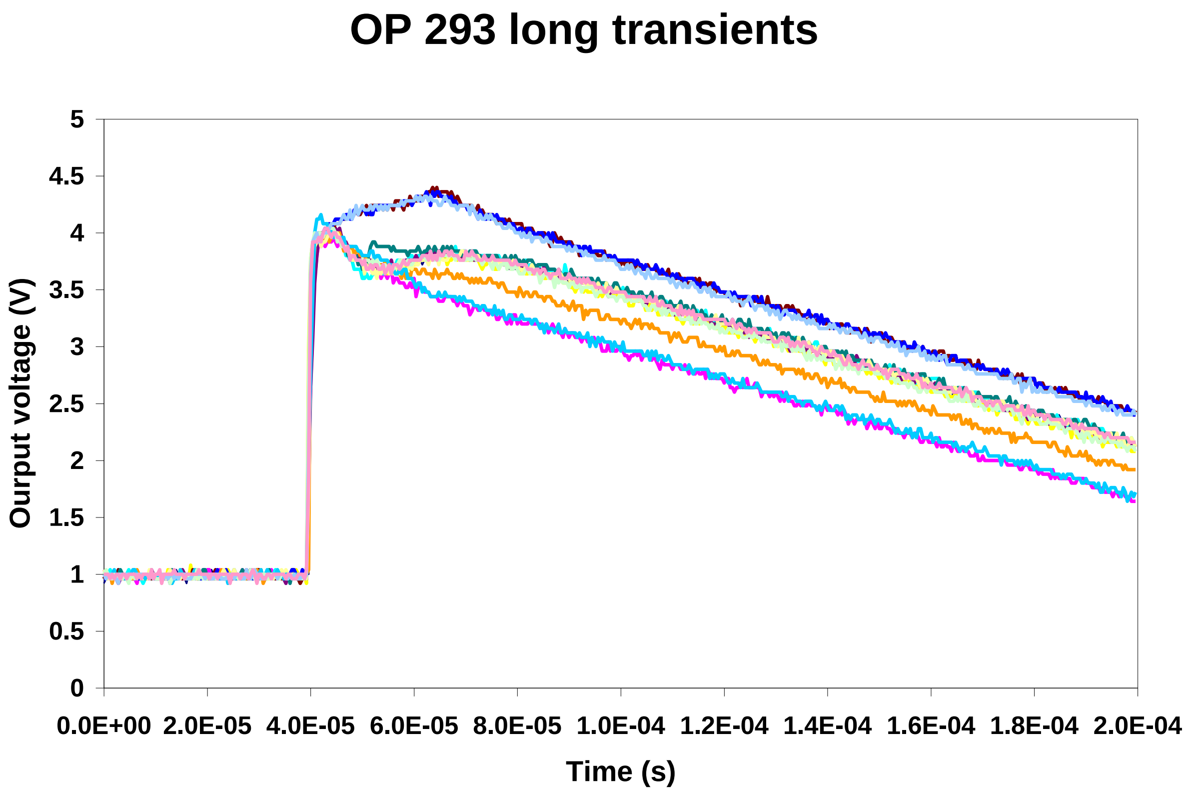
Use of models (SIMPA, PROFIT) to derive protons SEE information from Heavy ion data can be acceptable in certain situations (for memory devices). However, strict conditions and application of large margins is required.

For the SET criticality analysis of SET in analogue ICs, worst case SET templates in the Table below may be used in the absence of acceptable test data (ECSS-Q-ST-60-15C)

Device Function	SET template
Op-amps	$\Delta V_{max}=+/-V_{cc}$ & $\Delta t_{max}=15\ \mu s$
Voltage Comparators	$\Delta V_{max}=+/-V_{cc}$ & $\Delta t_{max}=10\ \mu s$
Voltage Regulators	$\Delta V_{max}=+/-V_{cc}$ & $\Delta t_{max}=10\ \mu s$
Voltage Reference	$\Delta V_{max}=+/-V_{cc}$ & $\Delta t_{max}=10\ \mu s$
Optocouplers	$\Delta V_{max}=+/-V_{cc}$ & $\Delta t_{max}=100\ ns$

Testing Deviations, SET templates

1. SET templates are not always worst case

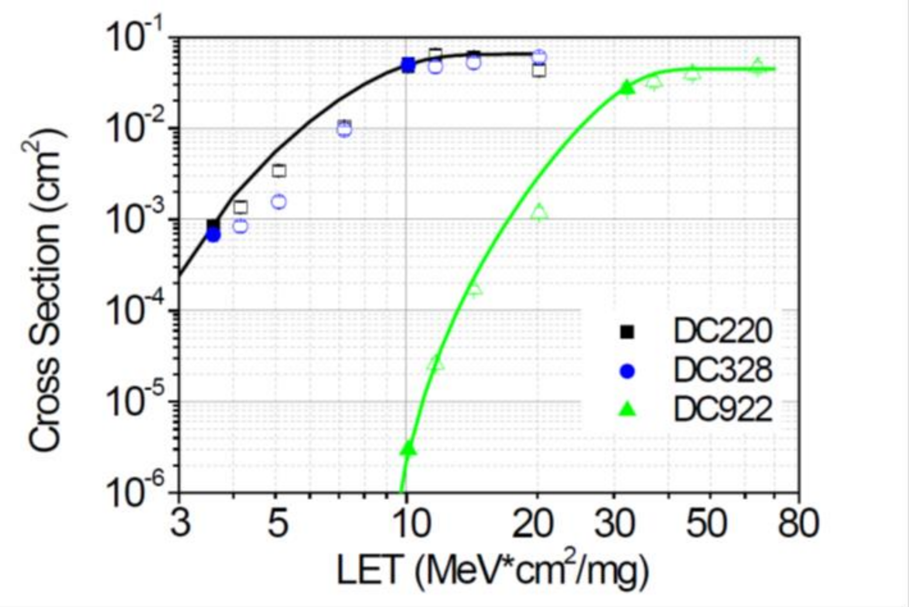


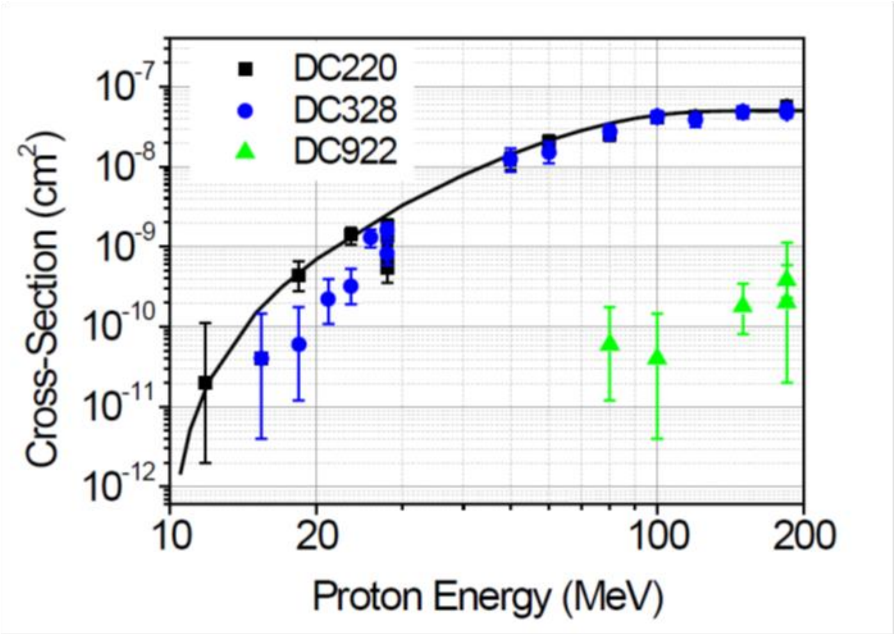
After Ladbury, NASA GSFC test report

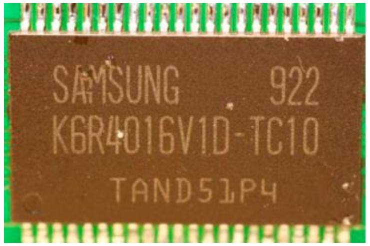
The template for op-amps indicate an SET duration of 15us.

The OP293 illustrate SETs > 15us.
For components in the critical path of the design testing shall be performed.

COTS variability, example
Samsung 4M SRAM K6R4016V1D







DC220 or DC328: ~ 1 SEL every 3 days on LEO polar orbit

SEE Radiation Design Margins

1. ECSS-Q-ST-60-15C
   a. 1 for heavy ion induced rates
   b. 1 for proton induced rates based on data
   c. 10 for proton induced rates based on models

Power MOSFETs

1. Power MOSFETs SEB/SEGR analysis is either based on rate analysis or V_{DS} versus V_{GS} Safe Operating Area (SOA)
2. There is no commonly agreed method to calculate SEB/SEGR rates
3. There is no agreement about minimum LET and ion range requirements to define SOA.

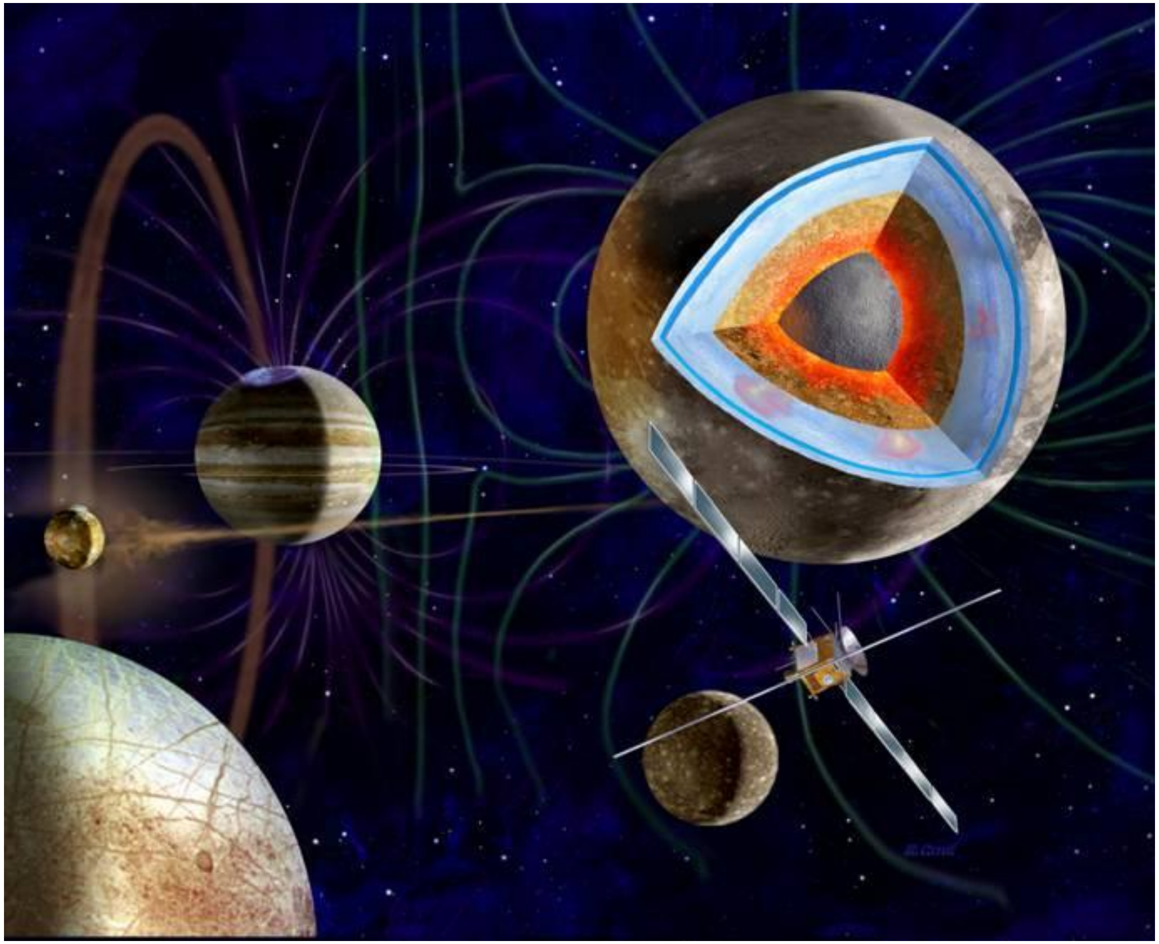
Practical implementation of the method used to assess power MOSFET SEB/SEGR sensitivity shall be defined by the supplier and submitted to customer for approval (ECSS-Q-ST-60-15C)

JUICE one of ESA's future Large Class Space Science Missions and Radiation Related R&D activities.

- ESA develops spacecraft and launchers for numerous applications. More than 50 missions are currently in operation, being developed or are planned developed.

- Due to time constraints only the JUICE mission and radiation related R&D activities are presented here. JUICE is of particular interest in this context due to its harsh radiation environment.

- General considerations:
    - In some cases significant number of radiation related R&D activities are carried out to identify the feasibility of a planned mission (e.g. JUICE). In other cases only one or a few number of R&D activities are required (e.g. identify radiation performance of main detector for a specific payload).



JUICE mission details

- JUICE - JUpiter ICy moons Explorer - is the first large-class mission in ESA's Cosmic Vision 2015-2025 programme.
- **Key science goals: The emergence of habitable worlds around gas giants.** Characterise Ganymede, Europa and Callisto as planetary objects and potential habitats Explore the Jupiter system as an archetype for gas giants.
- Planned for launch in 2022 and arrival at Jupiter in 2030, it will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa.
- Proposed payload: Laser Altimeter, Radio Science Experiment, Ice Penetrating Radar, Visible-Infrared Hyperspectral Imaging Spectrometer, Ultraviolet Imaging Spectrograph, Imaging System, Magnetometer, Particle Package, Submillimetre Wave Instrument, Radio and Plasma Wave Instrument

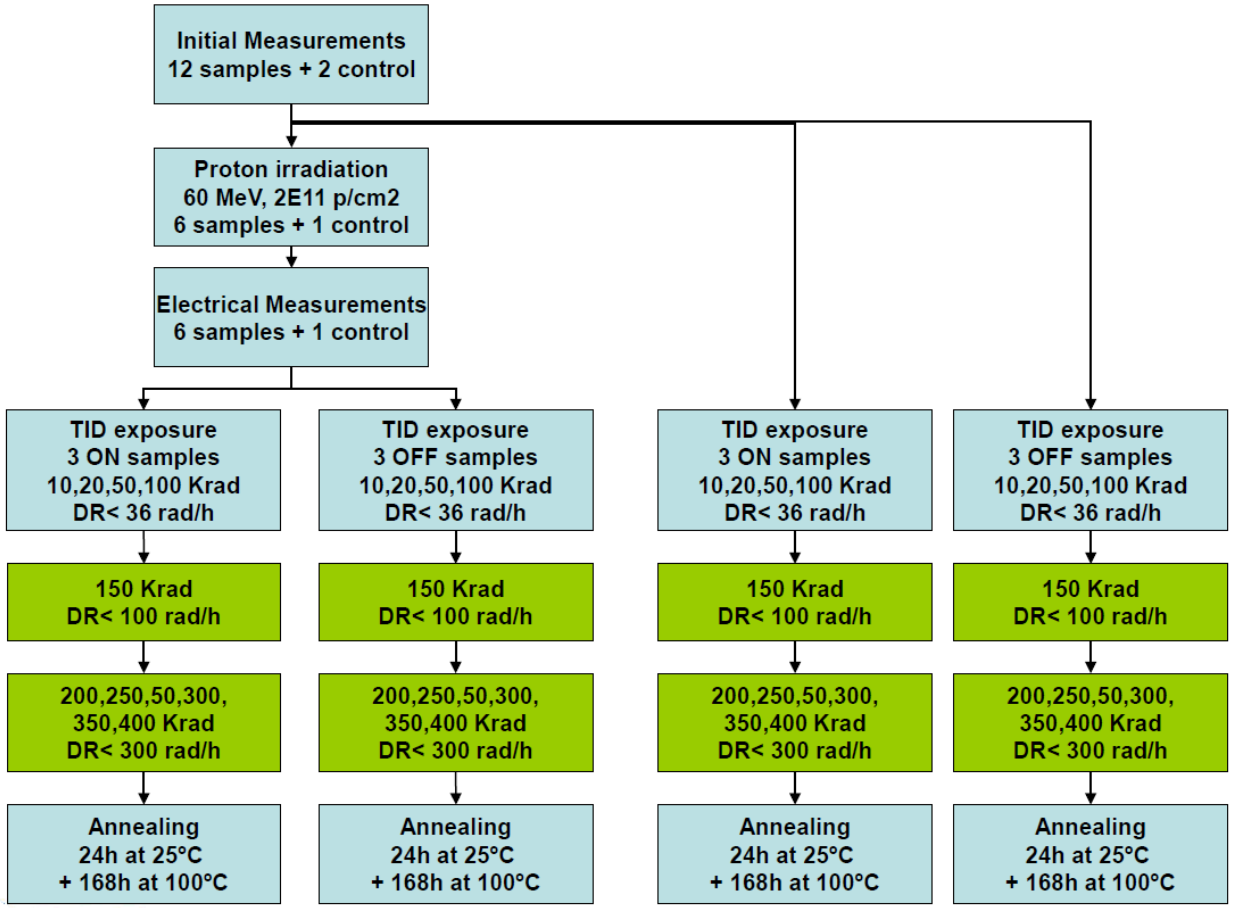
R&D activities related to JUICE

- Due to the harsh radiation environment that will be experienced by JUICE, a number of radiation related R&D activities were initiated to identify the feasibility of the mission.
- R&D activities foe 5 key technology areas were initiated:
  - Analogue Power/Linear devices
  - Front end ASICs
  - Mixed signal ASICs
  - Optoelectronics (e.g. optocouplers)
  - Memory devices (e.g. for solid state mass memory applications)
- Pure digital electronics (e.g. digital ASICs) were considered to be suitable for the JUICE applications. DARE+ library developed under ESA funding has a high TID tolerance.

Survey of Critical Components for 150 Krad-Si power system design Summary, September 2012

- The purpose of this activity was to identify whether a power system could be developed based on typical space qualified components flown on ESA missions when they were exposed to dose levels exceeding their guaranteed TID tolerance by manaufactirer.
- Characterize selected part types to the combined effects of TID up to 400 Krad-Si (was initially 150 Krad and extended to 400 Krad with a CCN) and TNID up to a 60 MeV protons fluence of $2*10^{11}$ #/cm^2
- The study shows that many electrical parameters go out of specification before 100krad. However, only one part illustrated functional failure.
- The study also shows the importance of performing DD and TID tests on linear bipolar rad power converter/system design and prototyping to select devices based on their combined DD and TID JUICE radiation environment.
- The results from this activity was employed to design a power system suitable for operation in the JUICE environment.

Survey of Critical Components for Si power system design



Activity irradiation test sequence

Survey of Critical Components for 150 Krad-Si power system design Summary, September 2012

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

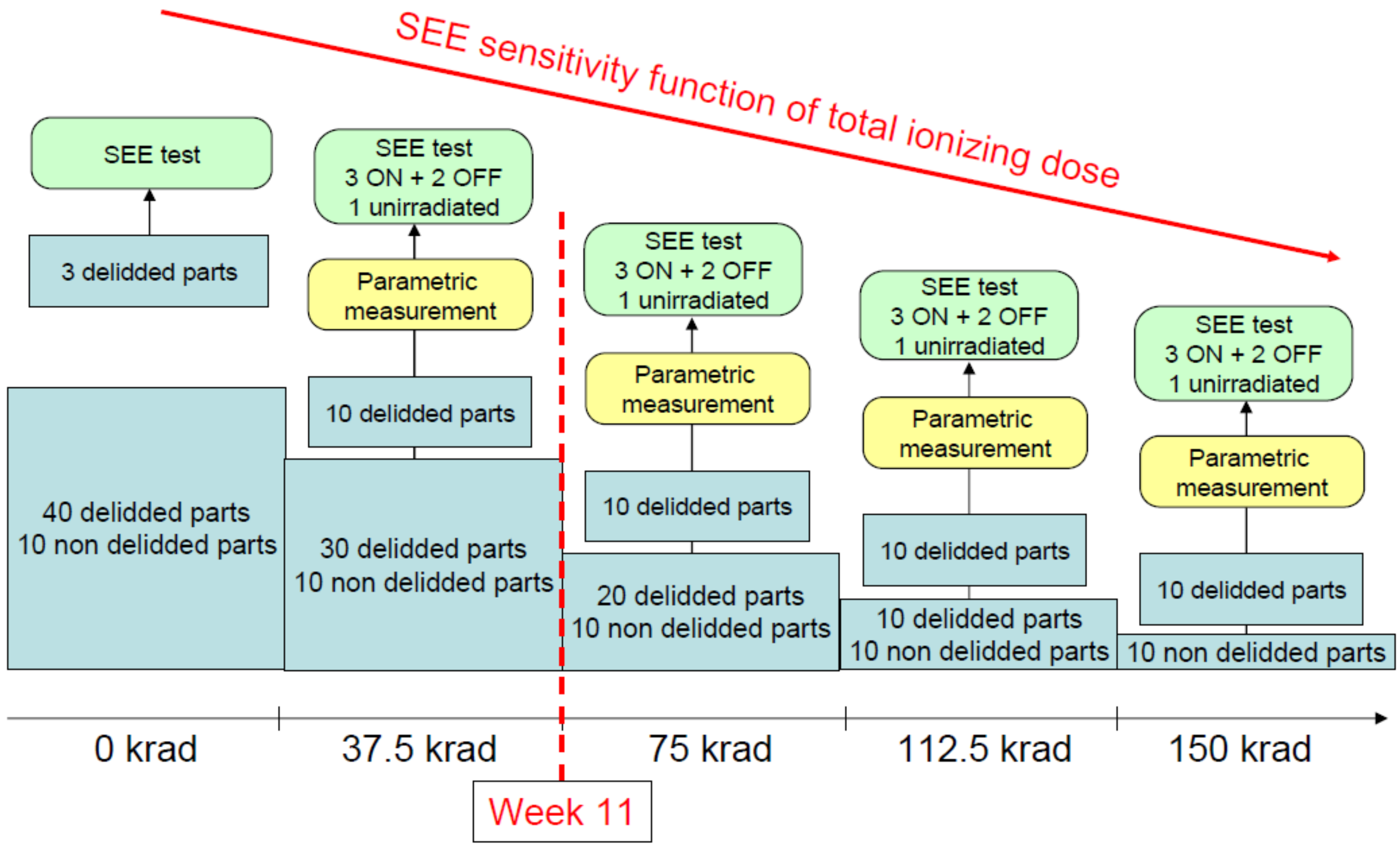
Parts tested in this activity

TID influence on the SEE sensitivity of EEE components.

- During their in-flight operation, EEE components are subject to TID and SEE at the same time. However, RHA requirements dictates that TID and SEE characterisation is performed independently
- There is not much information regarding the synergetic effects of TID and SEE. Considering the harsh Jupiter radiation environment, an activity has been initiated to investigate synergetic effects.
- The project will initially perform TID irradiation tests separately with subsequent SEE characterisation of the TID irradiated devices.
- The following devices are being tested:
  - ADC (AD9042, Analog Devices), DAC (AD558, Analog Devices), NAND FLASH (MT29F408AAC, Micron), SRAM (R1RW0416, Renesas)

TID influence on the SEE sensitivity of EEE components.

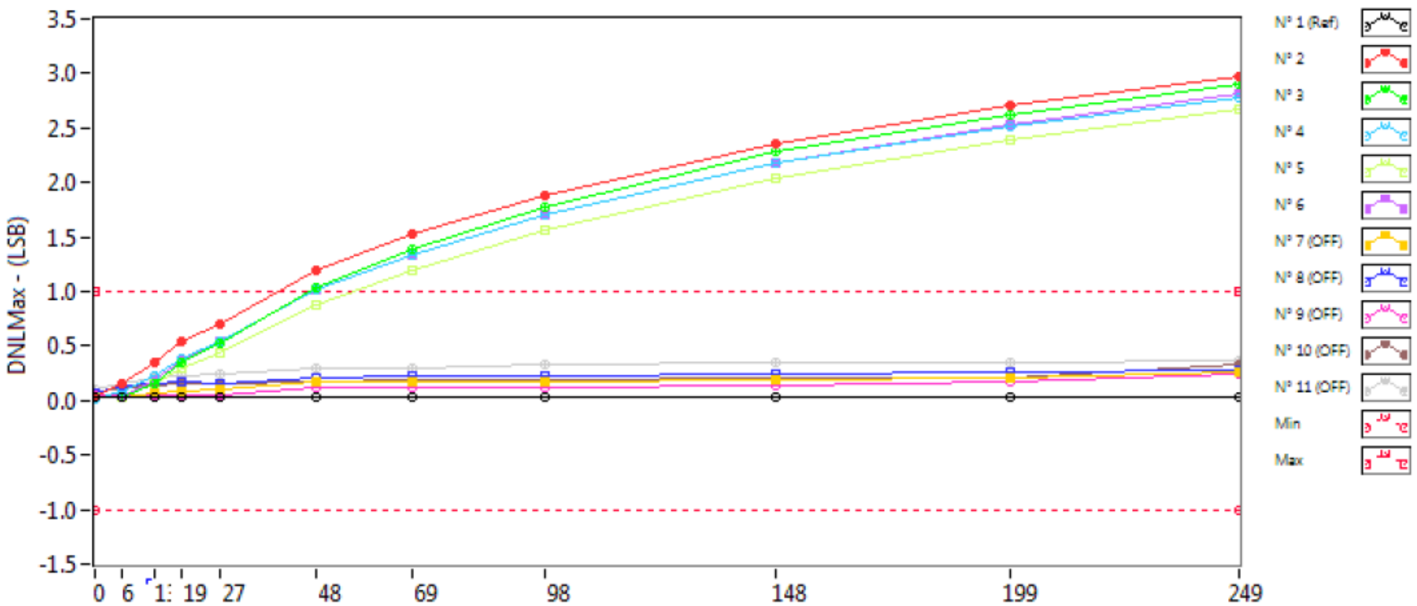
TID + SEE synergy effect test approach



From CNES/ESA radiation effects final presentation days 2015 by TRAD.

TID influence on the SEE sensitivity of EEE components. Results.

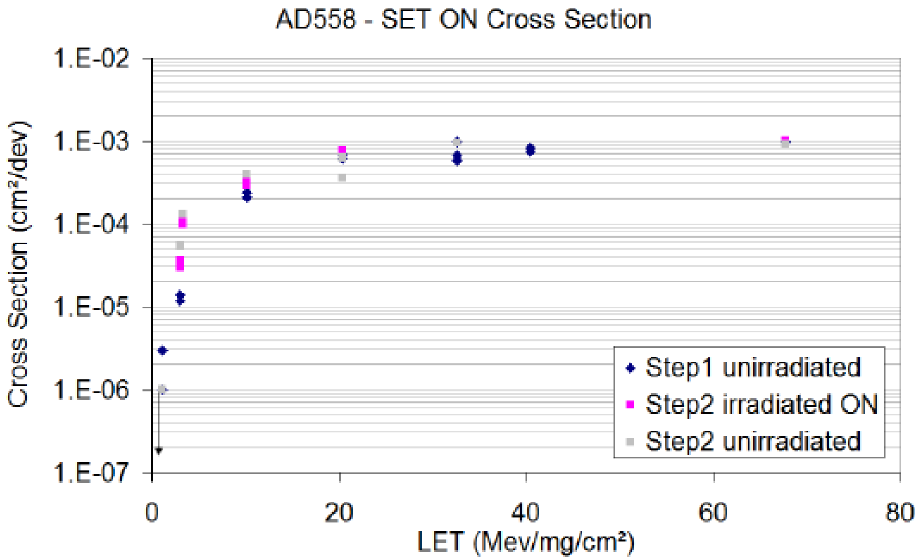
AD558



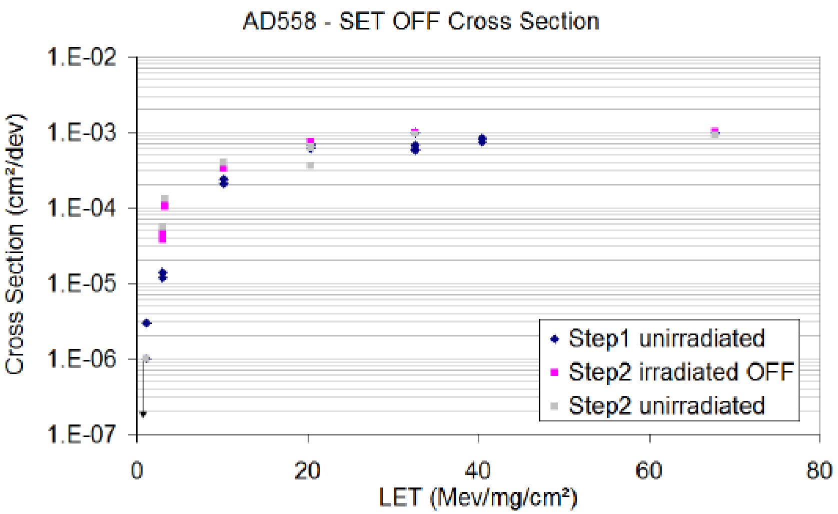
Differential nonlinearity MAX

From CNES/ESA radiation effects final presentation days 2015 by TRAD.

TID influence on the SEE sensitivity of EEE components.



From CNES/ESA radiation effects final presentation days 2015 by TRAD.



- This activity is still on-going. However, preliminary results indicate that no significant synergetic effects are observed for the tested devices.

Memory irradiation characterisation activity for JUICE

- The purpose of this activity was to identify the radiation performance of state of the art memory devices with possible use for the JUICE mission.
- In collaboration with the JUICE project it was decided that the focus of the activity be placed on DDR3 and NAND FLASH devices.
- The following project requirements were applied:
  - TID: Level of interest >400krad. Minimum level >50krad
  - SEE: Standard ECSS-Q-ST-60-15C requirement (SEE LET threshold >60MeV cm^2/mg)
  - Memory density > 4Gb
  - High Speed and low power
- This activity was awarded to Airbus DS and IDA

Memory irradiation characterisation activity for JUICE

- Part Selection:

4 Gb DDR3:

- Elpida EDJ4208BASE-DJ-F (obsolete)
- SK Hynix H5TQ4G83MFR-H9C
- Micron MT41J512M8RH-093:E
- Samsung K4B4G0846B-HCH9
- Nanya NT5CB512M8CN-EK

2 Gb DDR3 (2Gb DDR3 were also characterised for comparison purposes)

- SK Hynix H5TQ2G83BFR-H9C
- Nanya N5CB256M8BN-CG
- Micron MT41J256M8HX-15E:D
- Samsung K4B2G0846B
- Samsung K4B2G0846D

NAND FLASH Reference:

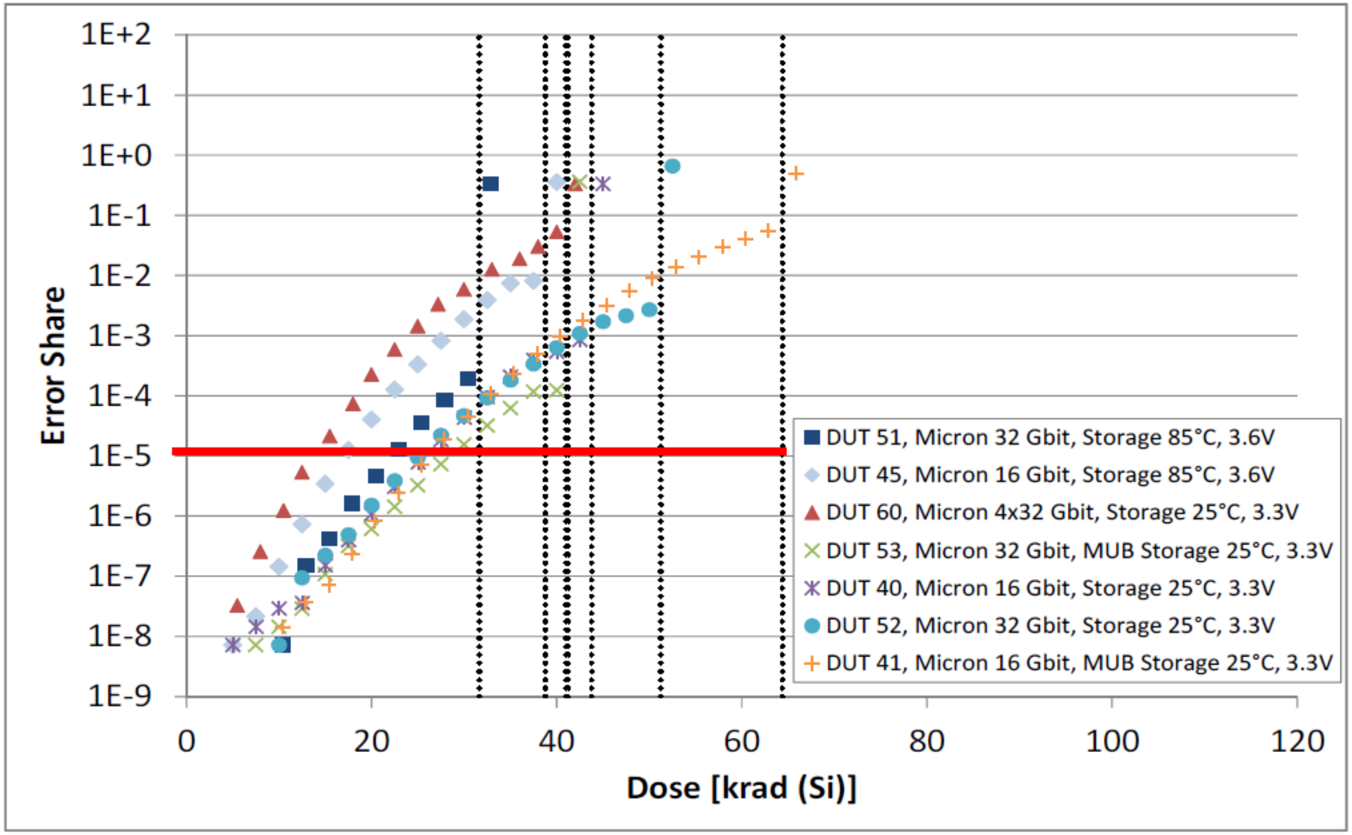
- Samsung K9WBG08U1M (SLC, 4 x 8 Gb, 51 nm)
- Micron MT29F8G08AAAWP-ET:A (SLC, 8 Gb, 50 nm)

NAND FLASH Focus on state-of-the-art technology:

- Micron MT29F16G08ABACAWP-IT:C (SLC, 16 Gb, 25 nm)
- Micron MT29F32G08ABAAAWP-IT:A (SLC, 32 Gb, 25 nm)

A large number of devices were tested during this activity

Memory irradiation characterisation activity for JUICE

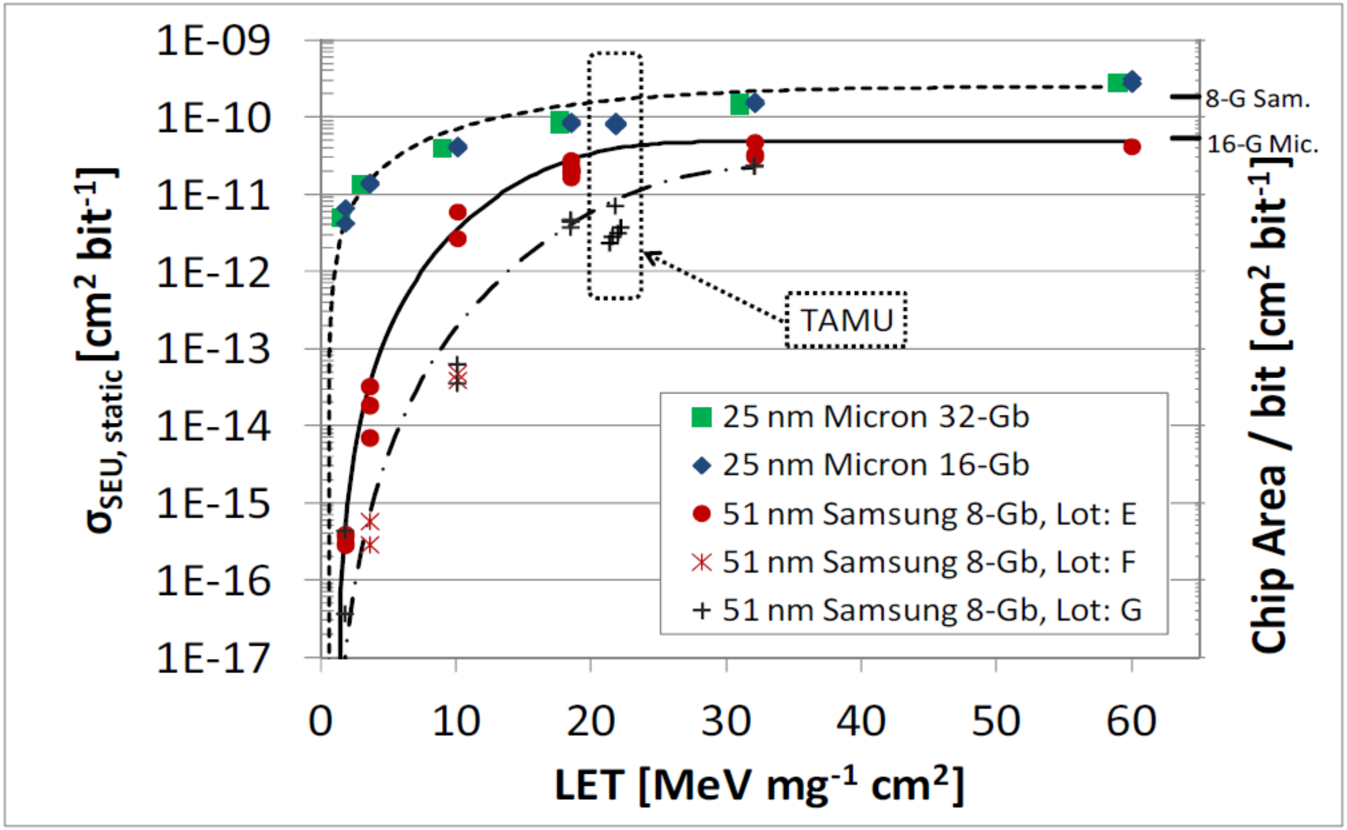


The figure illustrates the TID performance of the NAND FLASH devices.

NAND FLASH SEU cross section as a function of LET

From CNES/ESA radiation effects final presentation days 2015 by Airbus DS and IDA.

Memory irradiation characterisation activity for JUICE



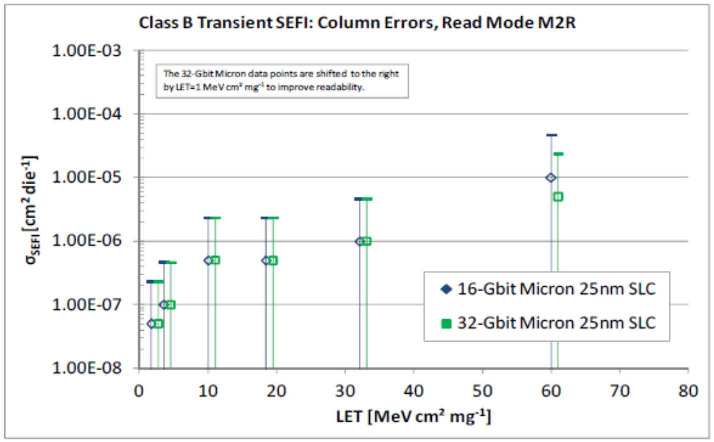
The Micron 16Gb devices shows lower SEU cross section than the 8Gb Samsung device.

NAND FLASH SEU cross section as a function of LET

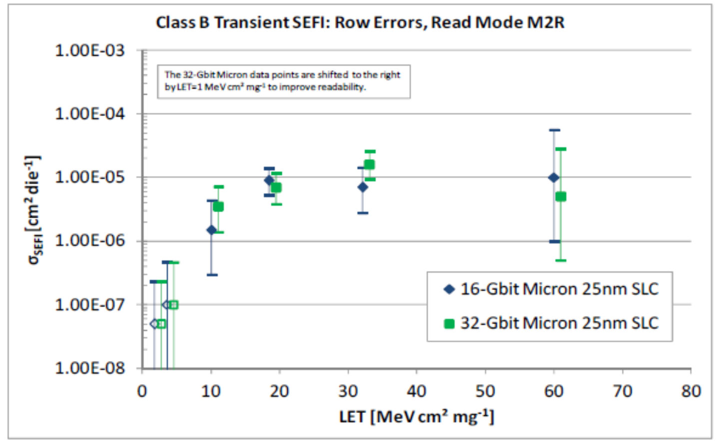
From CNES/ESA radiation effects final presentation days 2015 by Airbus DS and IDA.

Memory irradiation characterisation activity for JUICE

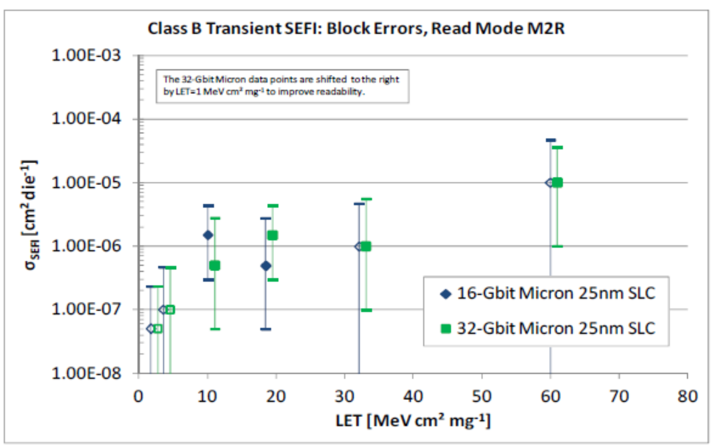
Column Errors



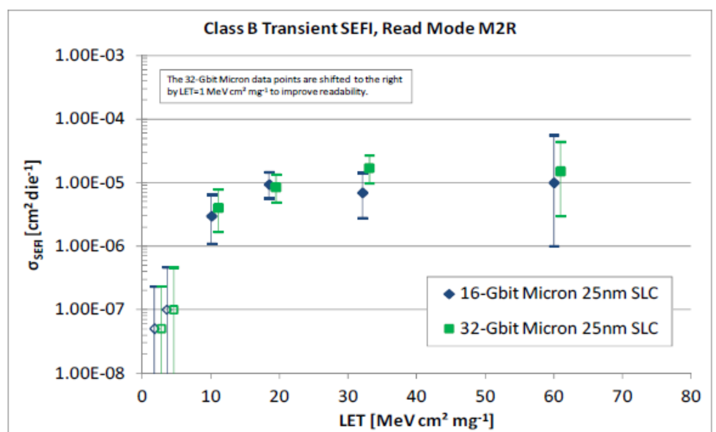
Row Errors



Block Errors



All Errors



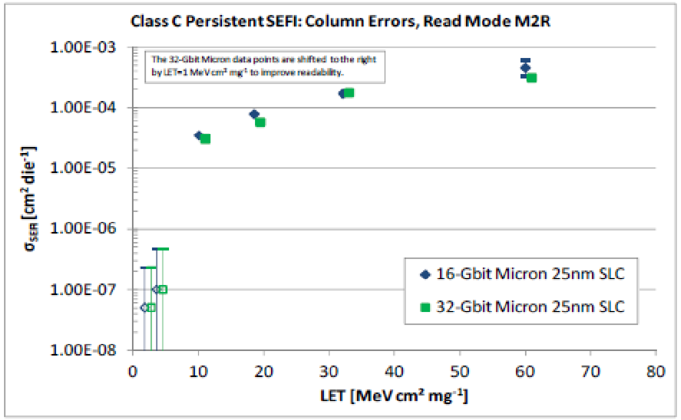
Transient SEFIs classified into Column, Row and Block errors.

The cross sections per device is lower than observed for SEUs.

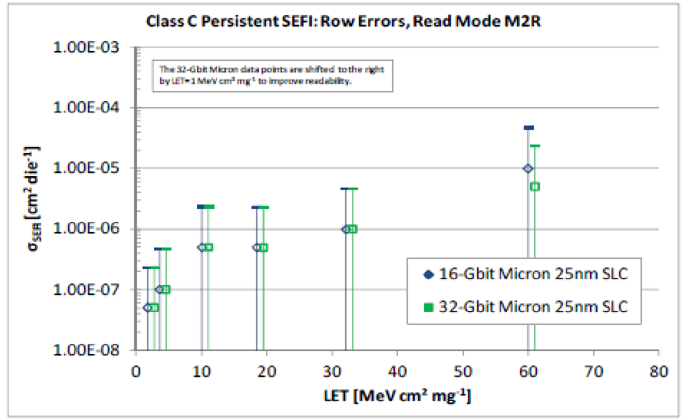
From CNES/ESA radiation effects final presentation days 2015 by Airbus DS and IDA.

Memory irradiation characterisation activity for JUICE

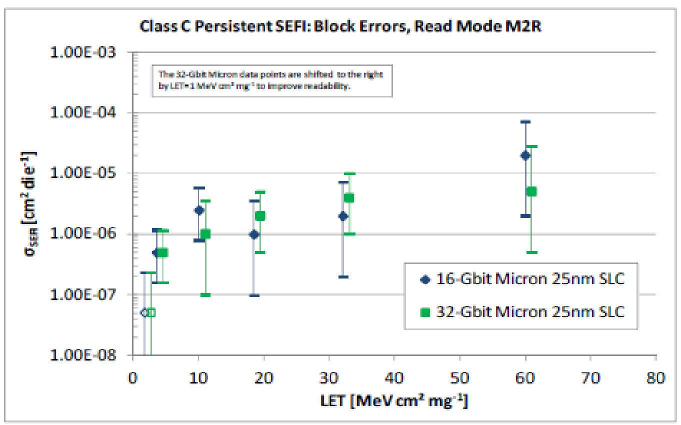
Column Errors



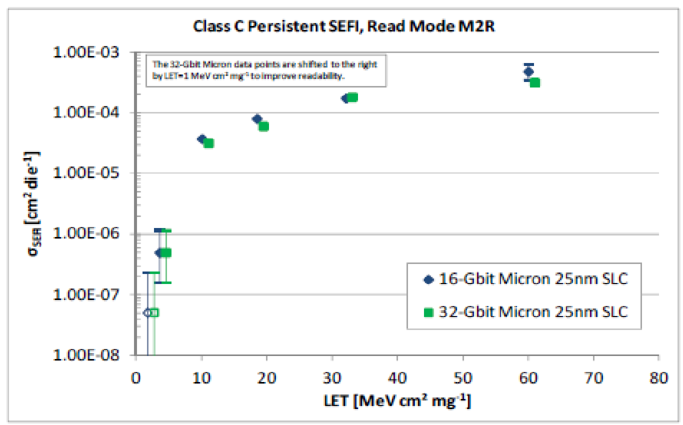
Row Errors



Block Errors



All Errors

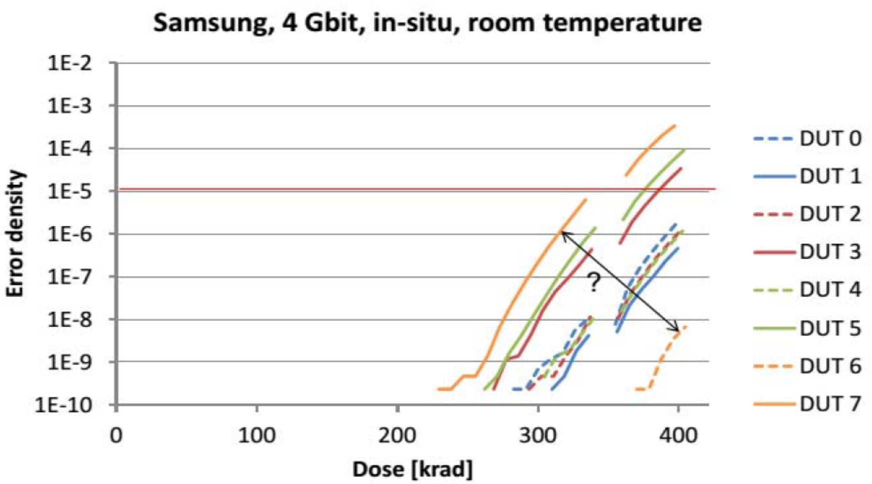


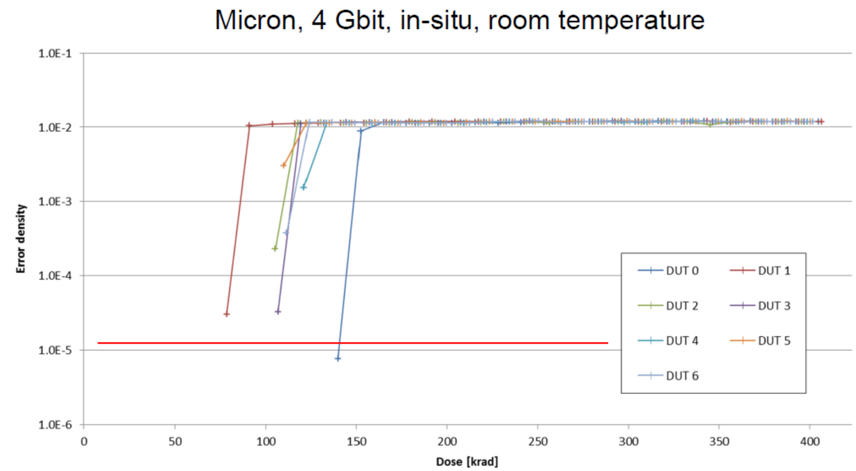
Persistent SEFIs classified into Column, Row and Block errors.

The cross sections per device is lower than observed for SEUs.

From CNES/ESA radiation effects final presentation days 2015 by Airbus DS and IDA.

Memory irradiation characterisation activity for JUICE





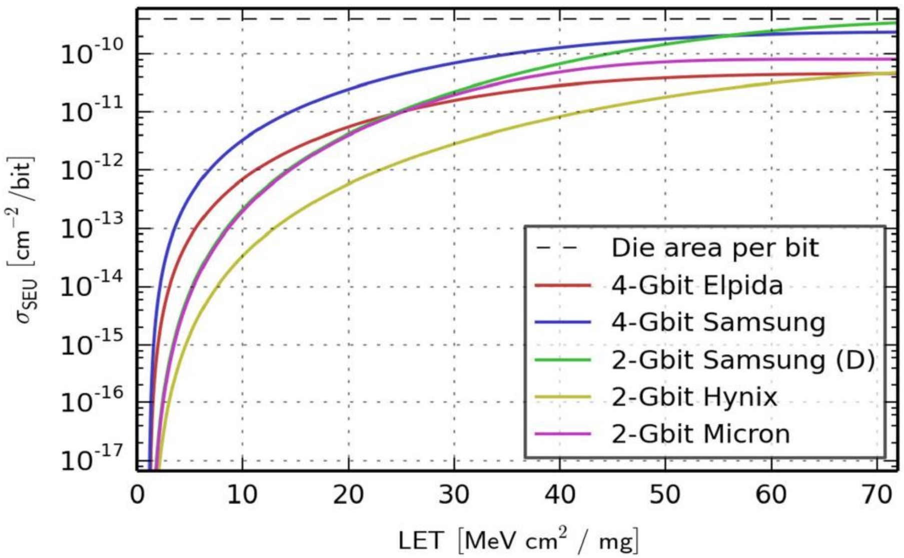
Error density as a function of dose for the Samsung 4 Gbit NAND FLASH. There is a large part to part variation.

Error density as a function of dose for the Micron 4 Gbit NAND FLASH

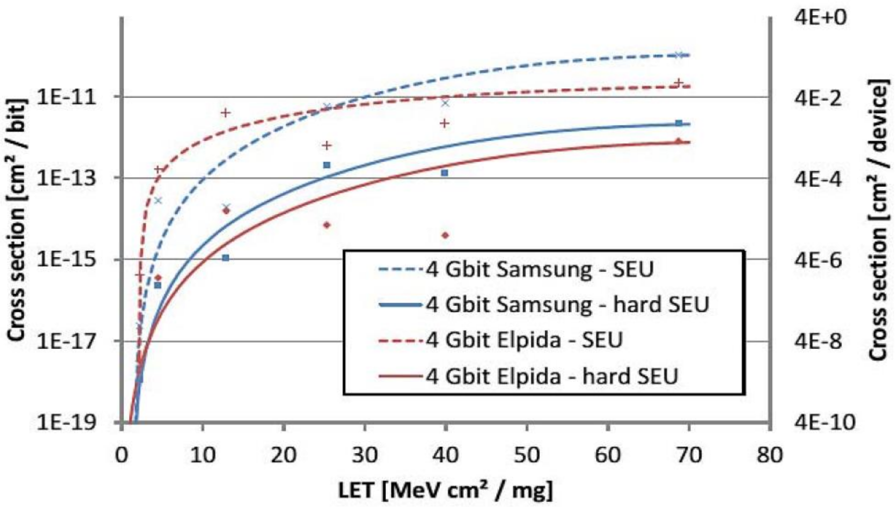
The Hynix device did not show any errors up to a TID value of 400krad.

From CNES/ESA radiation effects final presentation days 2015 by Airbus DS and IDA.

Memory irradiation characterisation activity for JUICE



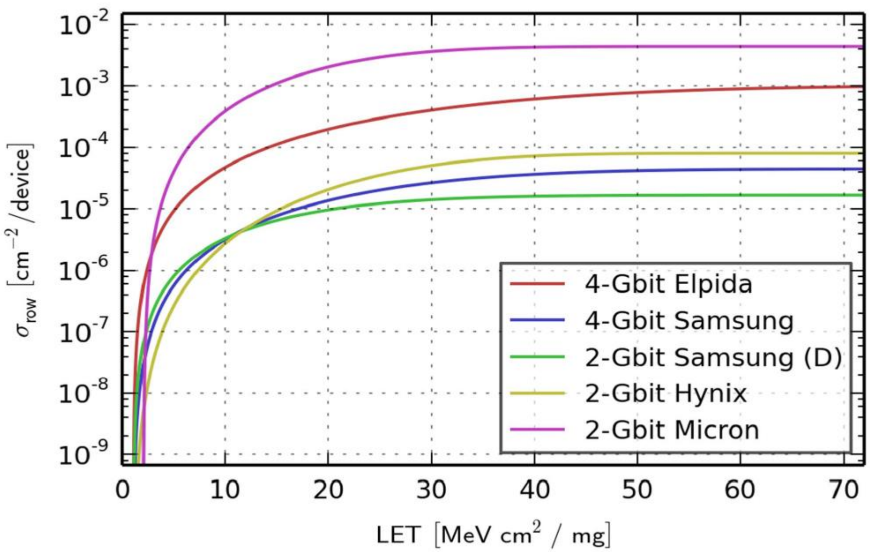
DDR3 SEU cross section as a function of LET. The 2-Gbit Hynix device showed the best SEU performance.



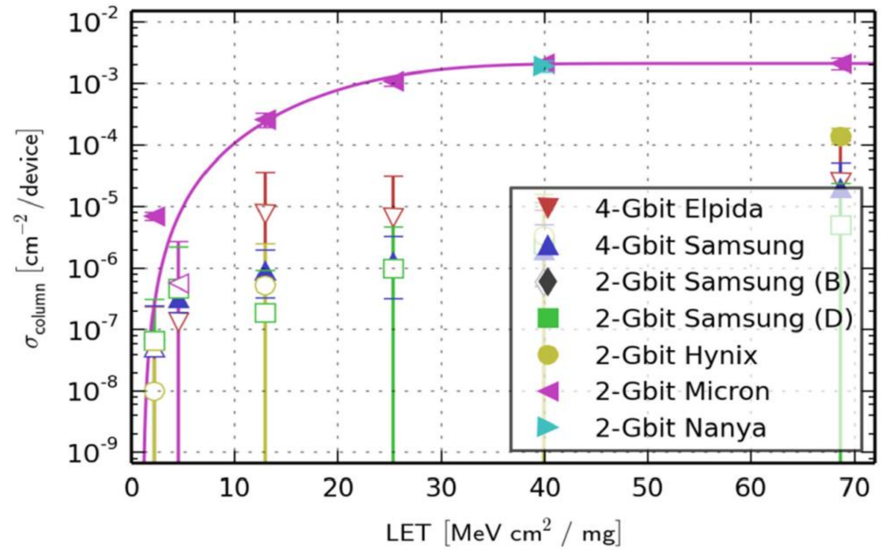
DDR3 Hard SEU cross section as a function of LET. Hard SEUs can not be removed by rewriting.

From CNES/ESA radiation effects final presentation days 2015 by Airbus DS and IDA.

Memory irradiation characterisation activity for JUICE



DDR3 heavy ion row SEFI cross section as a function of LET



DDR3 heavy ion column SEFI cross section as a function of LET

From CNES/ESA radiation effects final presentation days 2015 by Airbus DS and IDA.

Memory irradiation characterisation activity for JUICE

Main Conclusion:

- TID Tolerance:
  - The best NAND Flash: ≈ 30 krad
  - The best DDR3 SDRAM: ≈ 400 krad (Hynix). However, the device from Micron only managed approximately 70krad.
- SEE Tolerance:
  - Both types suffer from SEE error mechanisms with data loss.
  - NAND Flash: destructive failure (DF) observed
  - DDR3 SDRAM: device SEFI observed
  - Both types are latch-up free
  - Parts with good test coverage:

Radiation characterization of Laplace/Tandem critical RH optocouplers sensors and detectors

The objectives of the activity is:

- To test radhard optocouplers currently available and identify whether they are capable of withstanding the harsh Jovian environment. Total Ionising Dose and Displacement Damage effects will be investigated.

- To improve the characterisation of radiation induced degradations of a candidate APS detector for Laplace (HAS2 from Onsemi) used on Star trackers. Total Ionising Dose, Displacement Damage and Single Event Effects sensitivity will be evaluated. Neutron test campaigns will allow to isolate displacement damage specific degradation mechanisms.

Radiation characterization of Laplace/Tandem critical RH optocouplers sensors and detectors

Optocouplers selected for this activity

Manufacturer	Part type	Date Code	LED Structure		Photodetector type	Structure[2]	Radiation information[3]
MICROPAC	66179-002	1124	GaAlAs[1]	660nm[1]	silicon planar NPN Output phototransistor	Lateral	High radiation immunity
	66193-002	1120	GaAlAs[1]	660nm[1]	silicon planar phototransistor	Lateral	Proton radiation tolerant LED
	66221-103	1122	GaAlAs[1]	850nm[1]	silicon planar phototransistor	Lateral	Proton radiation tolerant
	66224-105	1038, 1111	GaAlAs[1]	850nm[1]	silicon planar phototransistor	Lateral	Proton radiation tolerant
AVAGO	HCPL5431	1116	AlGaAs	850nm[1]	integrated high gain photon detector.	Sandwich	High Radiation Immunity
	HCPL5501	1105	GaAsP	-	integrated photodiode-darlington detector IC	Sandwich	High Radiation Immunity
	HCPL5701	1116	GaAsP	-	integrated high gain photon detector.	Sandwich	High Radiation Immunity
ISOLINK	OLH400	1048	AlGaAs double heterojunction [1]	700nm[1]	integrated photodiode-darlington detector IC	Lateral	Radiation Tolerant
	OLS0449	0949	AlGaAs double heterojunction[1]	830nm[1]	NPN silicon phototransistor	Lateral	Radiation Tolerant Phototransistor
	OLH7000-0010	0721	AlGaAs double heterojunction[1]	870nm[1]	two PIN photodiode detectors	Lateral	Displacement damage tolerant LED

APS selected for this activity

- HAS2 from Onsemi (the HAS2 results will not be discussed in this presentation)

Radiation characterization of Laplace/Tandem critical RH optocouplers sensors and detectors

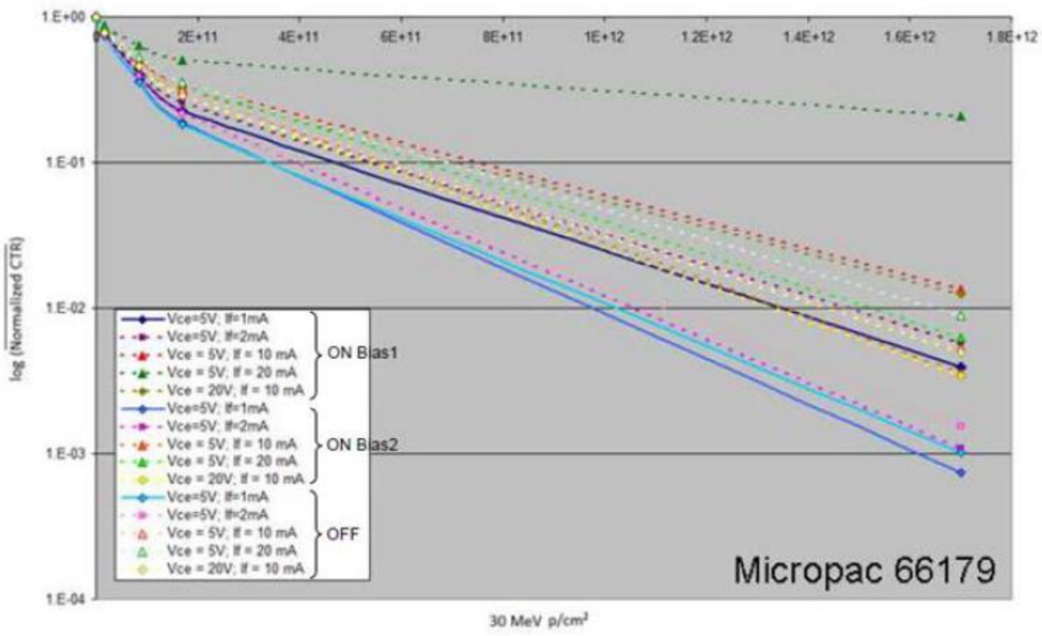
For optocoupler the following tests were performed:

- 1 MeV neutrons for TNID effects
- 3 proton energies (30, 60 and 190MeV) for TNID and TID effects
- 60Co irradiation for TID effects

- Neutron and proton results were converted to 10MeV equivalent proton energy

- Following the 60Co irradiation tests two annealing steps were performed.
  - 24h at +25 degree C
  - 168h at +100 degree C

Radiation characterization of Laplace/Tandem critical RH optocouplers sensors and detectors

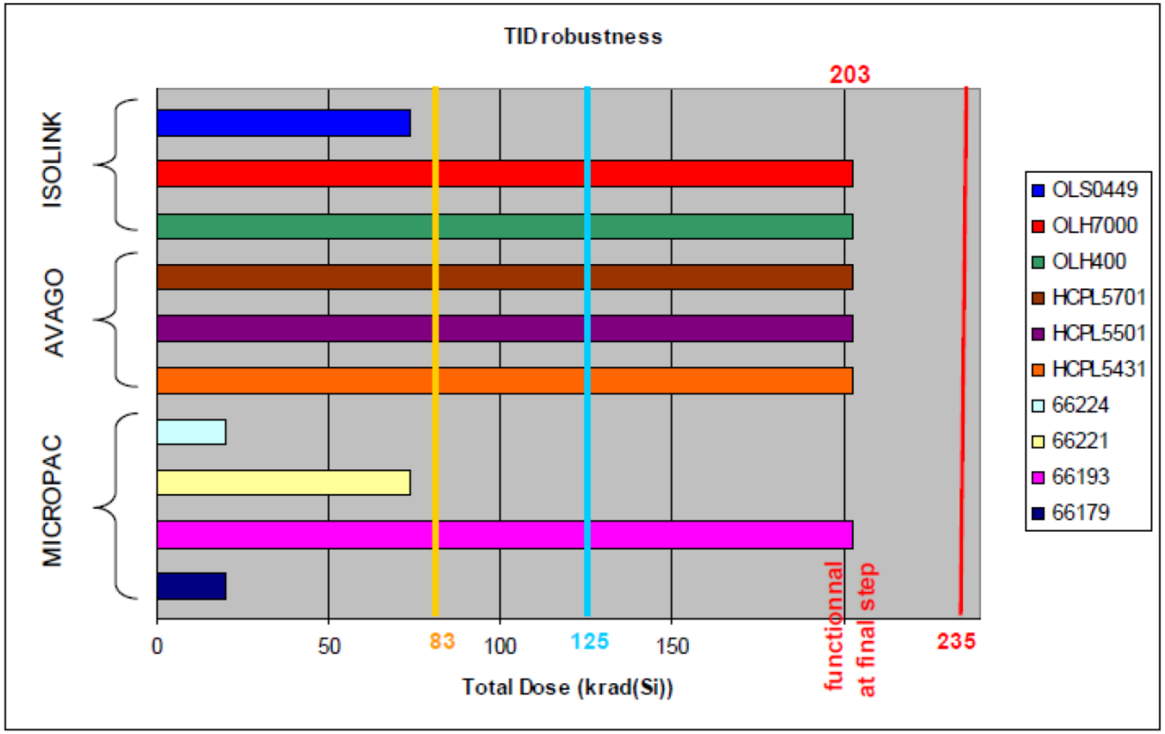


From CNES/ESA radiation effects final presentation days 2015.

Impact of bias condition on CTR degradation.

- Whatever the bias condition (ON1, ON2, OFF), CTR1 (Vce = 5V, If = 1mA) is the most sensitive configuration whereas CTR4 (Vce = 5V, If = 20V) exhibits the smallest average parameter drift.
- In all cases, the lower the forward current, the higher the degradation.

Radiation characterization of Laplace/Tandem critical RH optocouplers sensors and detectors

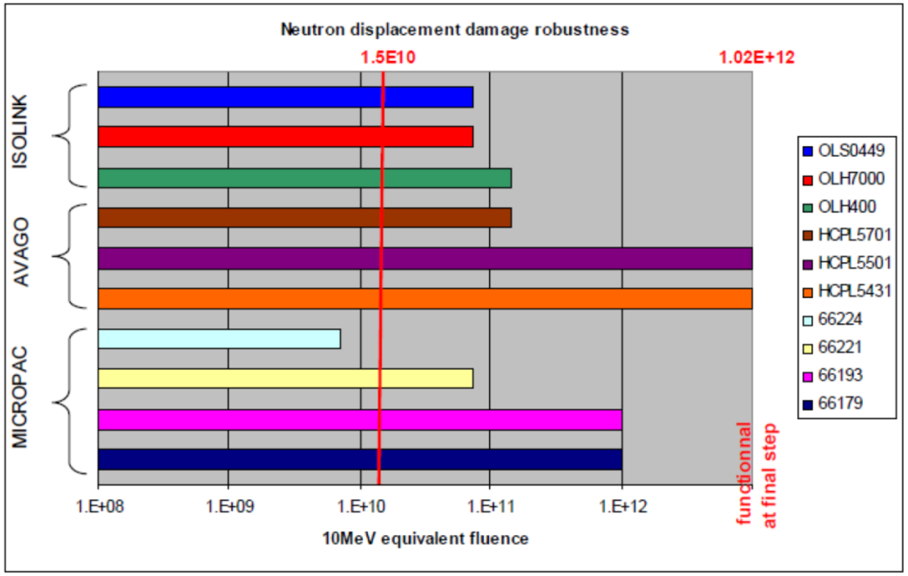


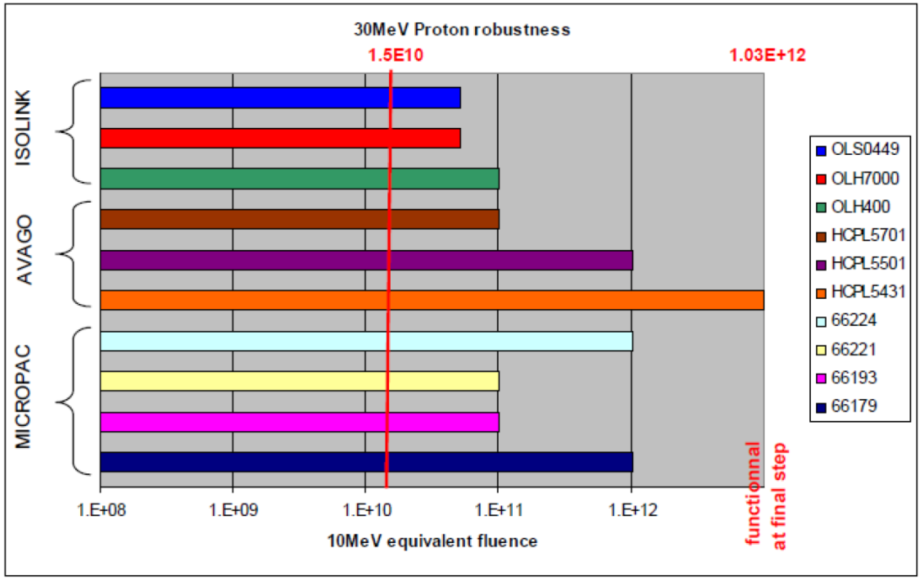
TID performance of all optocouplers tested.

- The AVAGO parts perform well following TID exposure.
- Three of the Micropack devices and one Isolink devices did not reach the 83 krad level.

From CNES/ESA radiation effects final presentation days 2015.

Radiation characterization of Laplace/Tandem critical RH optocouplers sensors and detectors





Neutron irradiation tolerance versus 10MeV equivalent proton fluence.

Protn irradiation tolerance versus 10MeV equivalent proton fluence.

The data illustrates that there are some dissimilarities between the neutron and the proton irradiation tests. In particular the Micropack 66224 shows larger degradation following neutron irradiation. Considering this parts poorer TID performance it would have been expected to see better performance in the neutron data.

From CNES/ESA radiation effects final presentation days 2015.

Radiation characterization of Laplace/Tandem critical RH optocouplers sensors and detectors

Conclusion:

- TNID damage at different fluence seem to be proton energy dependent. Additionally, some parameter degradation indicate proton energy dependence.
- Based on the results and to identify the worst case irradiation conditions, it is recommended to perform proton irradiation testing at different proton energies.
- The Micropack devices show the largest lot-to-lot variation. AVAGO devices show little lot-to-lot variation.
- Irradiation characterisation of every optocoupler lot is required.
- Optocouplers compliant with JUICE RHA requirements are available but have to be well chracterised.

Other radiation related R&D activities carried out or planned for carried out for JUICE

- Irradiation characterisation of Front-End ASICs
- Irradiation characterisation of mixed signal ASICs
- Validity of 60Co TID characterisation with respect to high energy electrons
- …

RHA recommendations summary

- Electronics are potentially very sensitive to radiation effects, keep in mind radiation sensitivity in design and part selection.
- Radiation constraints can be very different from one mission to another.
- Do not use parts for which no radiation information is available. It is better to fly what you know even with some radiation sensitivity.
- Avoid components sensitive to destructive events.
- Radiation sensitivity depends strongly on biasing conditions.
- Test enough parts to get statistics on part to part variation.
- Lot to lot variation must be considered, you may have radiation data on the same part type but your actual device may contain a completely different die.
- Mitigation is often possible through good design practices but in most of the cases radiation testing is unavoidable.
- If you have any doubt about RHA standards, ask a radiation expert.