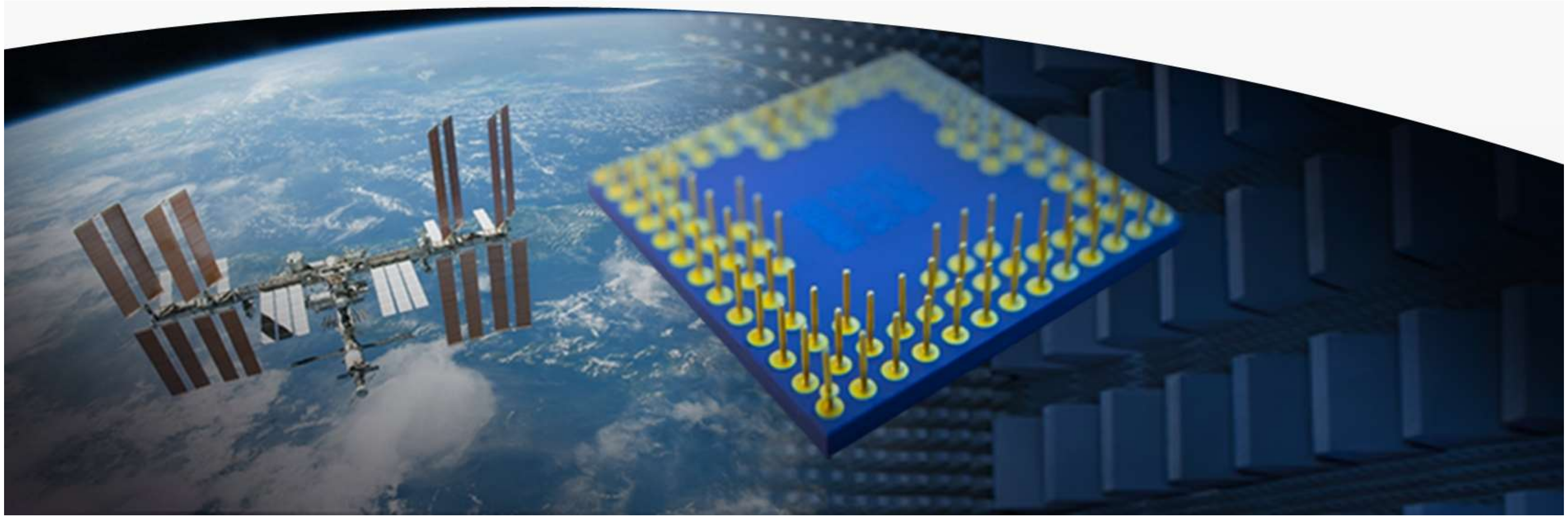


ALTER TECHNOLOGY TÜV NORD

1st Seminar on Electronics Under Harsh Environment

Space Radiation Hazards, Radiation Hardness Assurance

ETSI – USE Seville - 12th November 2018

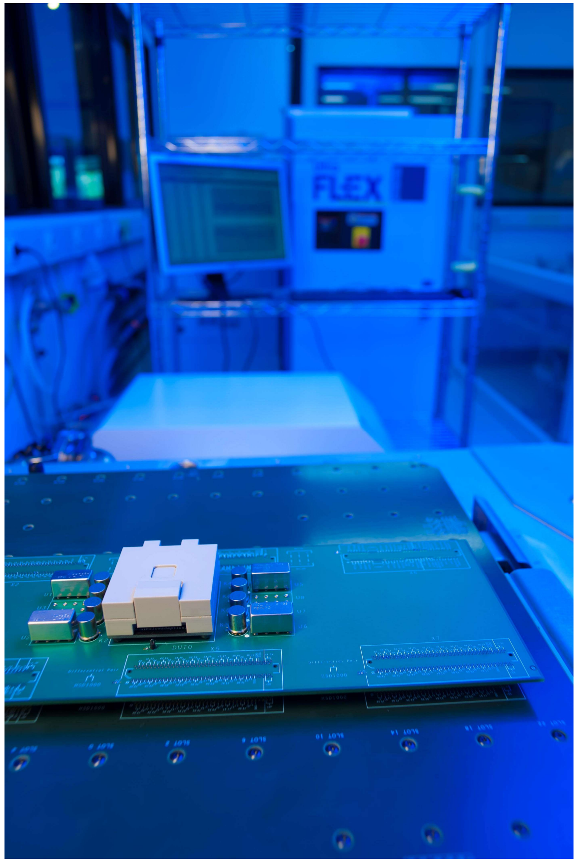
Gonzalo Fernández Romero

Technical Advisor

TÜV NORD GROUP

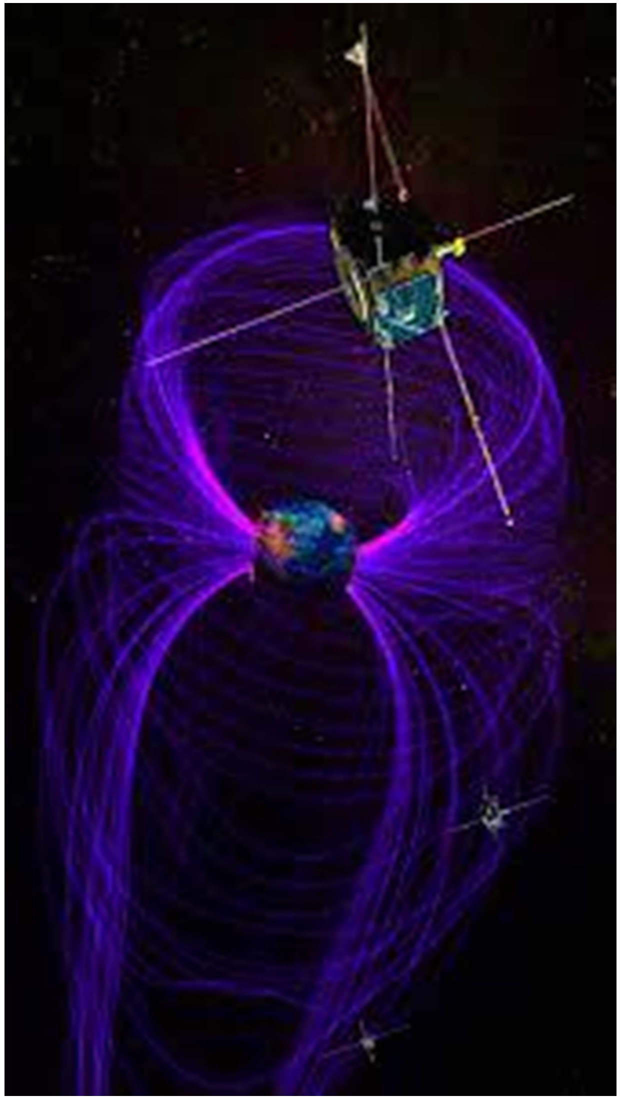
Content and index:

- Is the radiation environment a problem for electronics?
- Radiation types.
- Radiation Interaction. Microscopic effects.
- Radiation Environments:
  - Space
    - LEO Orbit
    - MEO
    - GEO
    - Other orbits and missions
  - Avionics
  - Others: ground radiation effects, radiotherapy rooms, etc…...



Content and index:

- Radiation effect on electronic devices:
  - Total Ionization Dose (TID).
  - ELDRS Effect
  - SEE (Single Event Effects).
  - TNID / DD (Displacement Damages).
- Radiation hardening assurance.
- Radiation test:
  - Assessment of radiation test need.
  - Radiation test plan design.
  - Radiation test performance.
  - Data assessment.
  - Examples of TID, SEE, DD and Laser testing.
  - Radiation test at equipment level
- Simulation and other radiation assessments
  - Software and hardware simulations.
  - TCAD

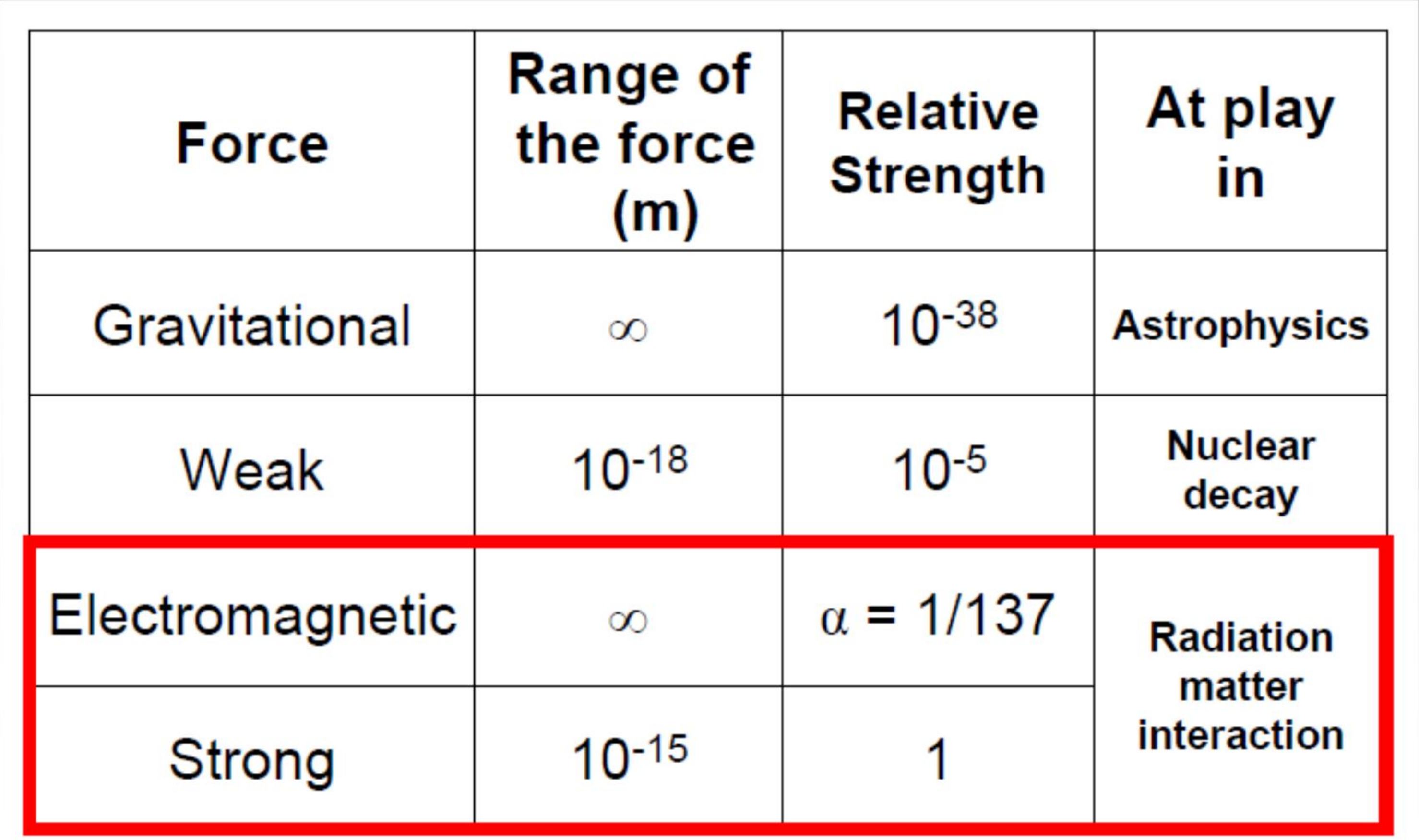


Is the radiation environment a problem for electronics?

1. Counters installed on the Explorer 1 and Explorer 3 missions detected particles and the presence of a severe radiation environment in the fifties, demonstrating the presence of energetic particles as part of the space environment.
2. The first lost satellite due to radiation effects was (TELSTAR, 1963). A general system failure, which was associated with a combination of radiation effects: human (nuclear test at high altitude) and natural.
3. In the 70s and early 80s were made different studies:
    - ✓ Identifying satellites damages due to cosmic rays,
    - ✓ Defects and failures were found in high altitude avionics,
    - ✓ and also, devices malfunction due to alpha particles coming from the material used in its manufacturing (plastic encapsulated).

The answer is yes. Radiation can degrade the electronic device perfomances.

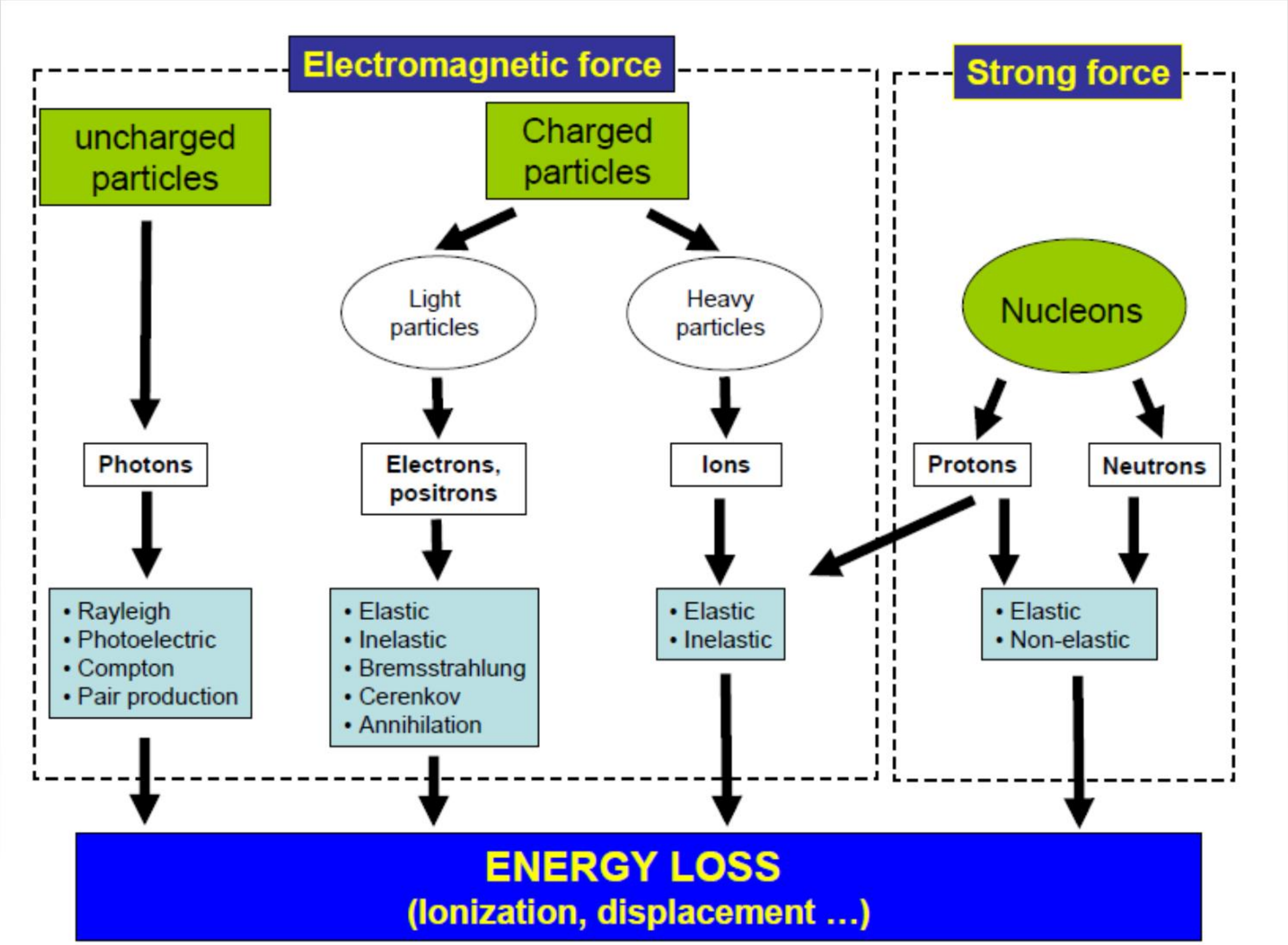
Types of physical interactions.



Force	Range of the force (m)	Relative Strength	At play in
Gravitational	∞	10^{-38}	Astrophysics
Weak	10^{-18}	10^{-5}	Nuclear decay
Electromagnetic	∞	$\alpha = 1/137$	Radiation matter interaction
Strong	10^{-15}	1	

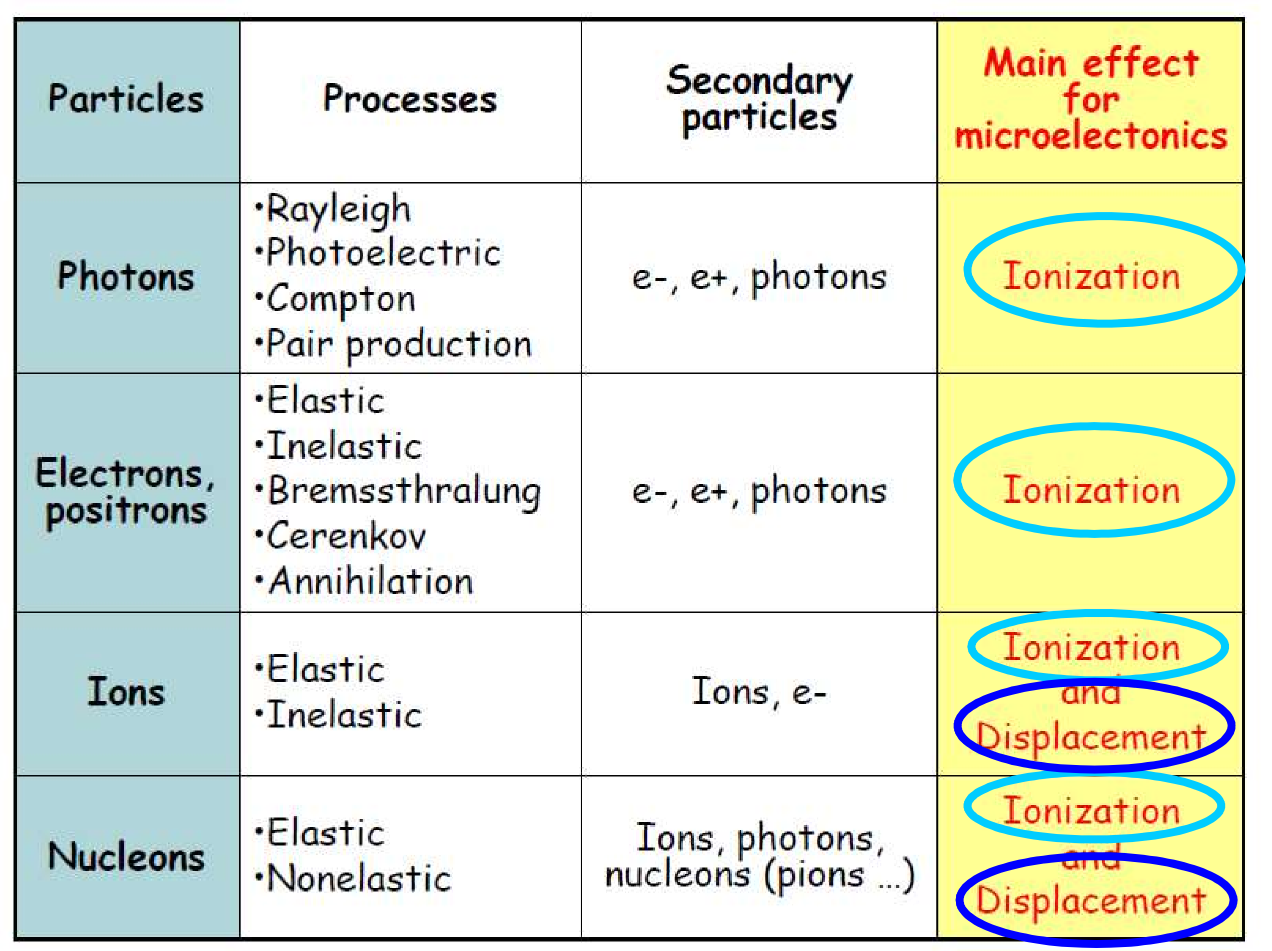
Fundamental on Radiation-Matter Interaction Frederic GROBEL (LPES-CRESA) **RADECS 2005**

Radiation – Matter Interaction.



Fundamental on Radiation-Matter Interaction **Frederic GROBEL (LPES-CRESA)** **RADECS 2005**

Radiation – Matter Interaction.



Particles	Processes	Secondary particles	Main effect for microelectonics
Photons	•Rayleigh •Photoelectric •Compton •Pair production	e-, e+, photons	Ionization
Electrons, positrons	•Elastic •Inelastic •Bremssthralung •Cerenkov •Annihilation	e-, e+, photons	Ionization
Ions	•Elastic •Inelastic	Ions, e-	Ionization and Displacement
Nucleons	•Elastic •Nonelastic	Ions, photons, nucleons (pions ...)	Ionization and Displacement

Fundamental on Radiation-Matter Interaction Frederic GROBEL (LPES-CRESA) **RADECS 2005**

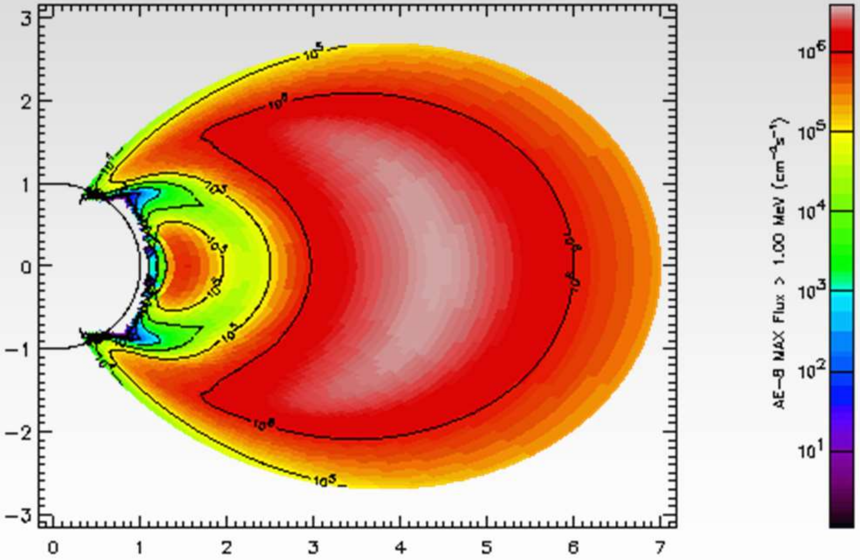
Space Radiation Environment

The main sources of energetic particles (ionizing radiation) in space mainly are:

- protons and electrons trapped in the Van Allen radiation belts
- heavy ions trapped in the magnetosphere
- protons and heavy ions from the sun: solar flares, …
- cosmic or galactic ray protons and heavy ions (from outside the solar system: 85% Protons, 14% Alpha particles, 1% Heavy ions.

Space Radiation Environment

Electron Belt

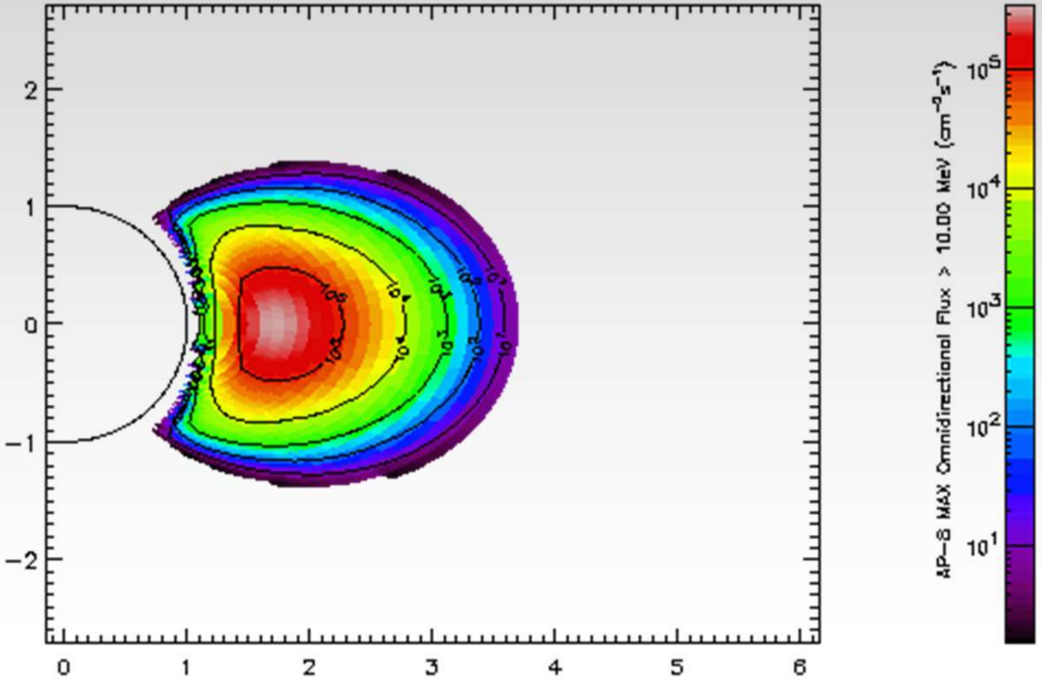


The electron belt is composed by two parts, the low-energy electron belt, that actually overlaps the volume of space occupied by the proton belt, and that has electrons with approximately 1 - 5 MeV, and the high-energy electron belt, that is located further out. Electrons in this Outer Belt carry higher energy values reaching levels of several tenths of MeV

Iso-flux lines of trapped proton belt. From AP-8 MAX (SPENVIS)

Space Radiation Environment

Proton Belt

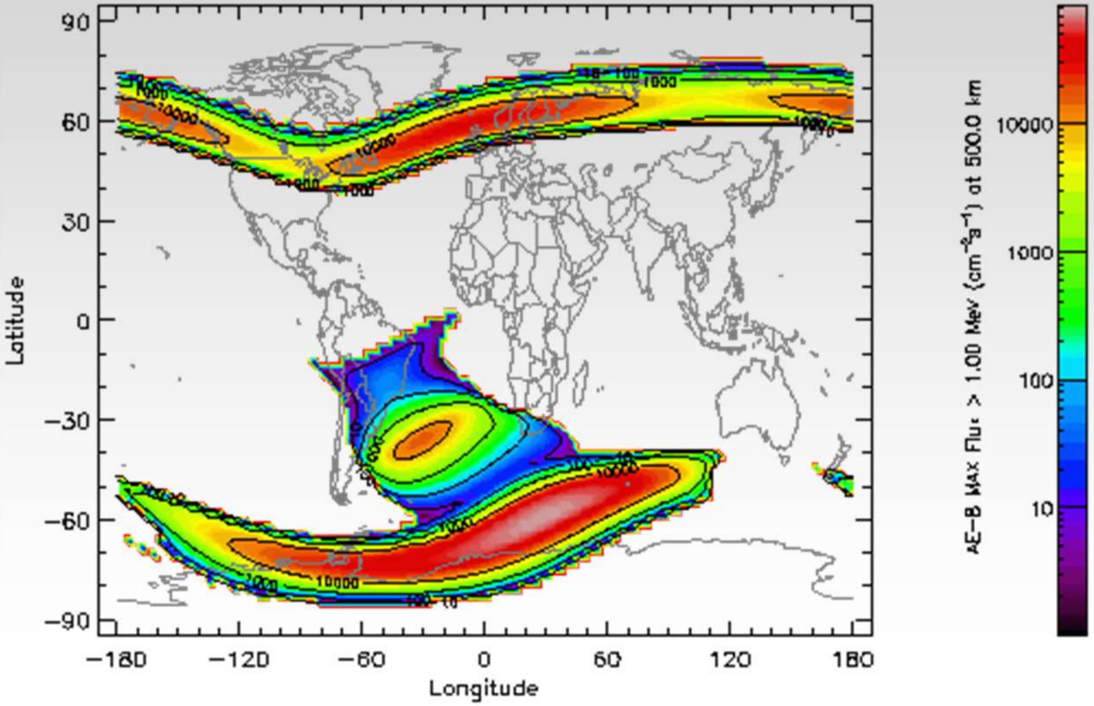


The proton belt is located from about 500 kilometers above Earth's surface and extends to 13,000 km. This Inner Belt contains protons with energies greater than 100 MeV

Iso-flux lines of trapped electron belt. From AP-8 MAX (SPENVIS)

Space Radiation Environment

South Atlantic Anomaly

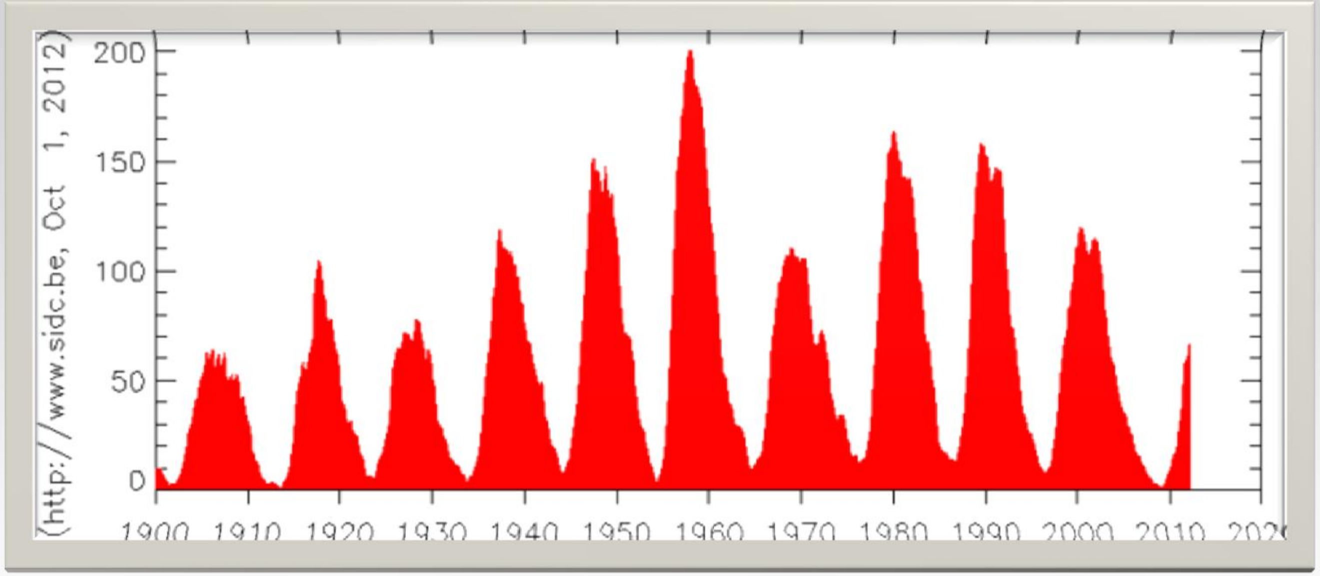


Due to the fact that the dipole axis of the Earth’s geomagnetic field is offset from the Earth’s axis of rotation by approx. 11º and is displaced by approx. 500 km. The result is that the radiation belts goes down to a low altitude over the South Atlantic area.

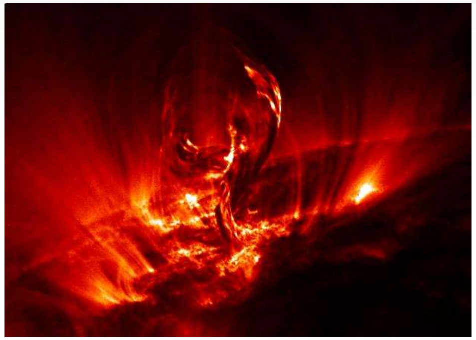
South Atlantic Anomaly. From AP-8 MAX (SPENVIS)

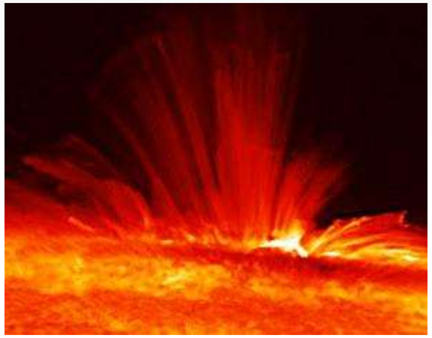
Space Radiation Environment

Solar Flares

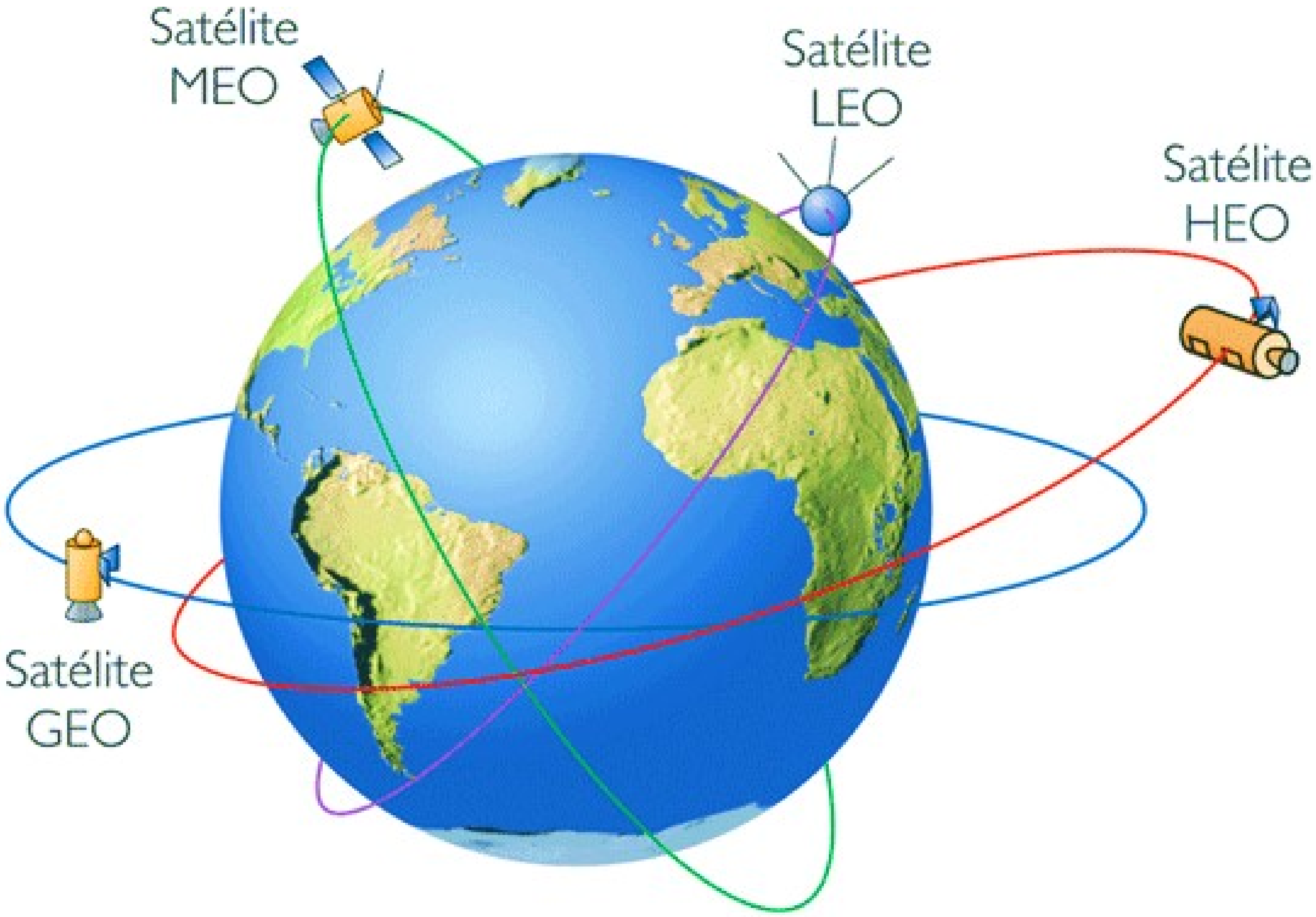


The cycle length varies from 9 to 13 years, with approximately 7 years of maximum solar activity and 4 with a minimum.

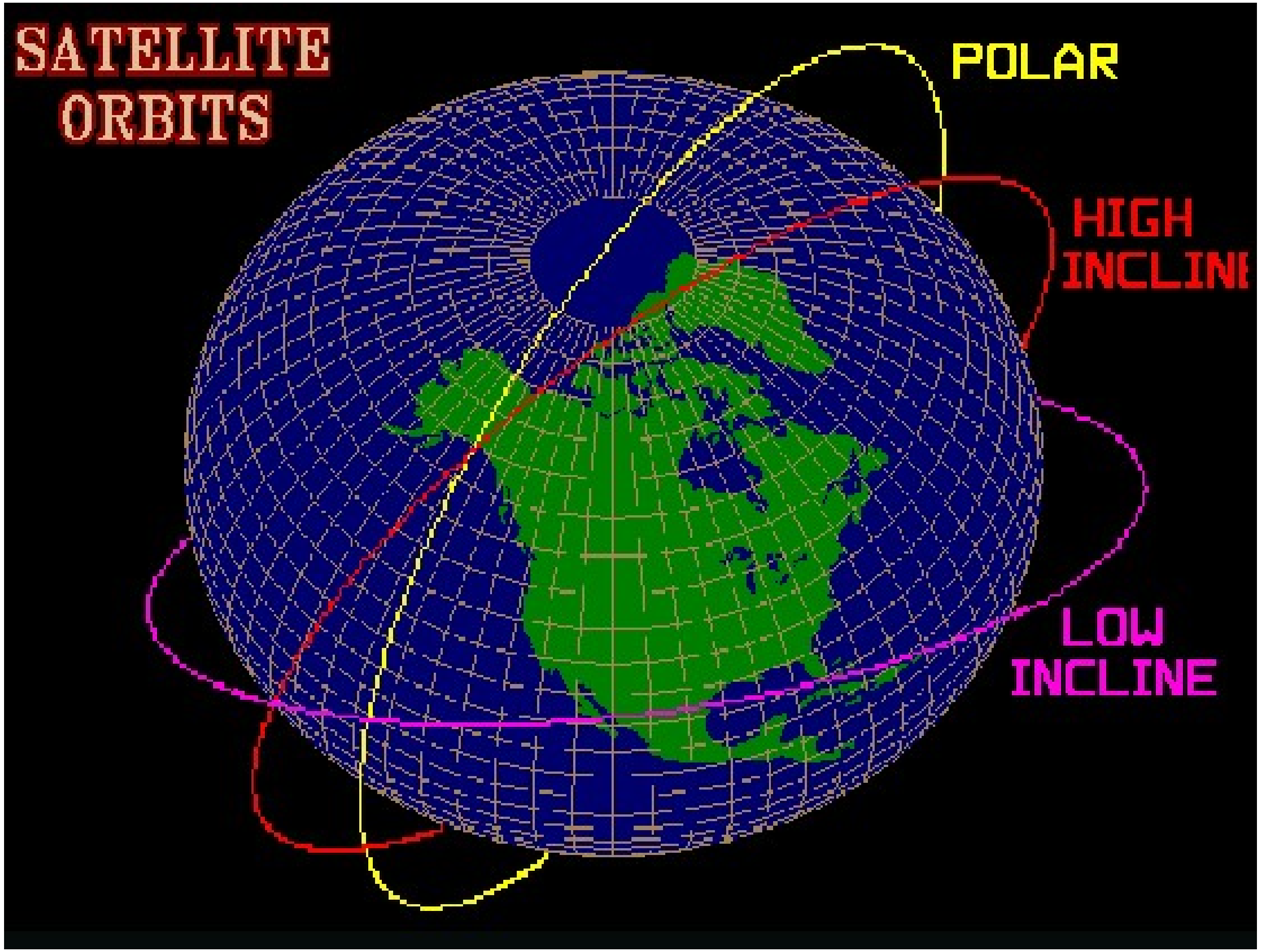




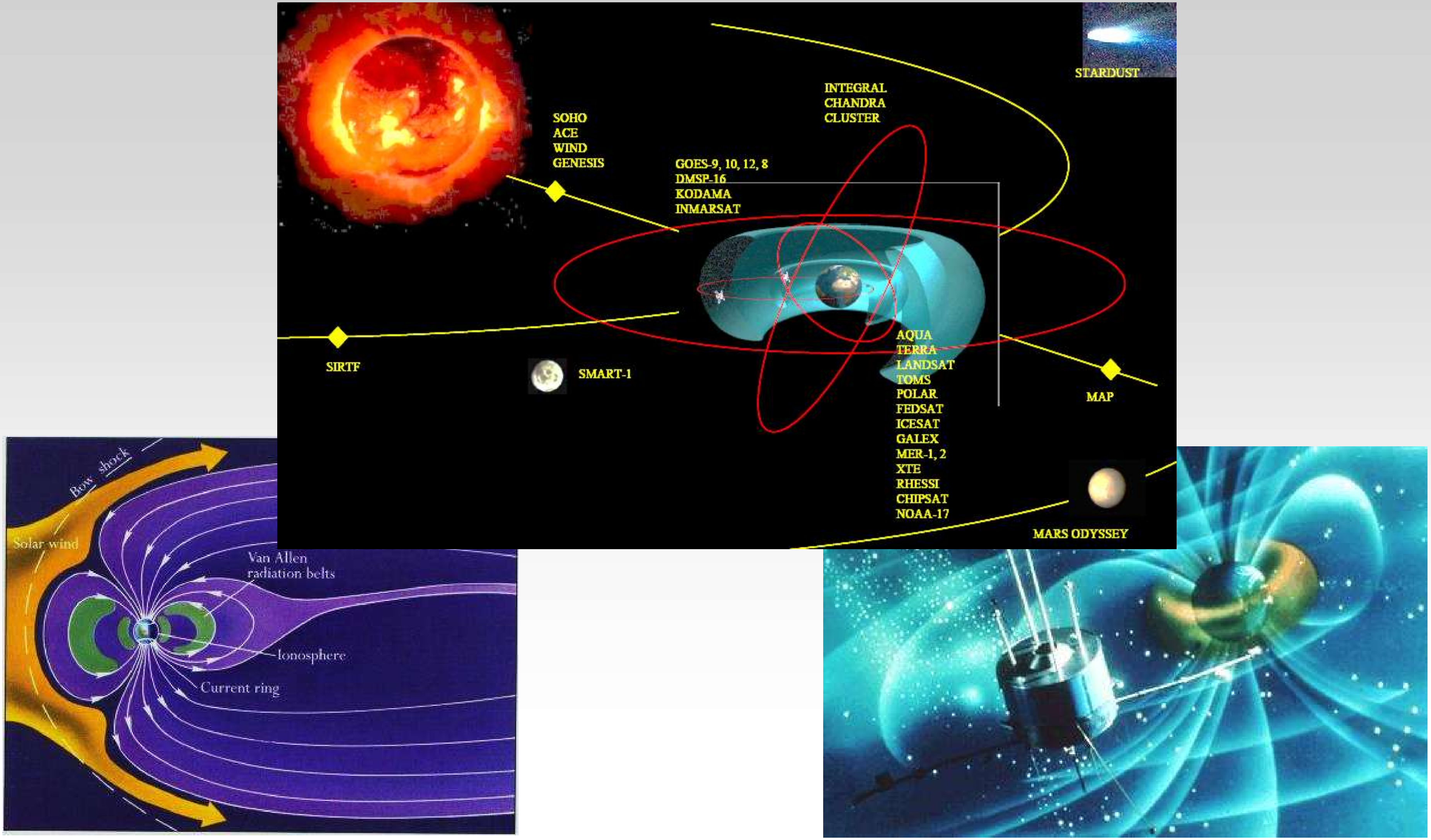
Space Radiation Environment. ORBITS



Space Radiation Environment. ORBITS



Space Radiation Environment



(From Stars, J. B. Kaler, Scientific American Library, Freeman, NY, 1992.)

Space Radiation Environment. ORBITS

Exposure to radiation from a space mission is determined by its orbit: latitude and altitude, along with the duration of the mission.

A) ***LEO (Low Earth Orbit). Orbiting the Earth at a distance <1000 km.***

1. (200 to 500 km) and inclination (<28°) produce low exposures <1 krad / year. Very low TID degradations TID and occasionally by SEU.
2. Orbits of low altitude (200 to 1000 km) and high inclination (> 28°) exposures occur typically <10Krad/year. (IRIDIUM)

C) MEO (1000 - 4000Km)

TID from 100 krad to Mrad per year. The geomagnetic shielding is reduced and the satellites are within Van Halen belts. SEU is likely. GPS

Tipycal MEO with high altitude (20.000km aprox) are Glonass, GPS and Galileo)

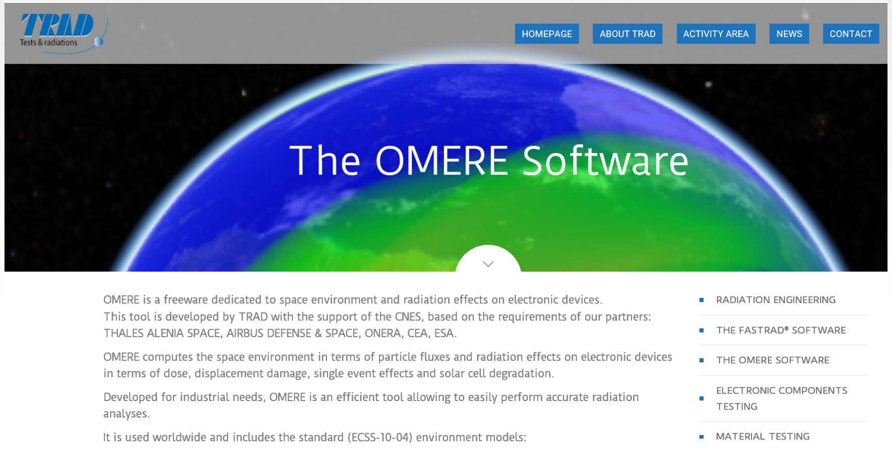
D) Geo Orbit (35.800Km) They are exposed to less than 10Krad per year but is very prone to SEU by not having the protection of the magnetosphere environment. It is used by some commercial and military satellite communications, etc. (METEOSAT, etc.)

F) Others: (elliptical orbits in general quite far from the Earth at perigee), solar orbits, interplanetary missions, etc.

Space Radiation Environment. Tools

Mission radiation is determined by its: latitude, altitude, mission life, orbit – multi orbit, using software tools like: OMERE:

- ❑ ***SPENVIS***
- ❑ ***OMERE***



OMERE is a freeware dedicated to space environment and radiation effects on electronic devices.
This tool is developed by TRAD with the support of the CNES, based on the requirements of our partners: THALES ALENIA SPACE, AIRBUS DEFENSE & SPACE, ONERA, CEA, ESA.

OMERE computes the space environment in terms of particle fluxes and radiation effects on electronic devices in terms of dose, displacement damage, single event effects and solar cell degradation.

Developed for industrial needs, OMERE is an efficient tool allowing to easily perform accurate radiation analyses.

It is used worldwide and includes the standard (ECSS-10-04) environment models:

Welcome to SPENVIS

SPENVIS is ESA's SPace ENVironment Information System, a WWW interface to models of the space environment and its effects; including cosmic rays, natural radiation belts, solar energetic particles, plasmas, gases, and "micro-particles".

Use of SPENVIS on this site is **free of charge**, but a user registration is required.

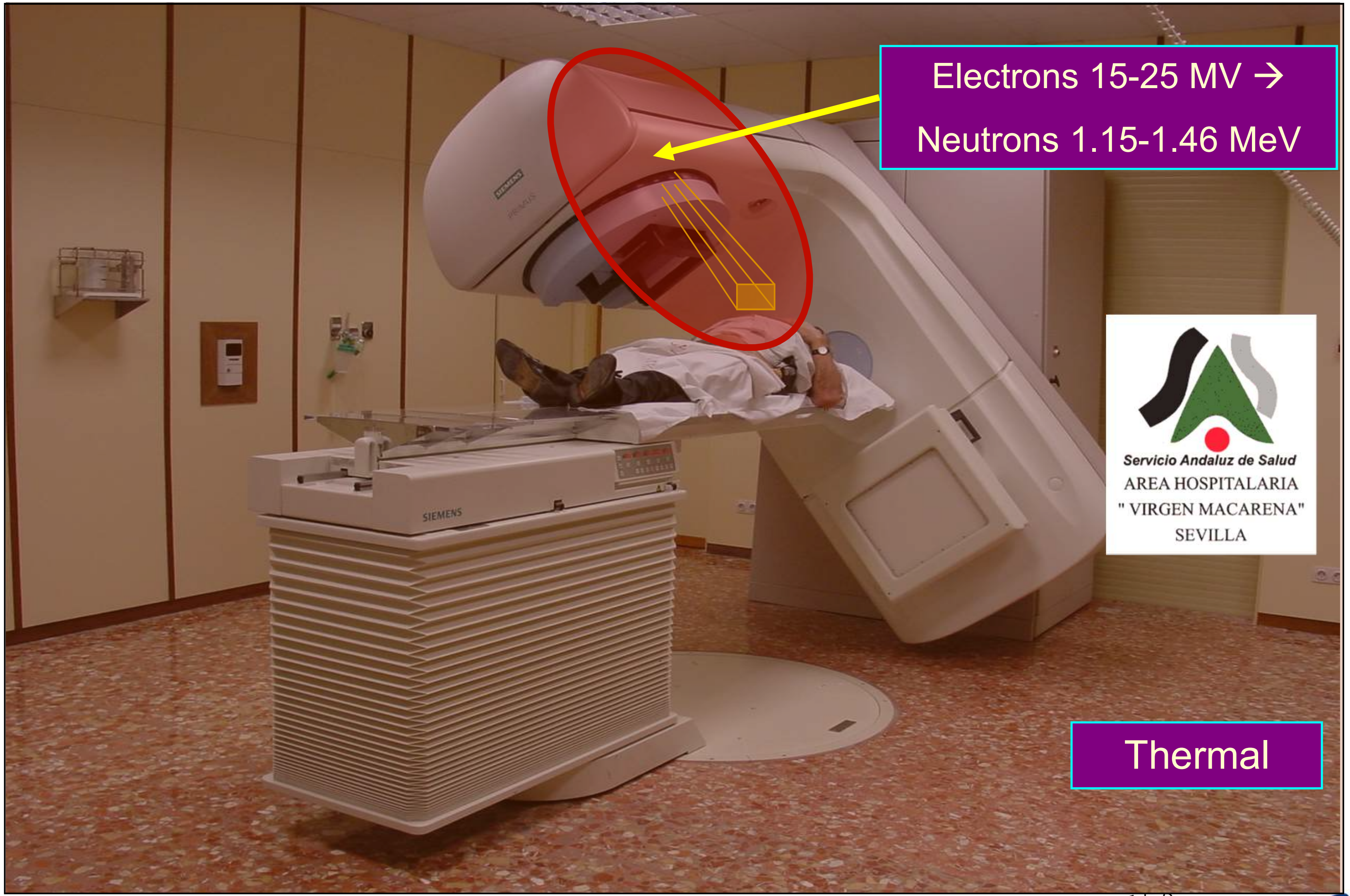
Current version
The current version of SPENVIS (**4.6.9**) was released on November 6, 2017.

System requirements
SPENVIS requires a browser with JavaScript support (tested with Firefox 23 and MS-IE 9). Some outputs require a VRML/X3D plugin (tested with Octaga Player 2.3.0.3).

Need help?
Beside a large set of contextual help pages, the SPENVIS system includes a forum (💬) where users can exchange their experiences and tips. In case of problems, please consult our bug tracker system (🐞) and feel free to post any bugs.

The SPENVIS system is developed by a consortium led by the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) for ESA's Space Environments and Effects Section through its General Support Technology Programme (GSTP). The system is

Radiotherapy Radiation Environment.



Electrons 15-25 MV →

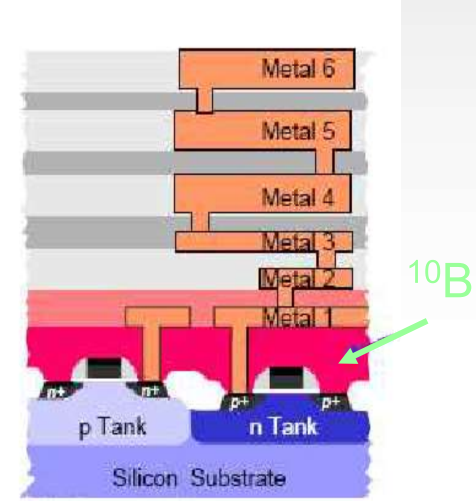
Neutrons 1.15-1.46 MeV

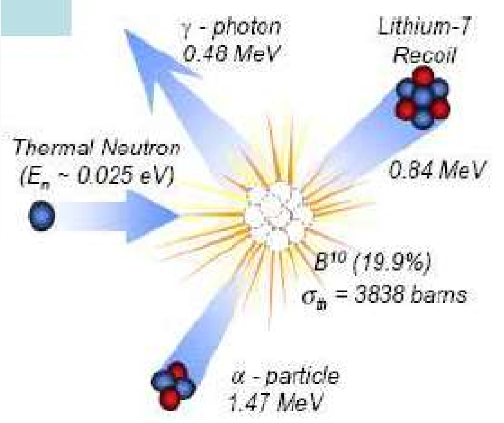
Thermal

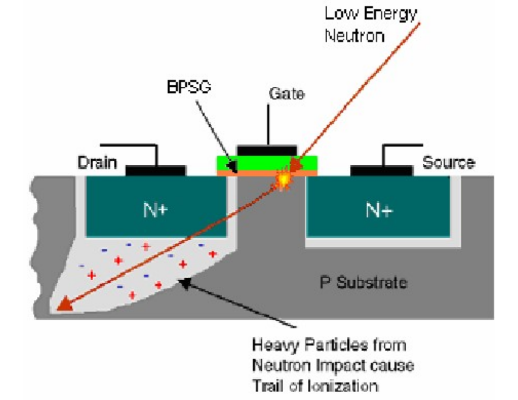
Radiotherapy Radiation Environment.

Solid State detector

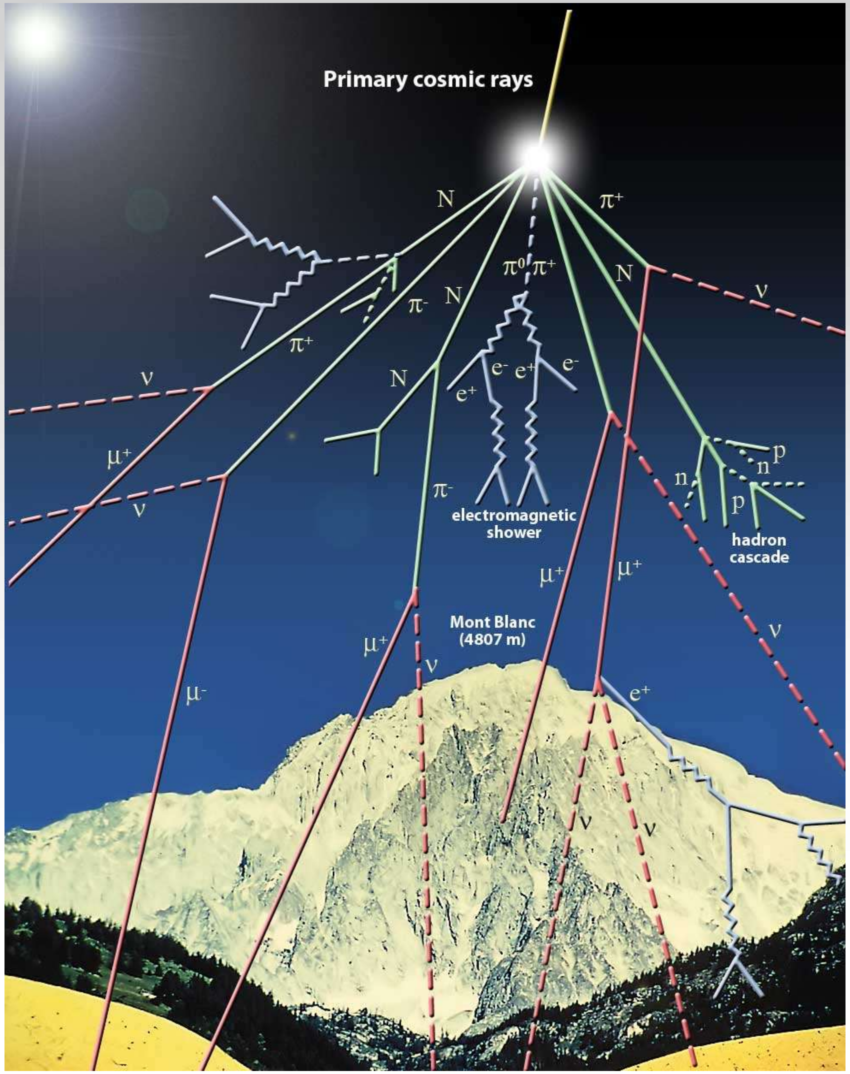
SRAM memories







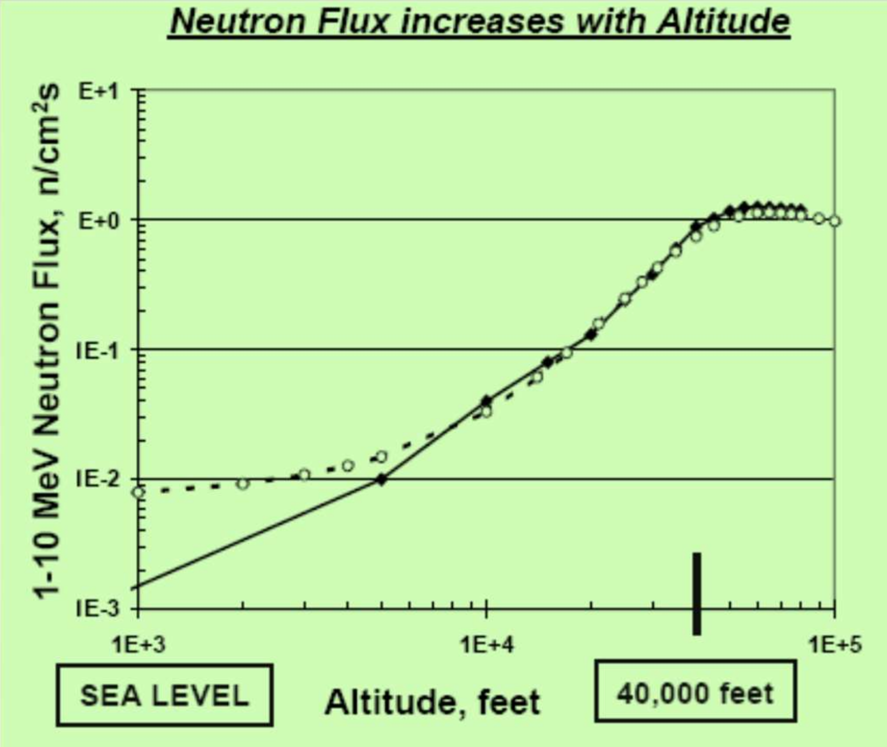
Ground and Avionic Radiation Environment.



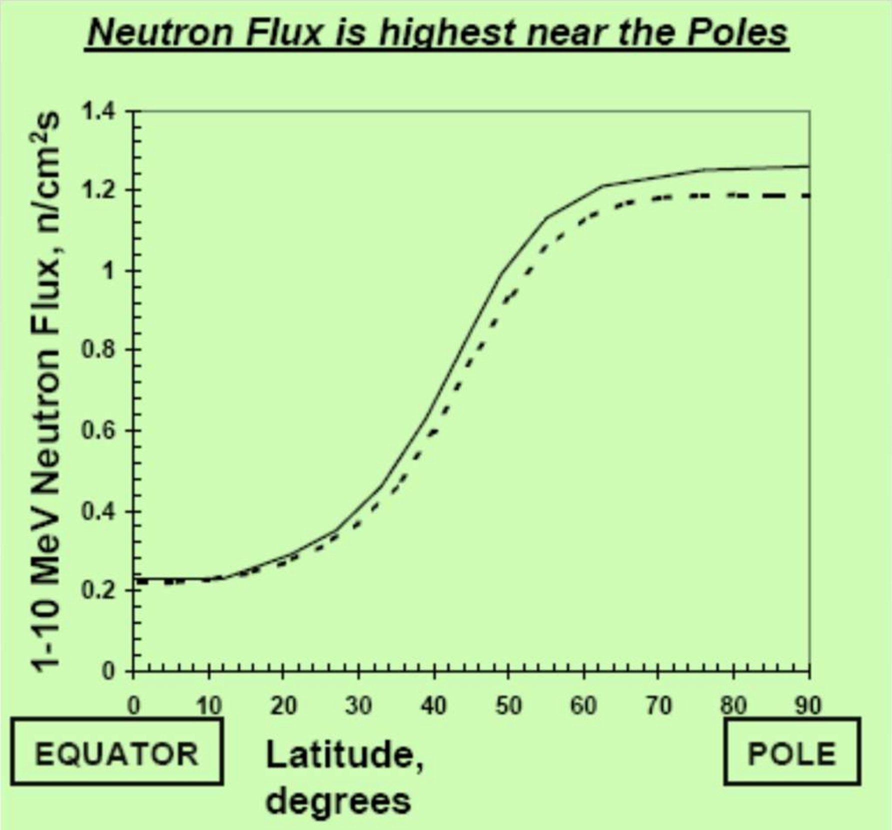
CÁTEDRA ALTER TECHNOLOGY

ALTER TECHNOLOGY

Effect of the radiation into electronic devices: Total dose (TID)

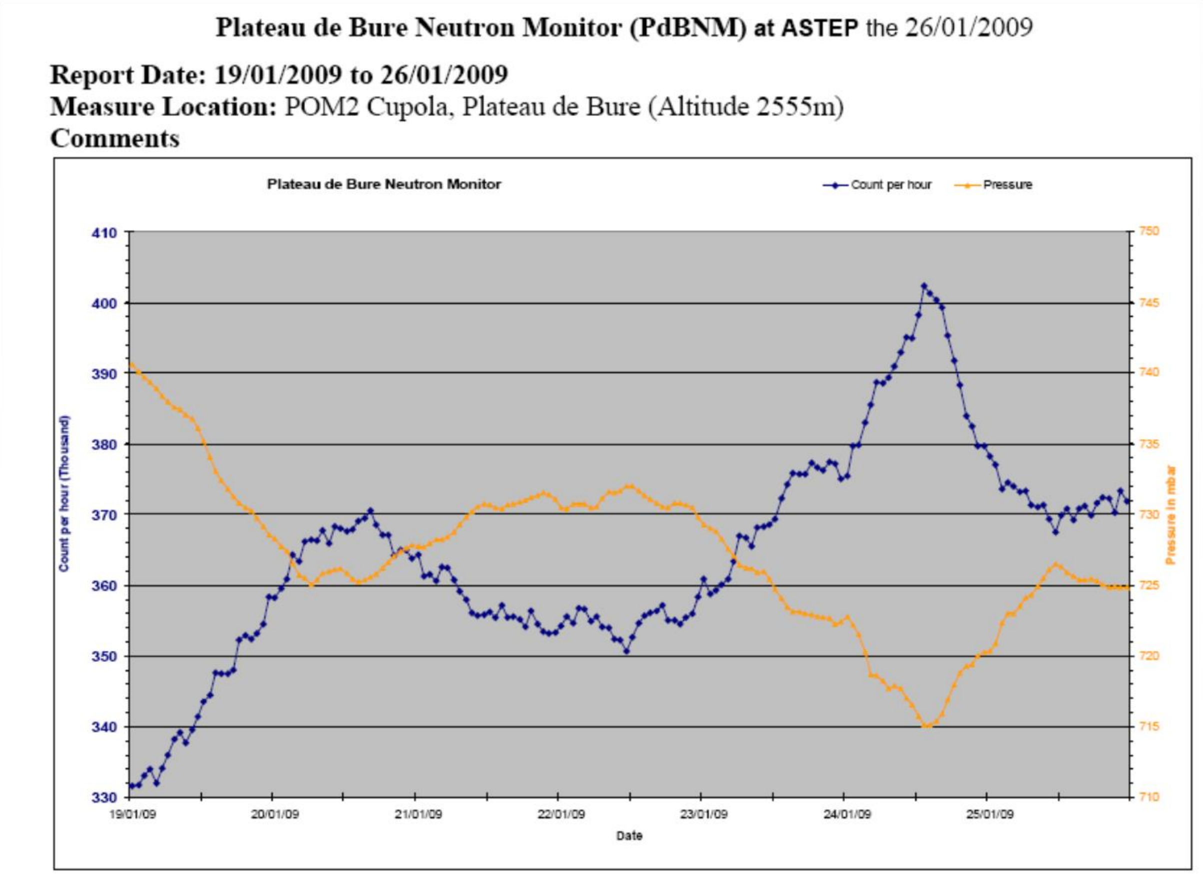


From sea level to 40,00 feet altitude the secondary neutron flux increases by approximately 300 times.



R. Edwards, C. S. Dyer and E. Normand, "Technical Standard for Atmospheric Radiation Single Event Effects (SEE) on Avionics Electronics", 2004 IEEE Radiation Effects.

Ground and Avionic Radiation Environment.



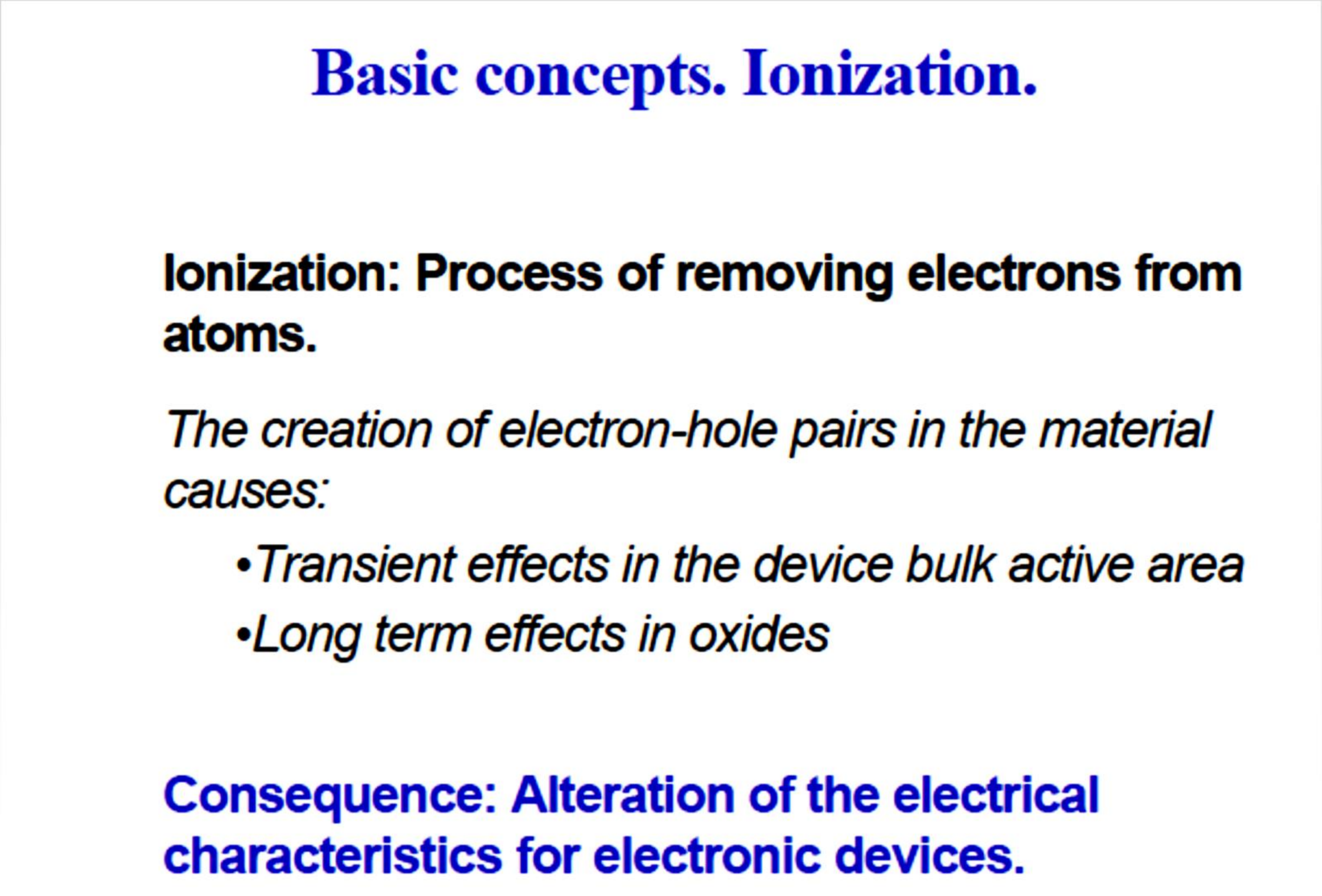
Plateau de Bure Neutron Monitor (PdBNM) at ASTEP the 26/01/2009

Report Date: 19/01/2009 to 26/01/2009
Measure Location: POM2 Cupola, Plateau de Bure (Altitude 2555m)
Comments

A relationship between the atmospheric air pressure and the neutron flux has been observed. A decrease of the air pressure is linked with an increase of the recorded neutron flux at ground level.

Provided by the Altitude SEE Test European Platform (ASTEP) and by IM2NP-CNRS Laboratory, Marseille, France (www.astep.eu)".

Total Ionization Dose Effects (TID) .



Basic concepts. Ionization.

Ionization: Process of removing electrons from atoms.

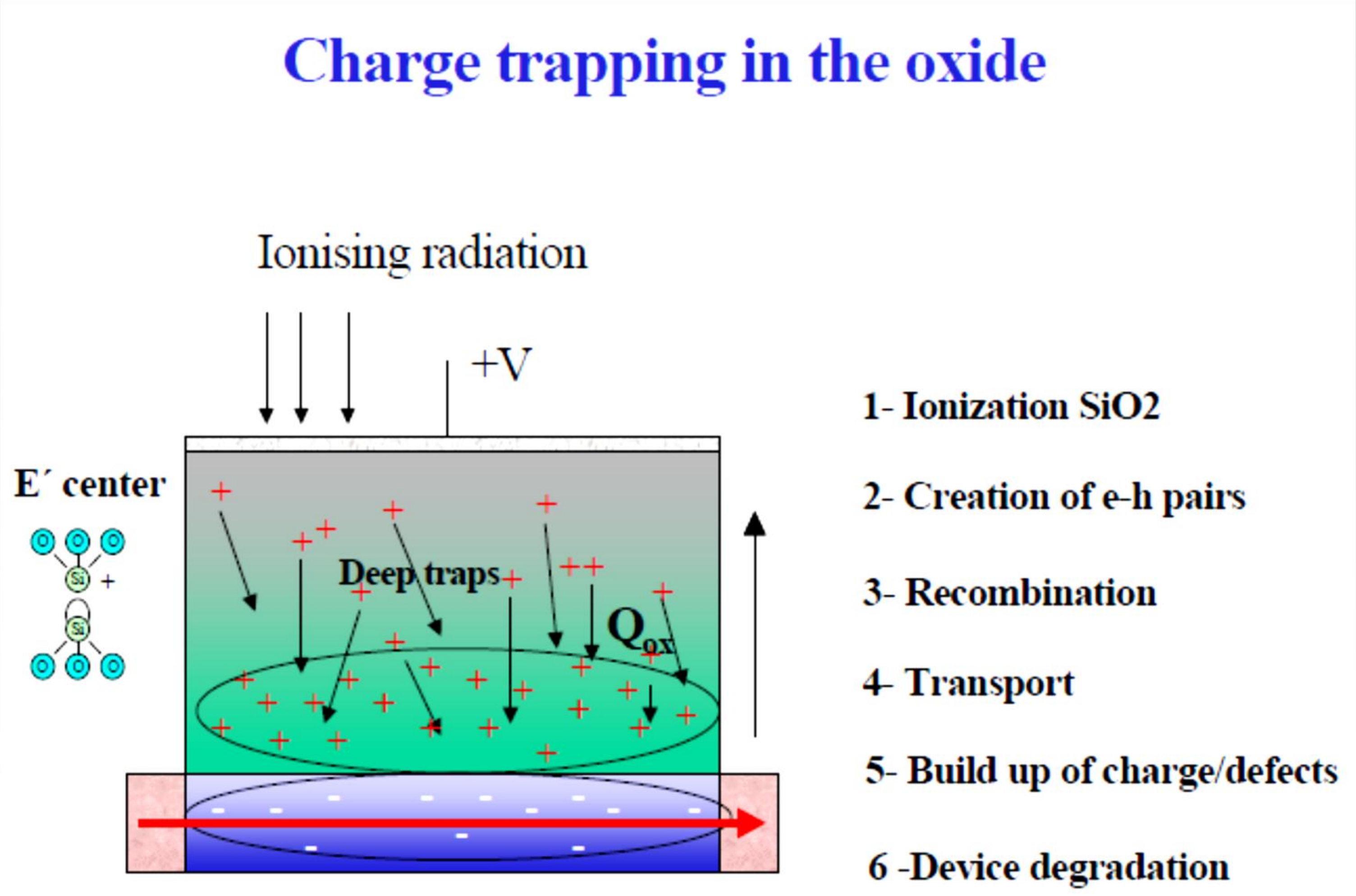
The creation of electron-hole pairs in the material causes:

- *Transient effects in the device bulk active area*
- *Long term effects in oxides*

Consequence: Alteration of the electrical characteristics for electronic devices.

Juan Cueto RADECS 2003 SHORT COURSE

Total Ionization Dose Effects (TID) .



Charge trapping in the oxide

1- Ionization SiO2

2- Creation of e-h pairs

3- Recombination

4- Transport

5- Build up of charge/defects

6 -Device degradation

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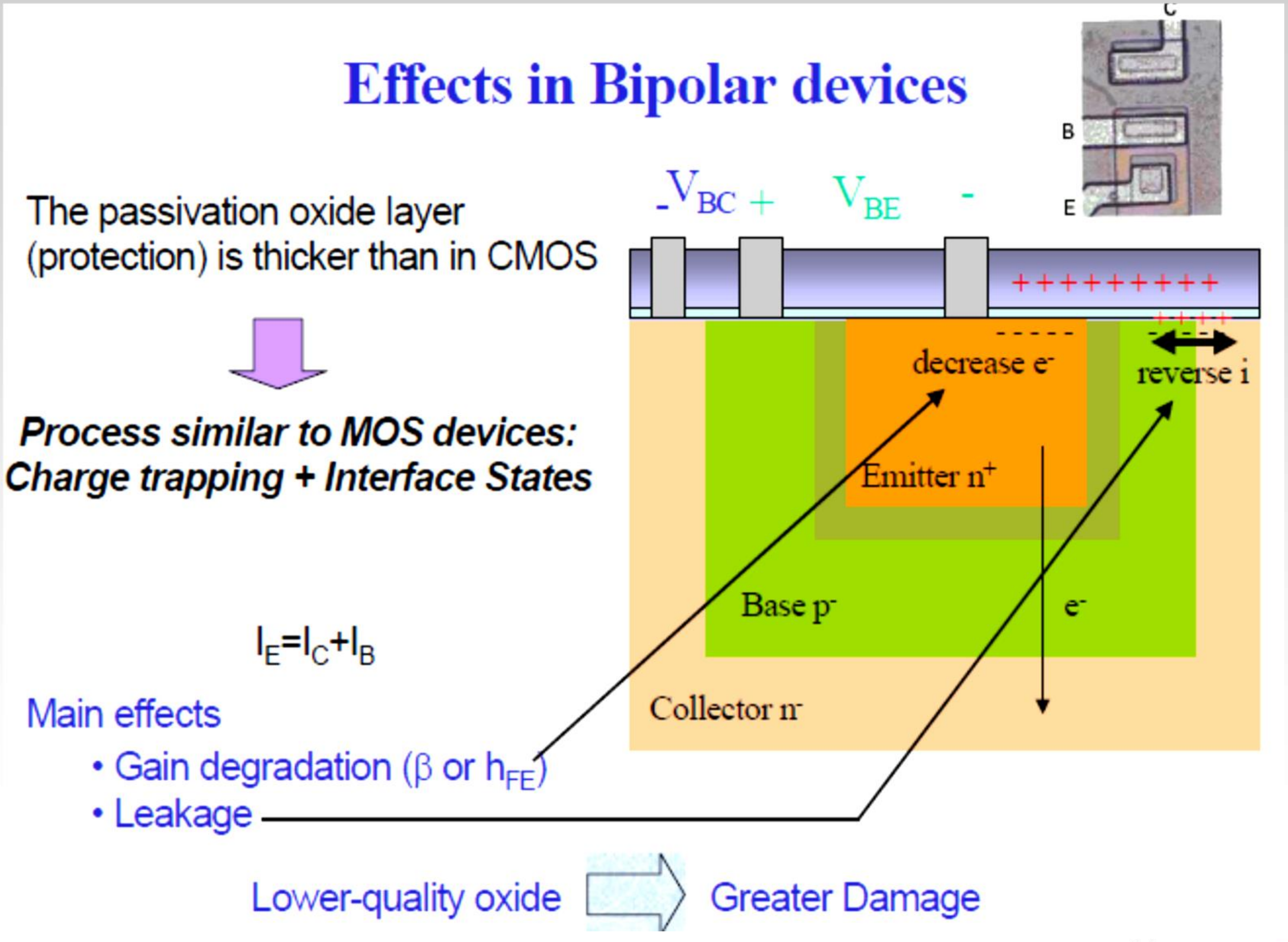
Total Ionization Dose Effects (TID) .



Effects in Bipolar devices

The passivation oxide layer (protection) is thicker than in CMOS

Process similar to MOS devices: Charge trapping + Interface States

$I_E=I_C+I_B$

Main effects

- Gain degradation (β or h_{FE})
- Leakage

Lower-quality oxide ⇨ Greater Damage

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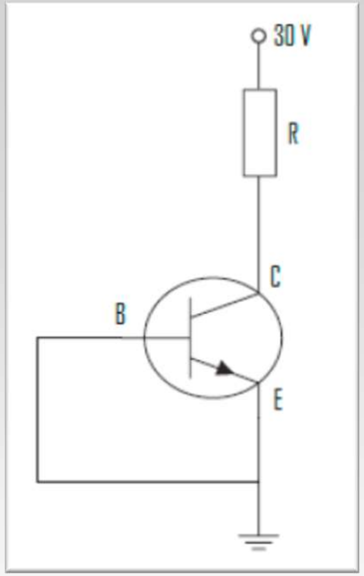
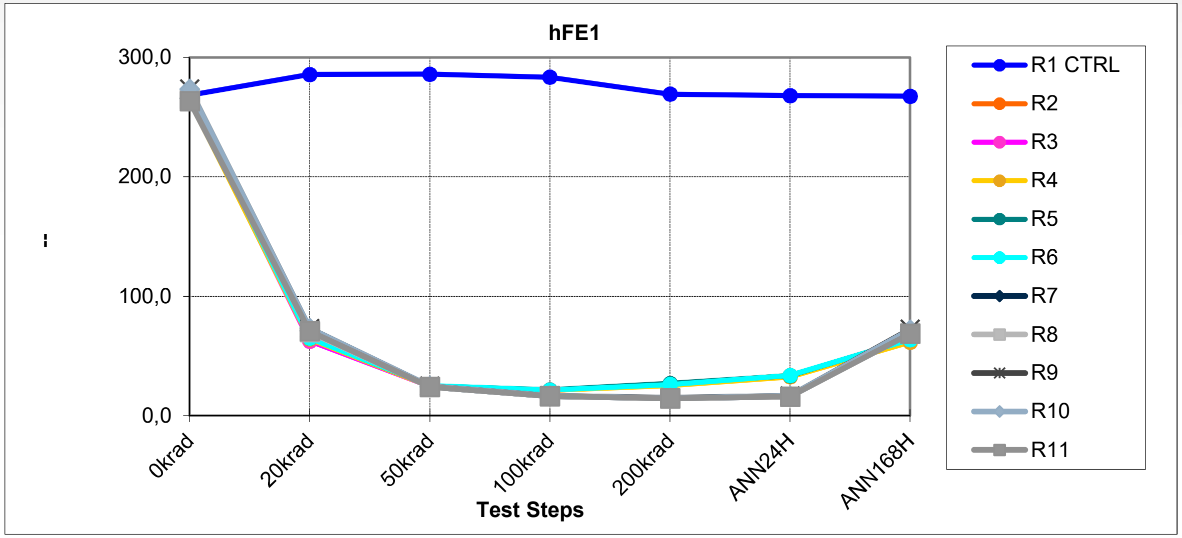
Radiation Test (TID) EXAMPLE I.

ATN-RR-369 (NPN GENERAL PURPOSE TRANSITOR – BC 847B)

EVALUATION	X	**TEST HOUSE**	ALTER TECHNOLOGY TUV NORD S.A.U. (SEVILLE, SPAIN)		
ACCEPTANCE DIFUSSION	--	**RAD. FACILITY**	RADLAB (SEVILLE, SPAIN)		
ACCEPTANCE LOT	--	**RADIATION SOURCE**	^{60}Co	**ENERGY**	1.33 / 1.17 MeV
IRRADIATION TEST	5 BIASED, 5 UNBIASED	**IRRADIATION UNITS**	10 + 1 CONTROL		
ANNEALING TEST	5 BIASED, 5 UNBIASED	**DOSE RATE**	203.14 rad (Si)/h		
IRRADIATION MEAS.	REMOTE TEST.	**INTEREST TEST LEVEL**	N/Av		
RADIATION PLAN	DLIB-ATN-RP-004 Iss.1	**MAXIMUM TEST LEVEL**	200 krad (Si)		

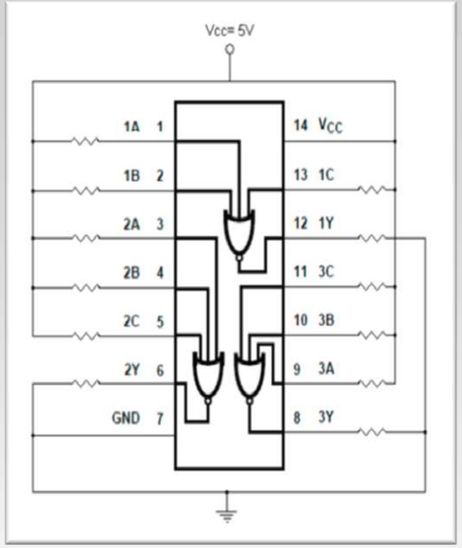


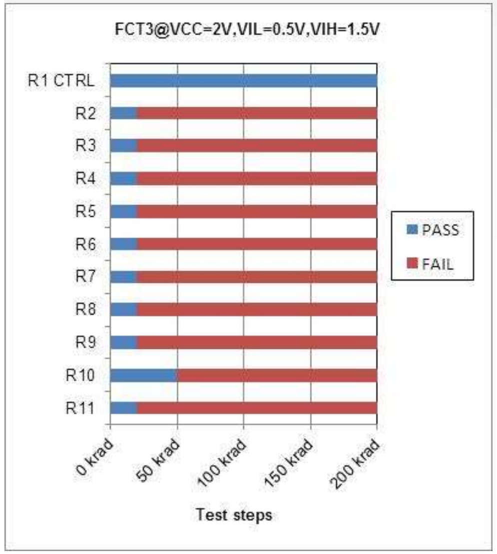


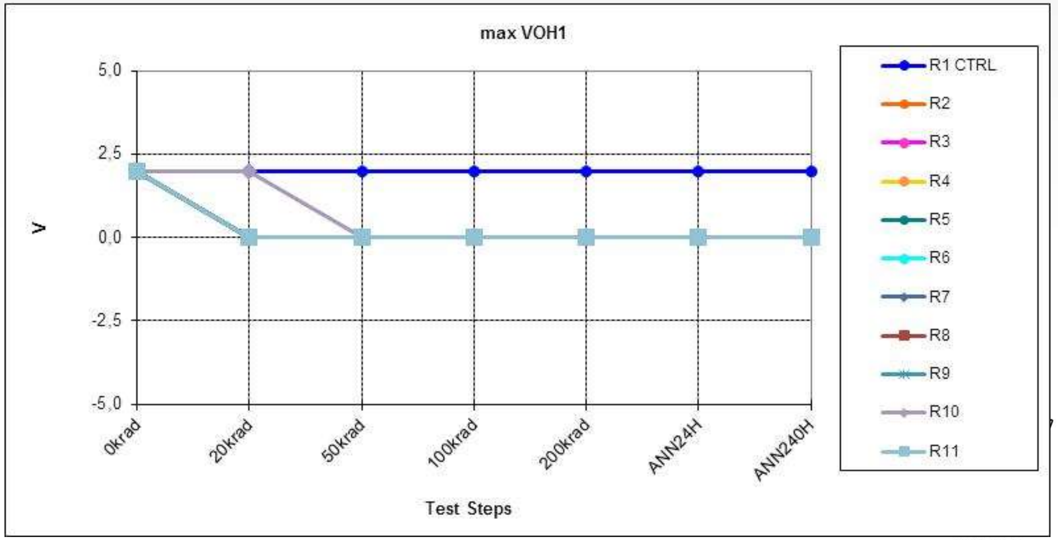
Radiation Test (TID) EXAMPLE II.

ATN-RR-371 (TRIPLE 3-INPUT NOR GATE – CD74HC27M)

EVALUATION	X	**TEST HOUSE**	ALTER TECHNOLOGY TUV NORD S.A.U. (SEVILLE, SPAIN)		
ACCEPTANCE DIFUSSION	--	**RAD. FACILITY**	RADLAB (SEVILLE, SPAIN)		
ACCEPTANCE LOT	--	**RADIATION SOURCE**	^{60}Co	**ENERGY**	1.33 / 1.17 MeV
IRRADIATION TEST	5 BIASED, 5 UNBIASED		**IRRADIATION UNITS**	10 + 1 CONTROL	
ANNEALING TEST	5 BIASED, 5 UNBIASED		**DOSE RATE**	216.65 rad (Si)/h	
IRRADIATION MEAS.	REMOTE TEST.		**INTEREST TEST LEVEL**	N/Av	
RADIATION PLAN	DLIB-ATN-RP-003 Iss 1		**MAXIMUM TEST LEVEL**	200 krad (Si)	





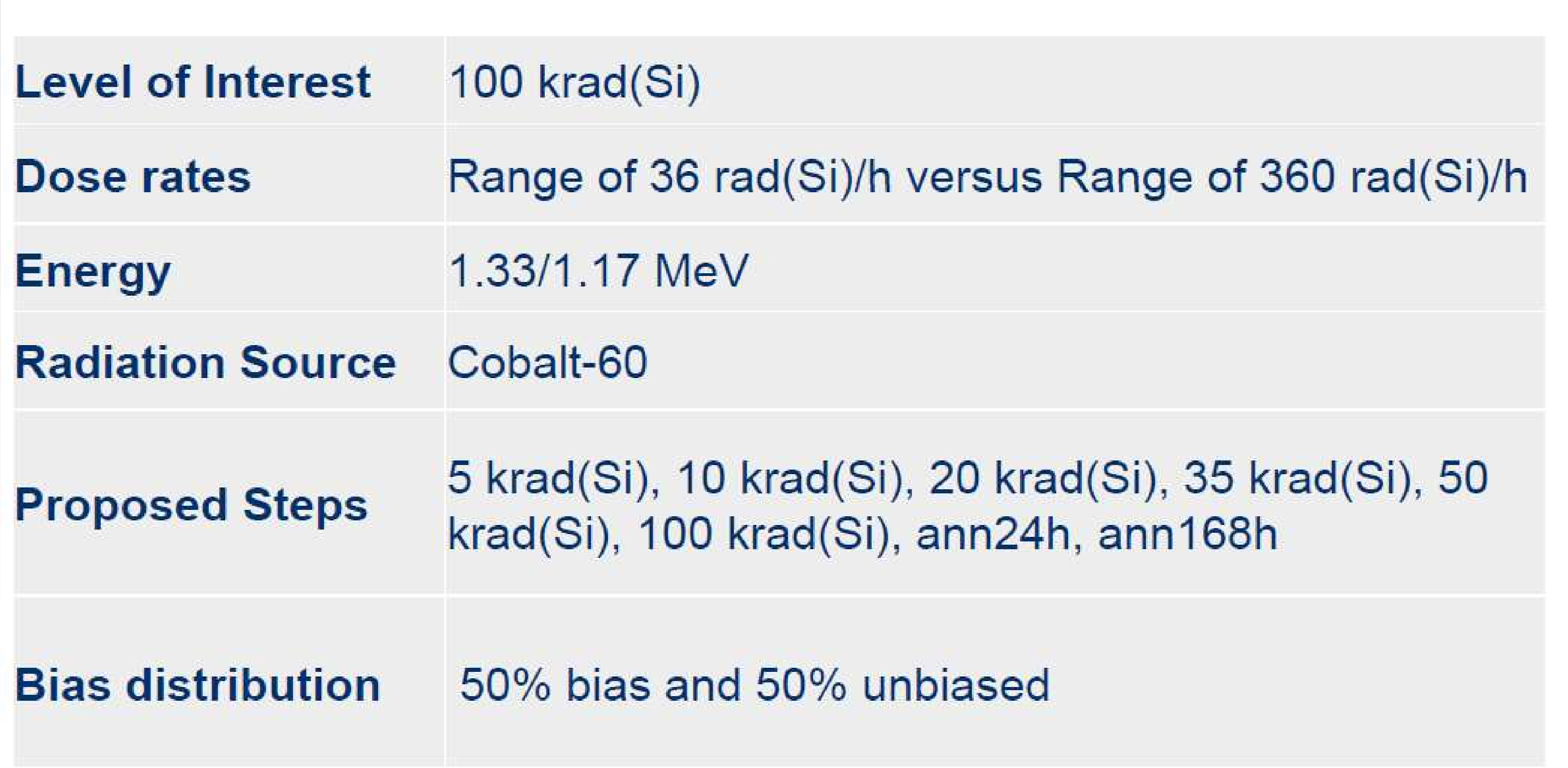


Total Ionization Dose Effects (TID). ELDRS Effect

ATN has performed an “ENHANCED LOW-DOSE RATE SENSITIVITY ANALYSIS” under ESA contract to assess the dose rate effect on Linear Bipolar Devices.

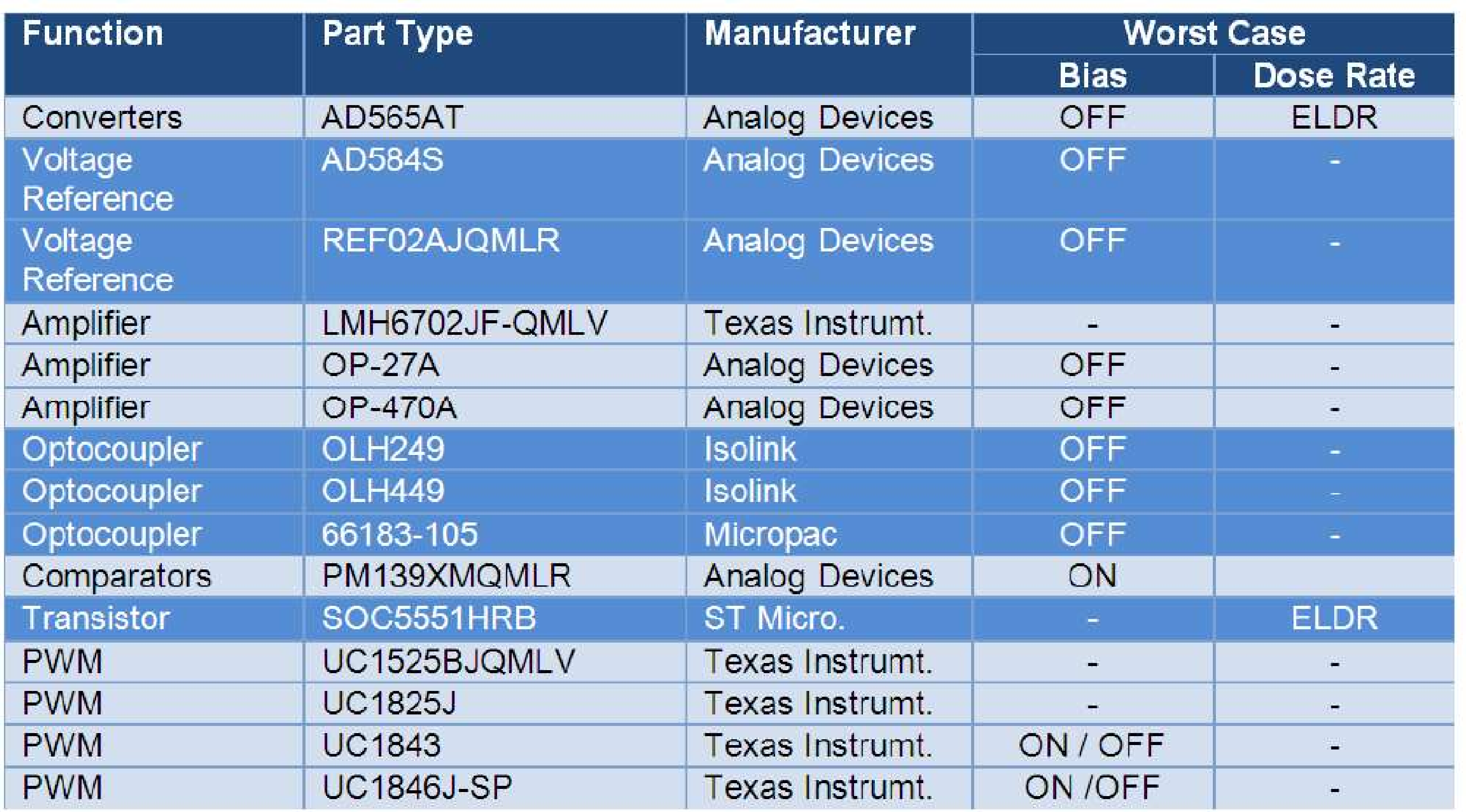
Function	Part Type
Converter	AD565AT
Voltage Reference	AD584S / REF02AJQMLR
Amplifier	LMH6702JF-QMLV / OP-27A / OP-470A
Optocoupler	OLH249 / OLH449 / 66183-105
Comparator	PM139XMQMLR
Transistor	SOC5551HRB
PWM	UC1525BJQMLV / UC1825J / UC1843 / UC1846J-SP

Total Ionization Dose Effects (TID). ELDRS Effect



Level of Interest	100 krad(Si)
Dose rates	Range of 36 rad(Si)/h versus Range of 360 rad(Si)/h
Energy	1.33/1.17 MeV
Radiation Source	Cobalt-60
Proposed Steps	5 krad(Si), 10 krad(Si), 20 krad(Si), 35 krad(Si), 50 krad(Si), 100 krad(Si), ann24h, ann168h
Bias distribution	50% bias and 50% unbiased

Total Ionization Dose Effects (TID). ELDRS Effect



Function	Part Type	Manufacturer	Worst Case	
			Bias	Dose Rate
Converters	AD565AT	Analog Devices	OFF	ELDR
Voltage Reference	AD584S	Analog Devices	OFF	-
Voltage Reference	REF02AJQMLR	Analog Devices	OFF	-
Amplifier	LMH6702JF-QMLV	Texas Instrumt.	-	-
Amplifier	OP-27A	Analog Devices	OFF	-
Amplifier	OP-470A	Analog Devices	OFF	-
Optocoupler	OLH249	Isolink	OFF	-
Optocoupler	OLH449	Isolink	OFF	-
Optocoupler	66183-105	Micropac	OFF	-
Comparators	PM139XMQMLR	Analog Devices	ON	
Transistor	SOC5551HRB	ST Micro.	-	ELDR
PWM	UC1525BJQMLV	Texas Instrumt.	-	-
PWM	UC1825J	Texas Instrumt.	-	-
PWM	UC1843	Texas Instrumt.	ON / OFF	-
PWM	UC1846J-SP	Texas Instrumt.	ON /OFF	-

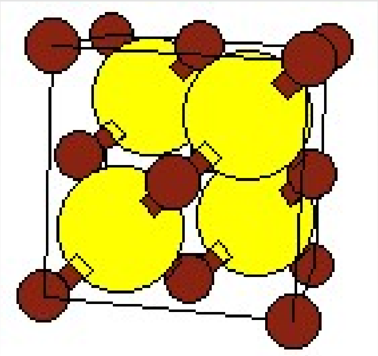
Total Ionization Dose Effects (TID). ELDRS Effect

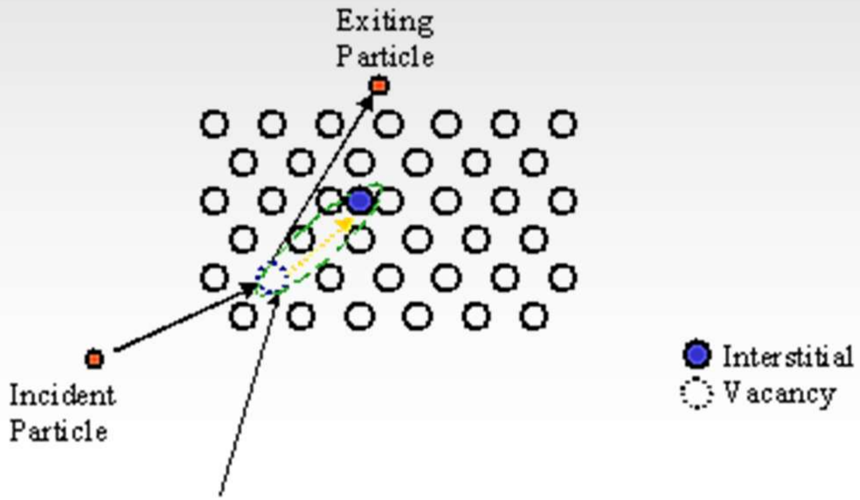
STUDY CONCLUSIONS:

- Not significant dose rate dependency on most items.
- Lack of correlation with current published data, maybe due to manufacturer efforts to enhance immunity to ELDRS.
- OFF condition: systematic worst case.
- PM139: ON biasing as worst case condition.
- PWM's: a specific pattern cannot be identified, depending on the parameter.

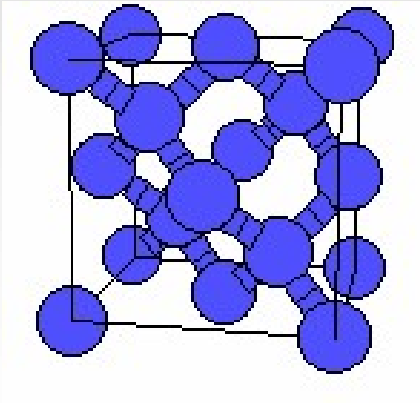
Displacement Damages (DD).

The effect is caused due to degradation / loss of the crystal structure of the material. This requires that the incident radiation has mass (ions, protons, neutrons, ..).





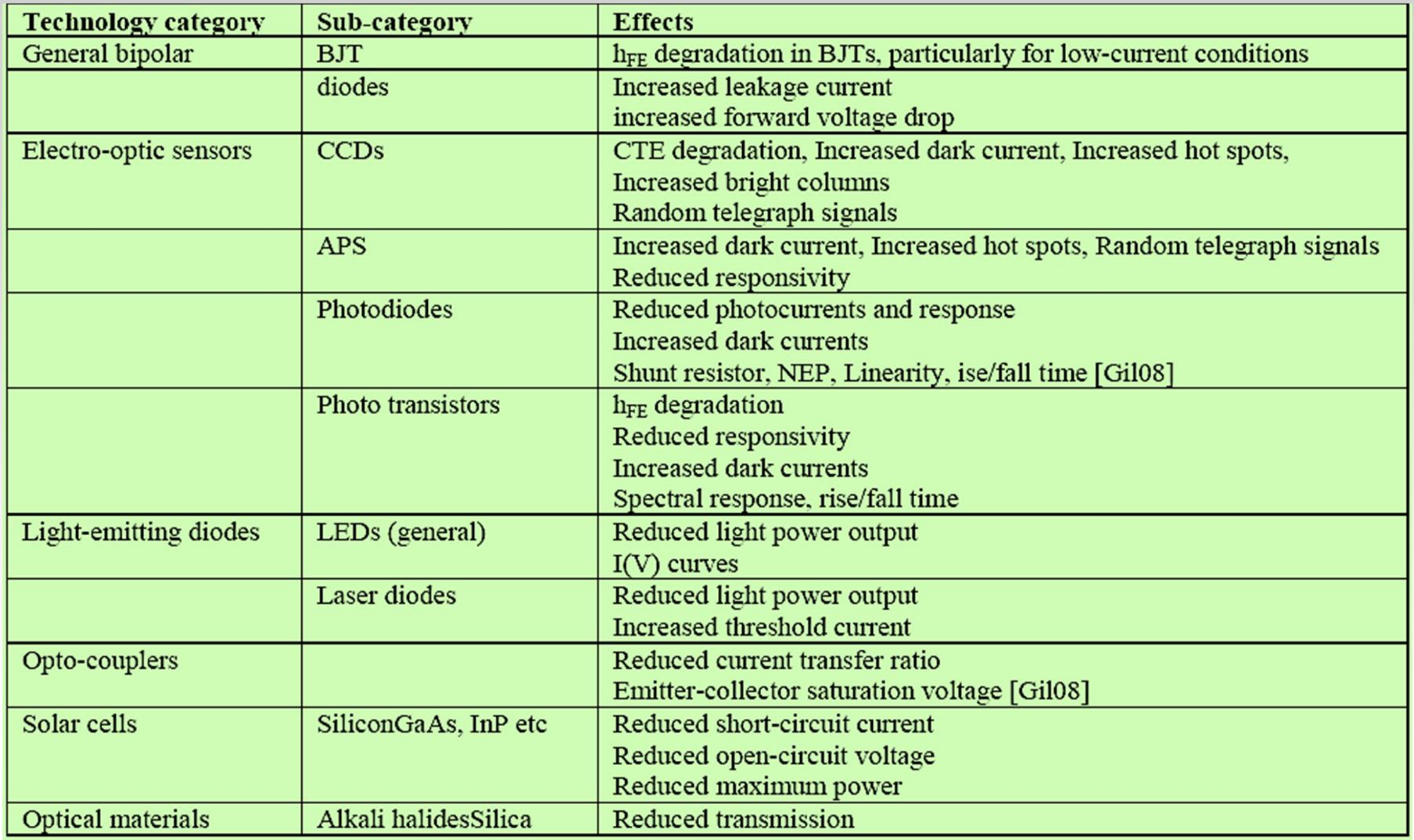
A Frenkel pair consists of a vacancy and an interstitial atom.



Displacement Damages (DD).

- Detectors show their dark current increases and their spectral response decreases.
- Transfer efficiency of CCDs is lowered.
- CCDs, APSs and photodiodes show temporal fluctuations in the dark current.
- LEDs experience a decrease of their emitted optical power and a degradation of their emission spectrum.
- Laser diodes exhibit an increase of their threshold current.
- Current Transfer Ratio of optocoupler is lowered.
- Solar cell efficiency is decreased.

Displacement Damages (DD).



Technology category	Sub-category	Effects
General bipolar	BJT	h_{FE} degradation in BJTs, particularly for low-current conditions
	diodes	Increased leakage current increased forward voltage drop
Electro-optic sensors	CCDs	CTE degradation, Increased dark current, Increased hot spots, Increased bright columns Random telegraph signals
	APS	Increased dark current, Increased hot spots, Random telegraph signals Reduced responsivity
	Photodiodes	Reduced photocurrents and response Increased dark currents Shunt resistor, NEP, Linearity, ise/fall time [Gil08]
	Photo transistors	h_{FE} degradation Reduced responsivity Increased dark currents Spectral response, rise/fall time
Light-emitting diodes	LEDs (general)	Reduced light power output I(V) curves
	Laser diodes	Reduced light power output Increased threshold current
Opto-couplers		Reduced current transfer ratio Emitter-collector saturation voltage [Gil08]
Solar cells	SiliconGaAs, InP etc	Reduced short-circuit current Reduced open-circuit voltage Reduced maximum power
Optical materials	Alkali halidesSilica	Reduced transmission

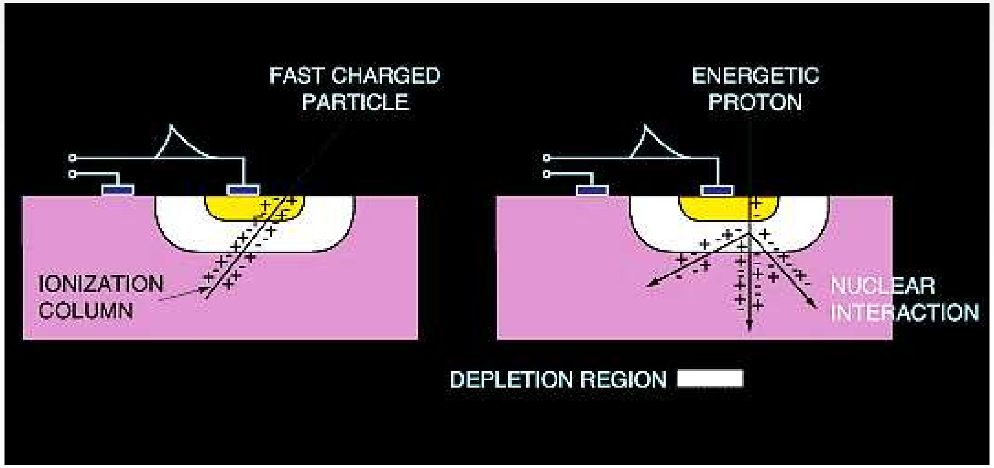
Displacement Damage Test Guidelines Development T. Nuns Onera (ESA / CNES Final Presentation Days 2017)

Single Event Effect (SEE).

When a high energy particle interacts with a semiconductor device, it leaves an ionized track behind, generating a perturbation area.

Depending on a set of circumstances, this perturbation can derive in many negative effects:

- a transient in the device output,
- a bit flip in a memory cell,
- a destructive latch-up,
- burn-out, especially in high-power transistors, etc.

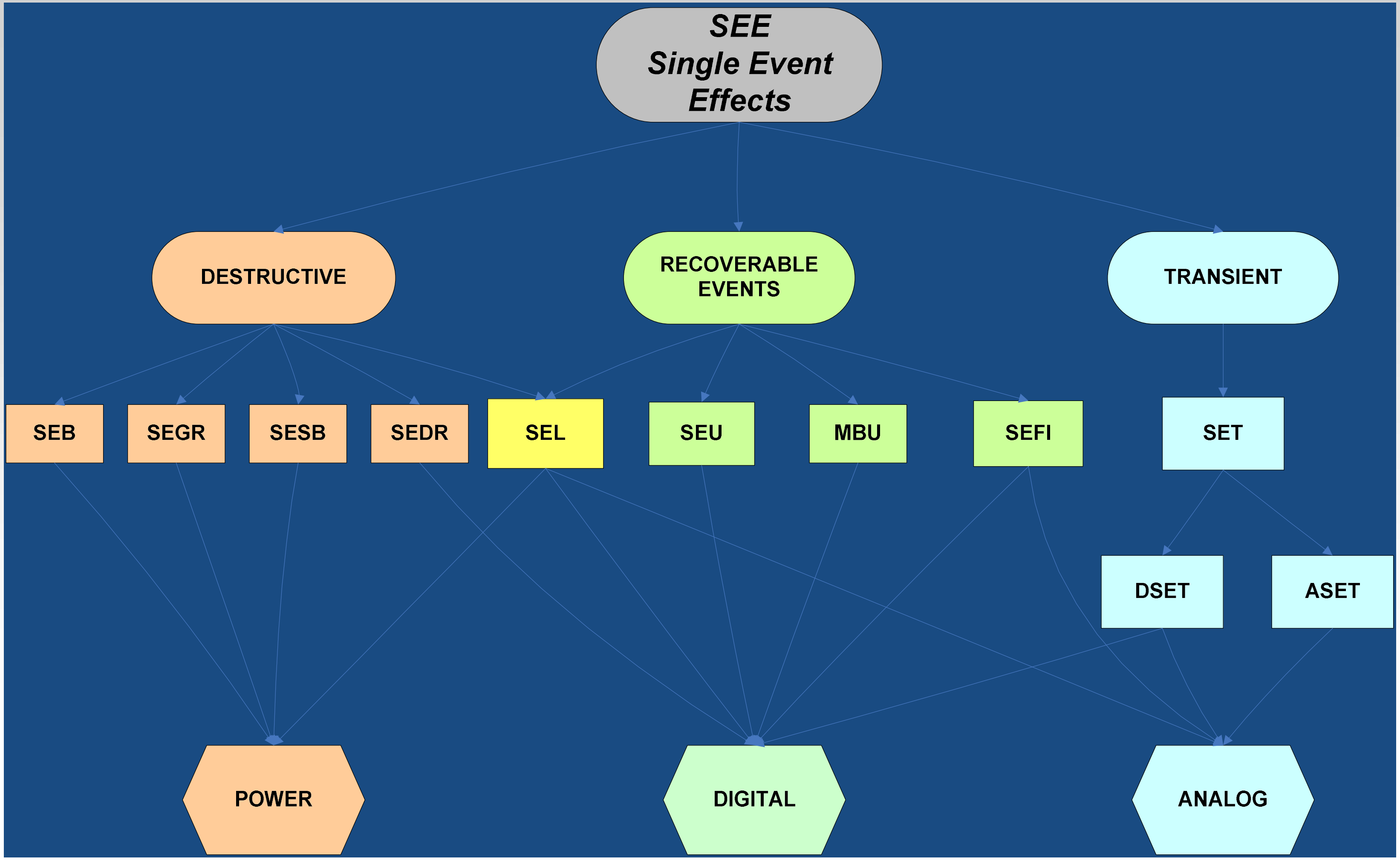


M. Lauriente, A. L. Vampola, "Spacecraft anomalies due to radiation environment in space," *NASDA/JAERI 2nd International Workshop on Radiation Effects of Semiconductor Devices for Space Applications*

Single Event Effect (SEE). Types.

		Dest.	Brief Description	Affected devices
SEU	Single Event Upset	N	Corruption of the information stored in a memory element.	Memories, latches in logic devices.
MBU	Multiple Bit Upset	N	Several memory elements corrupted by a single strike	Memories, latches in logic devices.
SEFI	Single Event Functional Interrupt	N	Loss of normal operation.	Complex devices with built-in state/control sections.
SET	Single Event Transient	N	Pulse response of certain amplitude and duration.	Analog, mixed signal devices
SED	Single Event Disturb	N	Momentary corruption of the information stored in a bit.	combinational logic, latches in logic devices
SHE	Hard Error Event	N	Unalterable change of state in a memory cell.	Memories, latches in logic devices.
SEL	Single Event Latch-up	Y	Unexpected high current generation.	CMOS, BiCMOS
SESB	Single Event Snapback	Y	Unexpected high current generation.	N-Channel Power MOSFET, SOI
SEB	Single Event Burnout	Y	Destructive burn-out.	BJT,
SEGR	Single Event Gate Rupture	Y	Rupture of the gate dielectric.	Power MOSFETs
SEDR	Single Event Dielectric Rupture	Y	Rupture of the dielectric layer.	Non-volatile NMOS, FPGA, linear devices, ..

Single Event Effect (SEE).



Single Event Effect (SEE).

Parameters affecting the SEE radiation behavior:

- Critical Charge (the amount of charge needed to be injected to change the cell’s logic state).
- Sensitive Geometry. The volume in which the deposited charge is effective to generate a device perturbation.
- Number of elements.

Technology Node (nm)	Sensitive Volume (Si) µ³	Critical Charge (Si) fC
250	0.245	8
130	0.025	2,5
90	0.02	1,2
65	0.0035	0,8

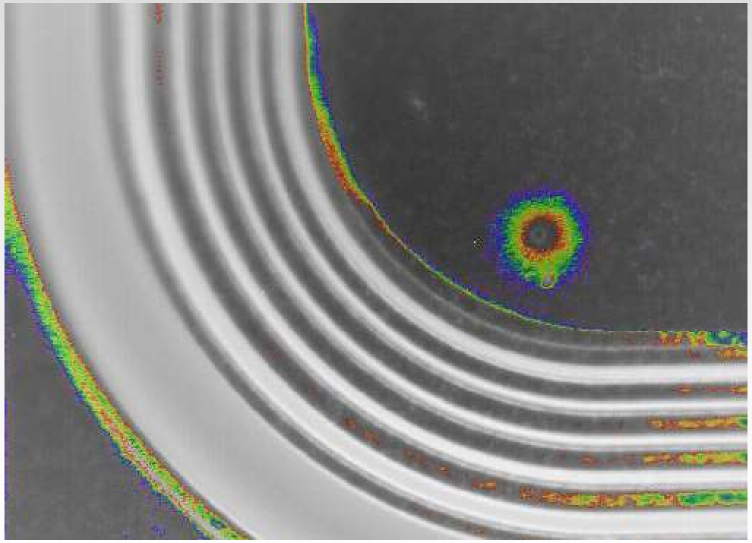
P. Roche, G. Gasiot, K. Forbes, V. O’Sullivan, V. Ferlet, “Comparisons of Soft Error Rate for SRAMs in Commercial SOI and Bulk Below the 130 nm Technology Node,” 2003 IEEE Nuclear and Space Radiation Effects Conference.

Radiation hardening assurance

SEE Test on SiC diodes show a severe weakness:

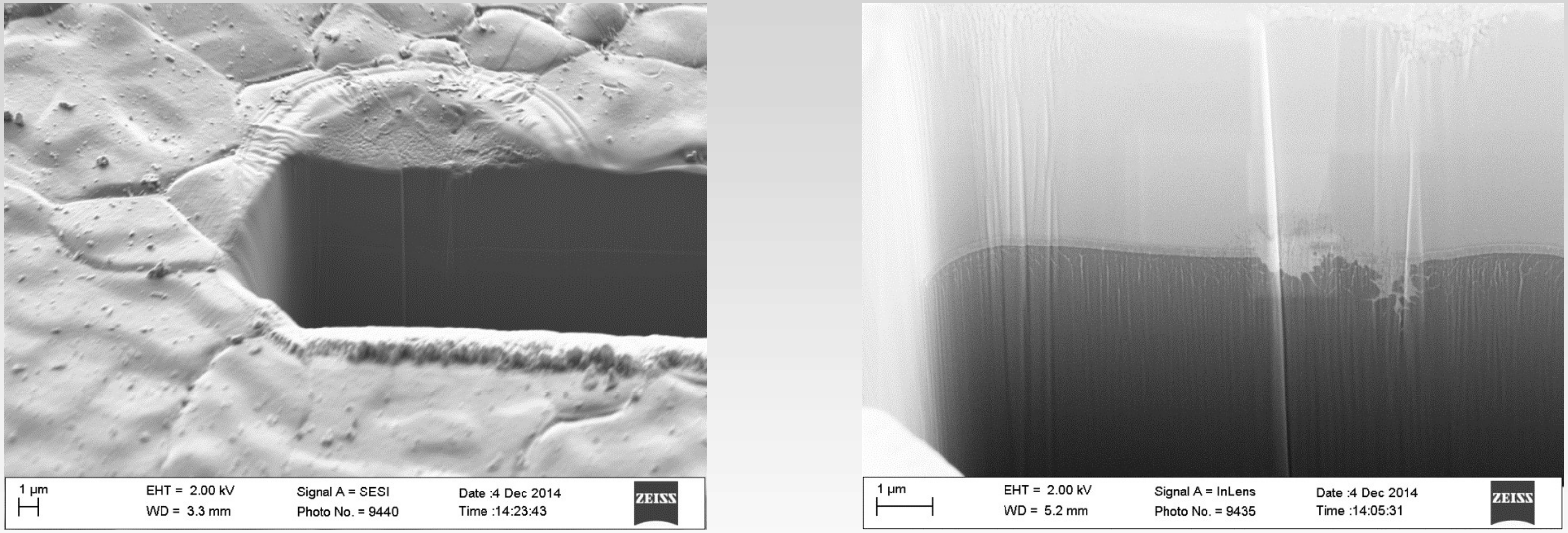
- Irreversible leakage current increase at 200V reverse bias.
- Silicon high voltage diodes show “Single Event Burnout” (SEB) at 800V...900V reverse bias.

The failure after SEE is observed in the active area of the diode.



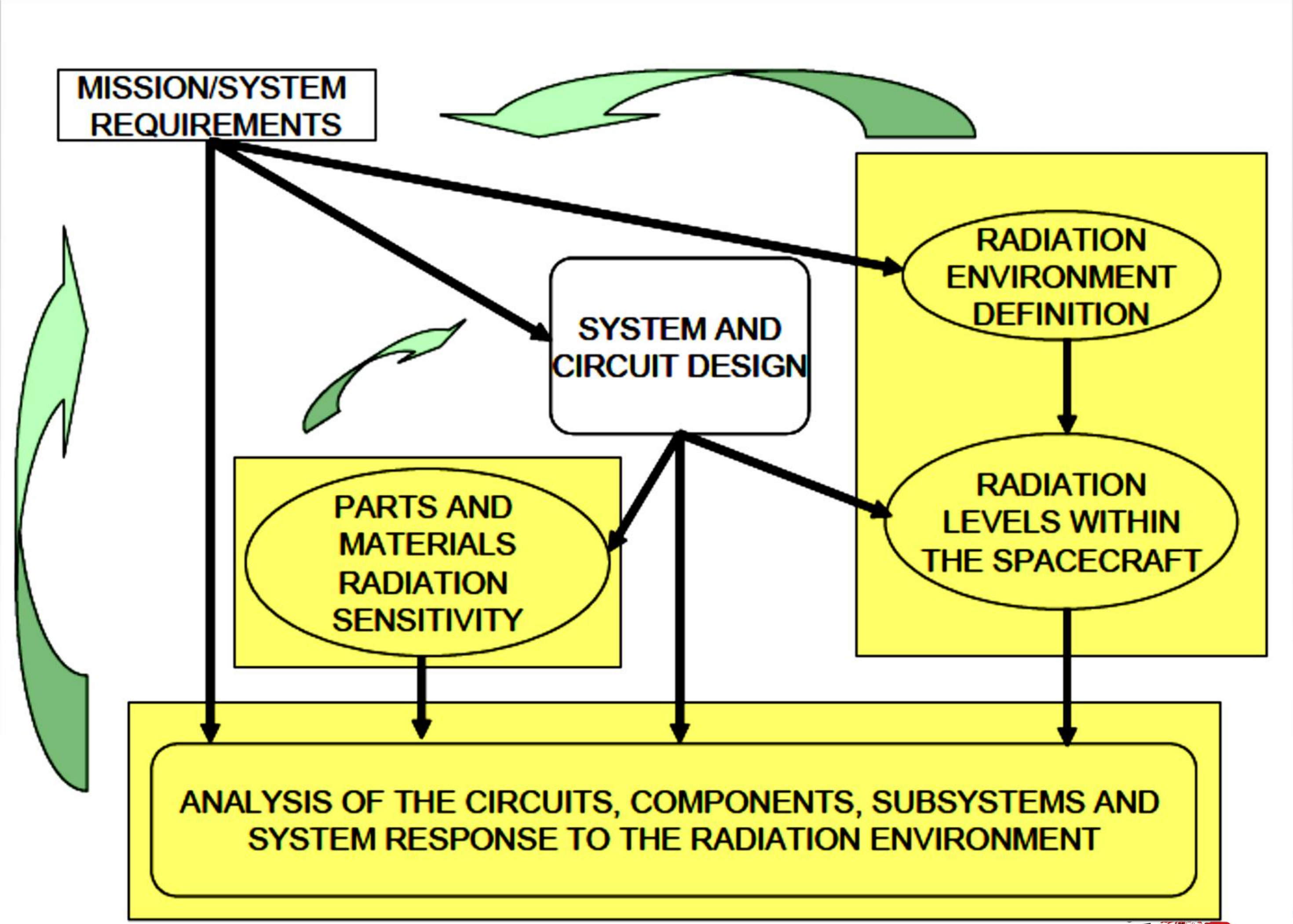
FIB and SEM show that the material is molten during SEB

Radiation hardening assurance

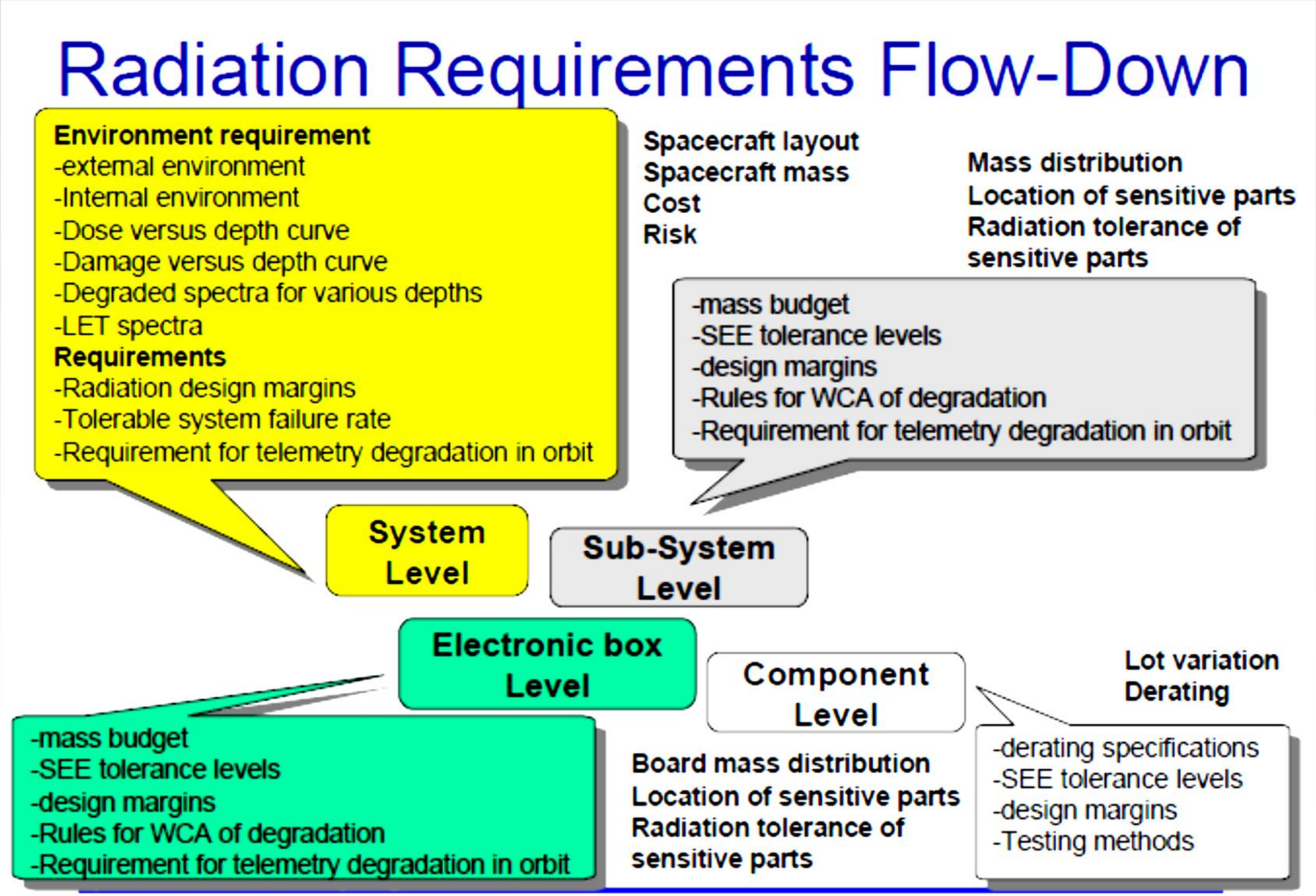


FIB and SEM show that the material is molten during SEB.

Radiation hardening assurance



Radiation hardening assurance



Radiation Requirements Flow-Down

Environment requirement
-external environment
-Internal environment
-Dose versus depth curve
-Damage versus depth curve
-Degraded spectra for various depths
-LET spectra
Requirements
-Radiation design margins
-Tolerable system failure rate
-Requirement for telemetry degradation in orbit

Spacecraft layout
Spacecraft mass
Cost
Risk

Mass distribution
Location of sensitive parts
Radiation tolerance of sensitive parts

-mass budget
-SEE tolerance levels
-design margins
-Rules for WCA of degradation
-Requirement for telemetry degradation in orbit

System Level

Sub-System Level

Electronic box Level

Component Level

Lot variation
Derating

-mass budget
-SEE tolerance levels
-design margins
-Rules for WCA of degradation
-Requirement for telemetry degradation in orbit

Board mass distribution
Location of sensitive parts
Radiation tolerance of sensitive parts

-derating specifications
-SEE tolerance levels
-design margins
-Testing methods

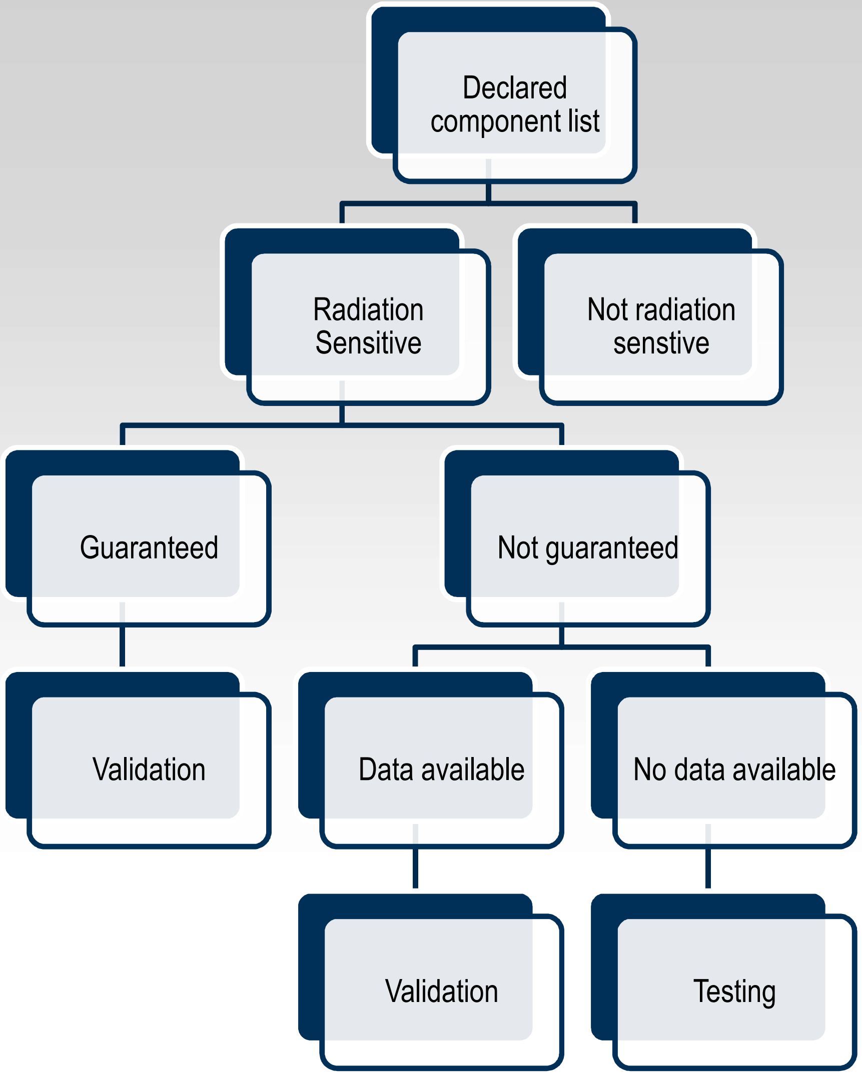
Radiation hardening assurance

- Programmatic aspects of RHA
- RHA components
  - ✓ requirements and specifications
  - ✓ mission radiation environment
  - ✓ equipment and component radiation requirement (sectorial analysis and Monte Carlo).
  - ✓ parts selection and radiation tolerance (as design DCL)
  - ✓ parts procurement and radiation testing (as built DCL)
- Analysis at the function/subsystem/system level
  - ✓ TID/DD
  - ✓ SEE

Radiation hardening assurance

	MAIN RADIATION SENSITIVITY EFFECTS		
TECHNOLOGY	**TID (Total Ionising Dose)**	**SEE (Single Event Effects)**	**NIEL (Non-ionising Energy Loss)**
CMOS	X	X	
BIPOLAR	X	X	X
GaAs		X	X
SiGe/InP			X
CCD, CID	X	X	X
Solar Cells			X
Power devices		X	
LEDs and Laser Diodes			X
Optocouplers	X	X	X
Fibre-optics	X		
MEMS	X		
Insulation materials	X		
Optical materials	X		
Cryogenics systems	X		

Radiation hardening assurance



Declared component list

Radiation Sensitive

Not radiation senstive

Guaranteed

Not guaranteed

Validation

Data available

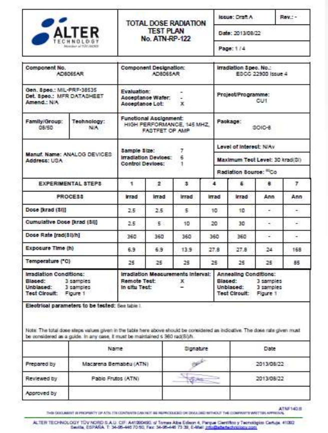
No data available

Validation

Testing

Radiation Test (TID).

- **Custom** radiation test plans generated reflecting your requirements, including, extensive data-sheet or procurement specification electrical parameter (DC, AC, functional test).



ALTER TECHNOLOGY	TOTAL DOSE RADIATION TEST PLAN No. ATN-RP-122	Issue: Draft A — Rev.: - Date: 2013/08/22 Page: 1 / 4
Component No. AD8065AR	Component Designation: AD8065AR	Irradiation Spec. No.: ESCC 22900 Issue 4
Gen. Spec.: MIL-PRF-38535 Det. Spec.: MFR DATASHEET Amend.: N/A	Evaluation: - Acceptance Wafer: - Acceptance Lot: X	Project/Programme: CU1
Family/Group: 08/50 Technology: N/A	Functional Assignment: HIGH PERFORMANCE, 145 MHZ, FASTFET OP AMP	Package: SOIC-8
Manuf. Name: ANALOG DEVICES Address: USA	Sample Size: 7 Irradiation Devices: 6 Control Devices: 1	Level of Interest: N/Av Maximum Test Level: 30 krad(Si) Radiation Source: ^{60}Co

EXPERIMENTAL STEPS	1	2	3	4	5	6	7
PROCESS	Irrad	Irrad	Irrad	Irrad	Irrad	Ann	Ann
Dose [krad (Si)]	2.5	2.5	5	10	10	-	-
Cumulative Dose [krad (Si)]	2.5	5	10	20	30	-	-
Dose Rate [rad(Si)/h]	360	360	360	360	360	-	-
Exposure Time (h)	6.9	6.9	13.9	27.8	27.8	24	168
Temperature (°C)	25	25	25	25	25	25	85

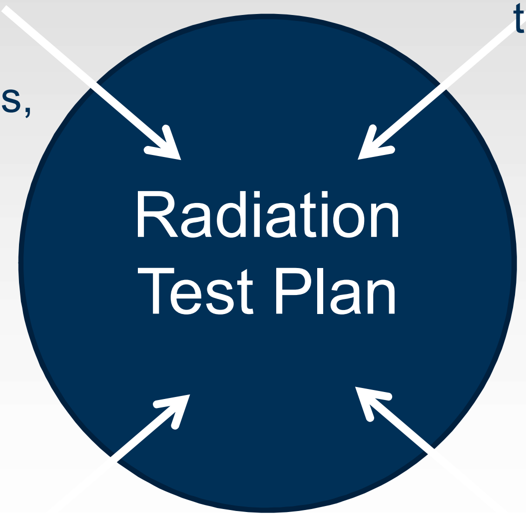
Irradiation Conditions: Biased: 3 samples Unbiased: 3 samples Test Circuit: Figure 1	Irradiation Measurements Interval: Remote Test: X In situ Test: –	Annealing Conditions: Biased: 3 samples Unbiased: 3 samples Test Circuit: Figure 1

Electrical parameters to be tested: See table I.

Note: The total dose steps values given in the table here above should be considered as indicative. The dose rate given must be considered as a guide. In any case, it must be maintained ≤ 360 rad(Si)/h.

	Name	Signature	Date
Prepared by	Macarena Bernabéu (ATN)		2013/08/22
Reviewed by	Pablo Frutos (ATN)		2013/08/22
Approved by			

Radiation Parameters (dose rate, steps, total dose, …)



Radiation Test Plan

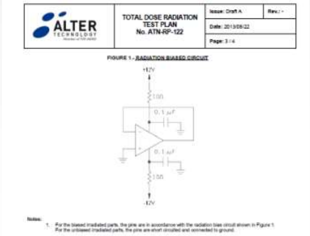
Electrical Parameters to be measured

ALTER TECHNOLOGY	TOTAL DOSE RADIATION TEST PLAN No. ATN-RP-122	Issue: Draft A — Rev.: - Date: 2013/08/22 Page: 4 / 4

TABLE I.- ELECTRICAL MEASUREMENTS AT ROOM TEMPERATURE

Nº	SYMBOL	TEST	CONDITIONS	LIMITS MIN.	LIMITS MAX.	UNIT
1	V_{IO}	Input Offset Voltage	VCM=0V	–	1.5	mV
2	I_B	Input Bias Current	–	–	[illegible]	pA
3	I_{IO}	Input Offset Current	–	–	10	pA
4	AVOL	Open-Loop Gain	VO=±3V, RL=1kΩ	100	–	dB
5	CMRR	Common-mode Rejection Ratio	VCM=-1V to +1V	[illegible]	–	dB
6	$\pm V_{OUT}$	Output Voltage Swing	RL=1 kΩ	-4.88	–	V
7				[illegible]	–	V
8	I_{CC}	Quiescent Current	–	–	7.2	mA
9	PSRR	Power Supply Rejection Ratio	–	[illegible]	–	dB

Notes:



ALTER TECHNOLOGY	TOTAL DOSE RADIATION TEST PLAN No. ATN-RP-122	Issue: Draft A — Rev.: - Date: 2013/08/22 Page: 3 / 4

FIGURE 1.- RADIATION BIASED CIRCUIT

Notes:

Annealing conditions

Biasing Conditions

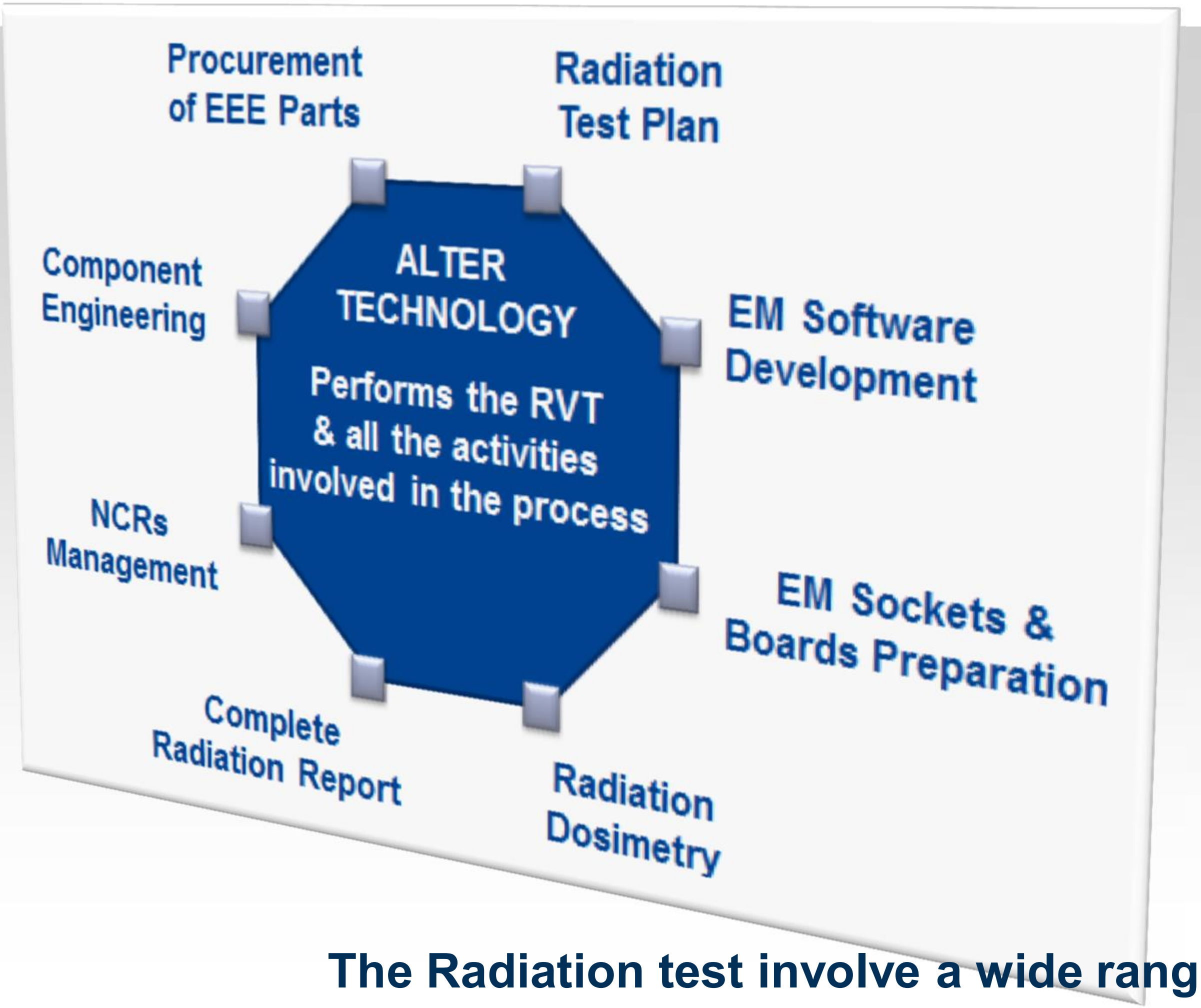
Radiation Test (TID).

Each RVT test requires a careful preparation and performance, covering a set of different activities:

- Device study and Radiation Test Design.
- Biasing boards. Design, manufacture and verify the circuits that will assure the powering and the signals reach the device in the wised conditions.
- Biasing system and radiation exposure control and monitoring.
- Electrical test performance. Test programme preparation and validation, etc.
- Annealing
- Test data processing and analysis. Final test report Issue

All activities are under an strict quality management environment to guarantee all key factors: safety procedures, inspectors certification, the use of calibrated equipment, environmental condition: temperature, humidity, right device handling, ESD protection,…., etc.

Radiation Test



Procurement of EEE Parts

Radiation Test Plan

Component Engineering

ALTER TECHNOLOGY

Performs the RVT & all the activities involved in the process

EM Software Development

NCRs Management

EM Sockets & Boards Preparation

Complete Radiation Report

Radiation Dosimetry

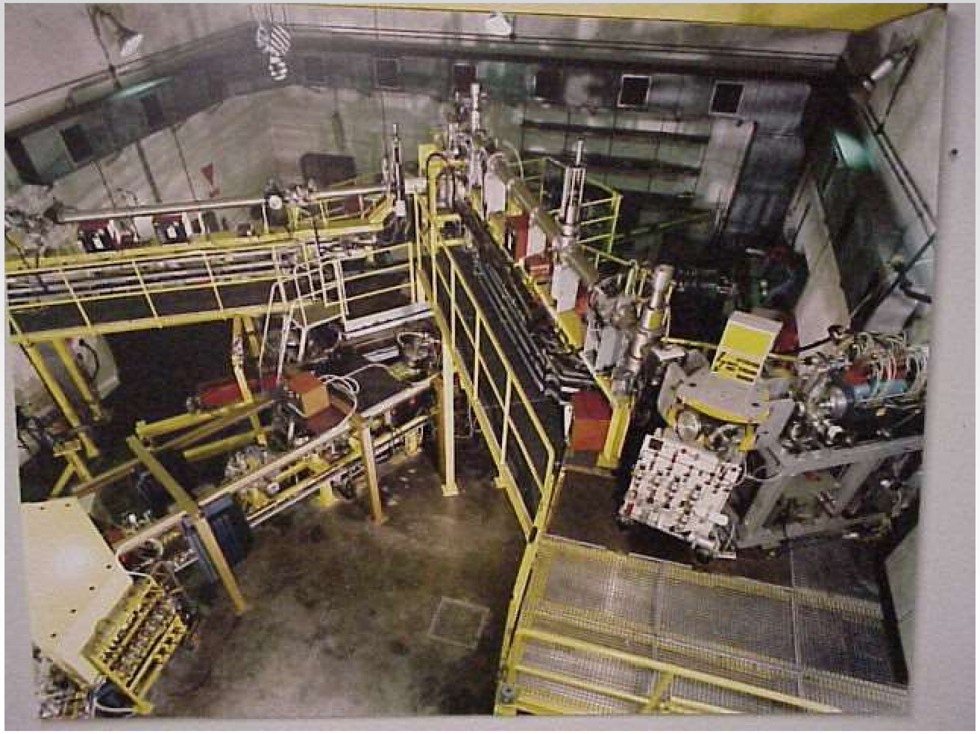
The Radiation test involve a wide range of elements.

Radiation Test (SEE).
SEE TEST PLAN AND PERFORMANCE

- Selection of ion source
- Ion cocktail selection and dosimetry
- Test sample preparation
- Biasing conditions and boards
- Test performance and monitoring
- Data processing

Radiation Test (SEE).

SEE Particle testing



ION COCKTAIL			
	energy [MeV]	LET [MeV/mg/cm²]	[µm Si]
41 Ar 12+	372	10.10	119
83 Kr 25+	756	32.40	92
132 Xe 26+	459	55.90	43

European Heavy Ion Irradiation Facility (HIF)
at Cyclone, Université Catholique de Louvain (Belgium)

Radiation Test (SEE).

Example SEE Heavy ion test on LTC1150

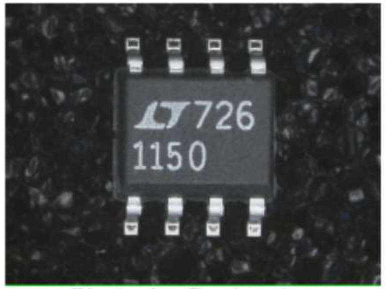


Photo 1 – Device, top

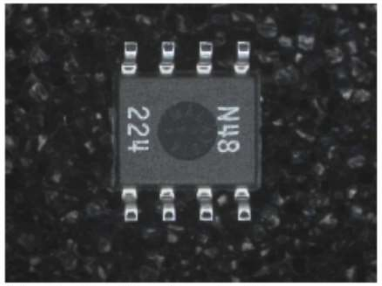


Photo 2 – Device, bottom

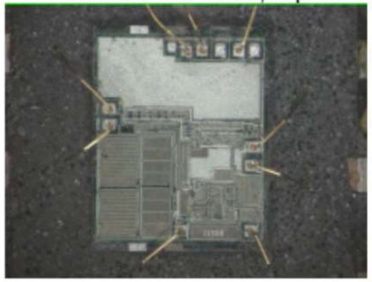


Photo 3 – Die full view

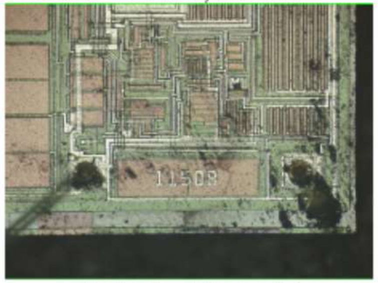
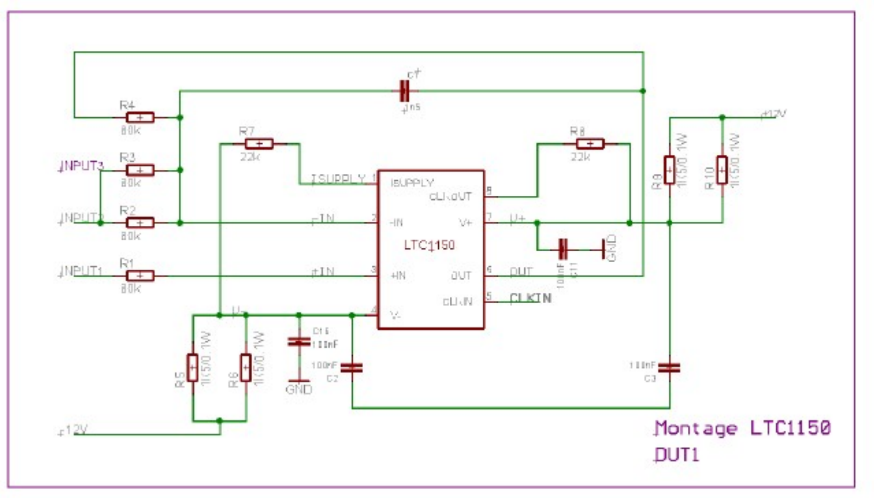


Photo 4 – Die marking

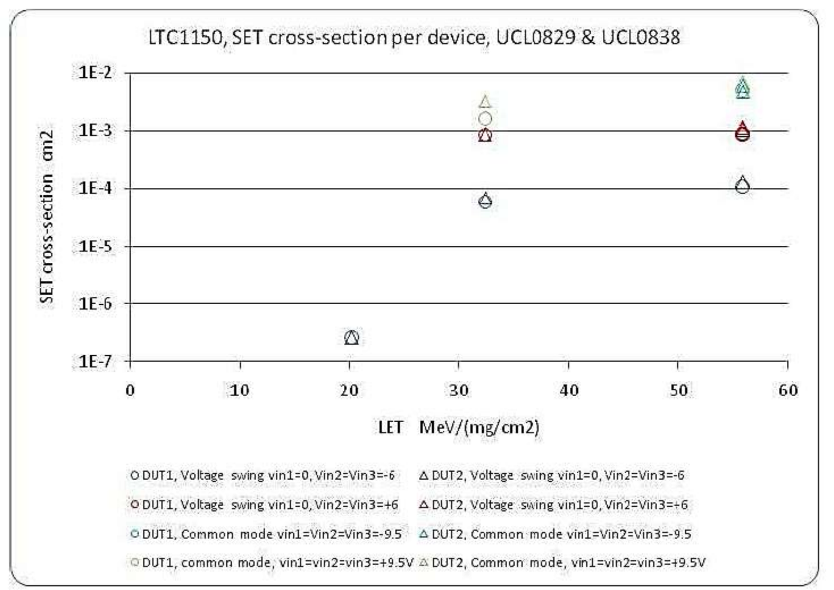


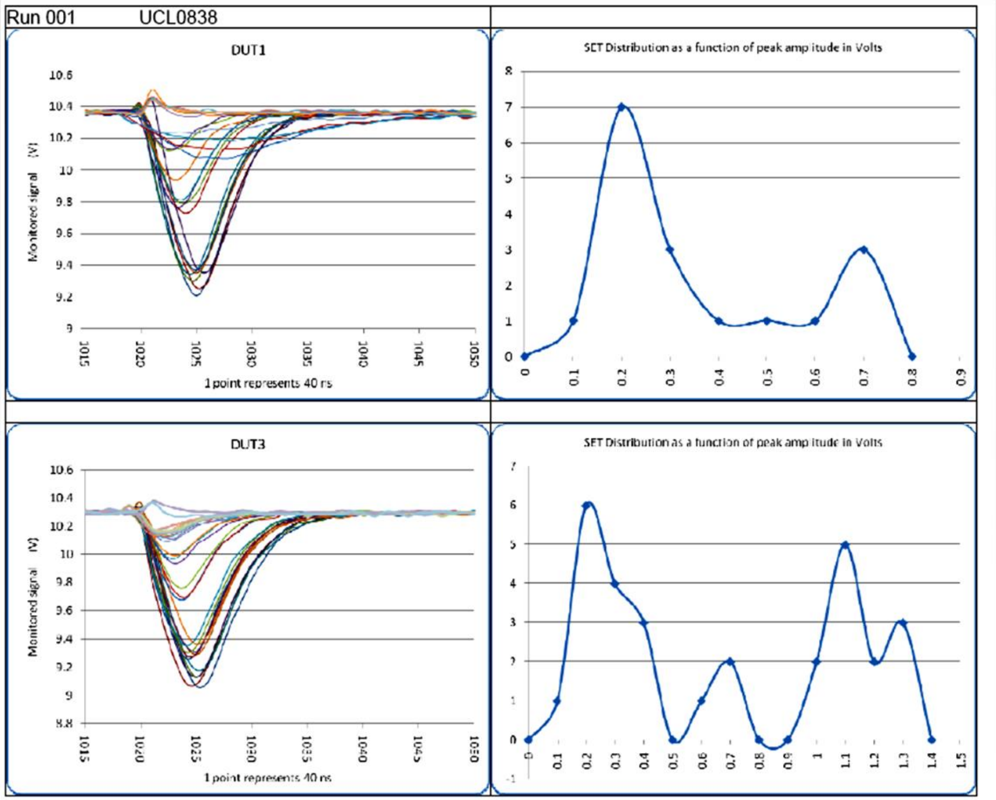
Setup	Vin1	Vin2	Vin3	Vout
Voltage Swing	0	-6V	-6V	11.5
Voltage Swing	0	+6V	+6V	-11.5
Common Mode	9.5V	9.5V	9.5V	9.5
Common Mode	-9.5V	-9.5V	-9.5V	-9.5

- **SET; record of each transient considered as a SET**
- **SEL: if device supply current exceeds given limit.**

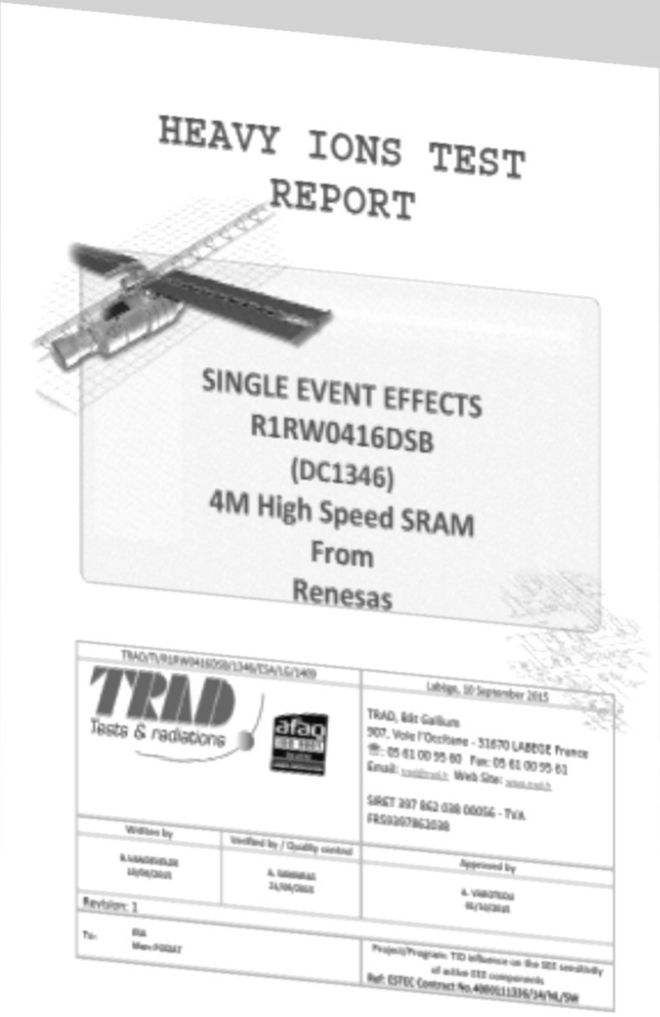
Radiation Test (SEE).

ALTER Technology Group SEE report Ref: HRX/SEE/0232 Iss1 Sep 30, 2008





Radiation Test (SEE).



HEAVY IONS TEST REPORT

SINGLE EVENT EFFECTS
R1RW0416DSB
(DC1346)
4M High Speed SRAM
From
Renesas

TRAD Tests & radiations

Labège, 10 September 2015

TRAD, Bât Gallium
907, Voie l'Occitane - 31670 LABEGE France
Tél.: 05 61 00 95 60 Fax: 05 61 00 95 61
Email: Web Site:

SIRET 397 862 038 00056 - TVA FR59397862038

Written by
Verified by / Quality control
Approved by

Revision: 1

To:

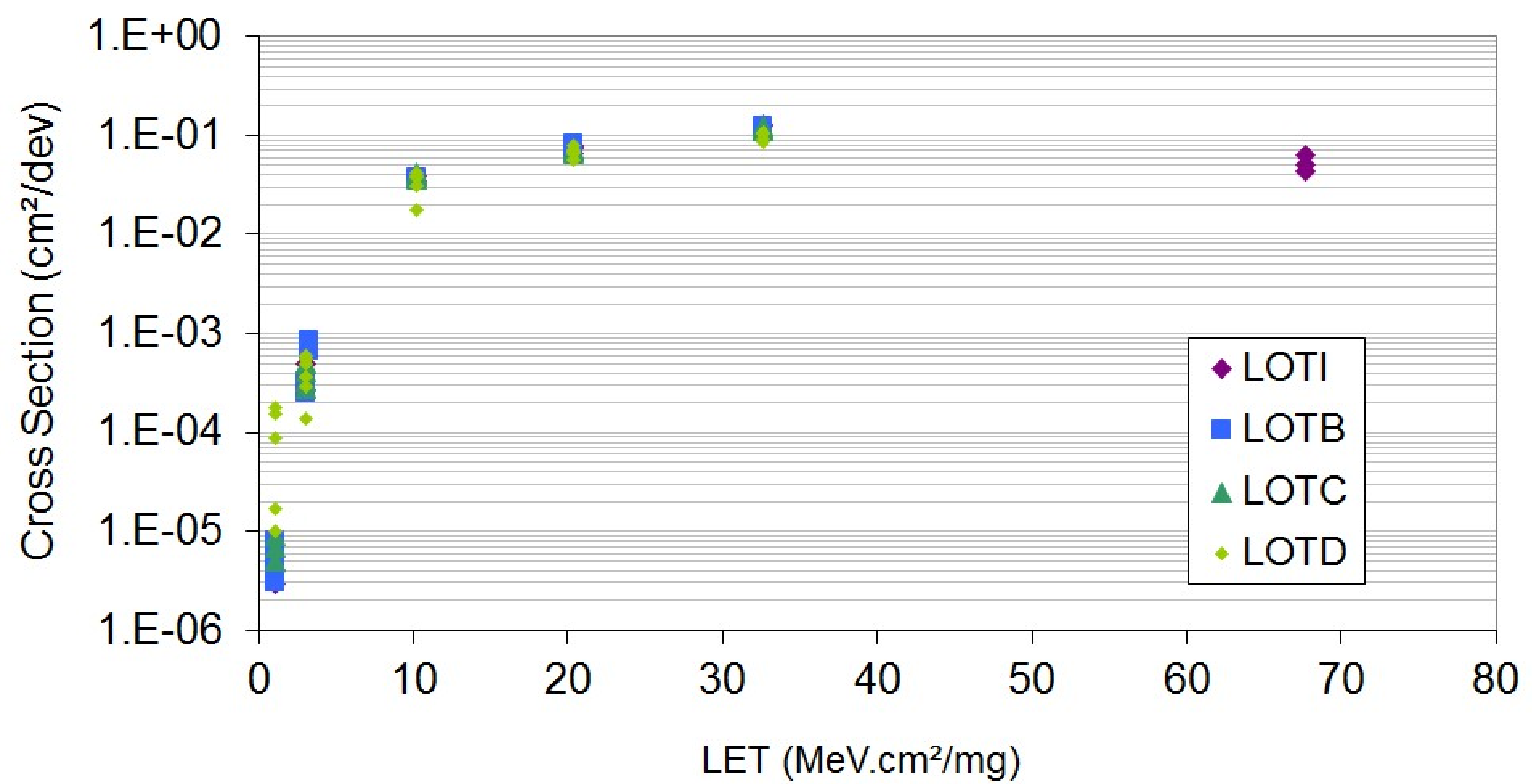
Project/Program: TID influence on the SEE sensitivity of active EEE components
Ref: ESTEC Contract No.4000111336/14/NL/SW

SEU Test Report Example

R1RW0416DSB
(DC1346)
[4M High Speed SRAM]

TID Influence on the SEE sensitivity of Active EEE

MT29F4G08AAC SEU cross section curve comparison
[LOTI (0 krad(Si)), LOTB (36 krad(Si)), LOTC(72 krad(Si)) and LOTD(100 krad(Si))]



TID Influence on the SEE sensitivity of Active EEE Final Report Ref: TRAD/ESA/IR/SYN/AS3/080615 (A. SAMARAS-TRAD).

Simulation and other radiation assessments

TCAD and SPICE simulation

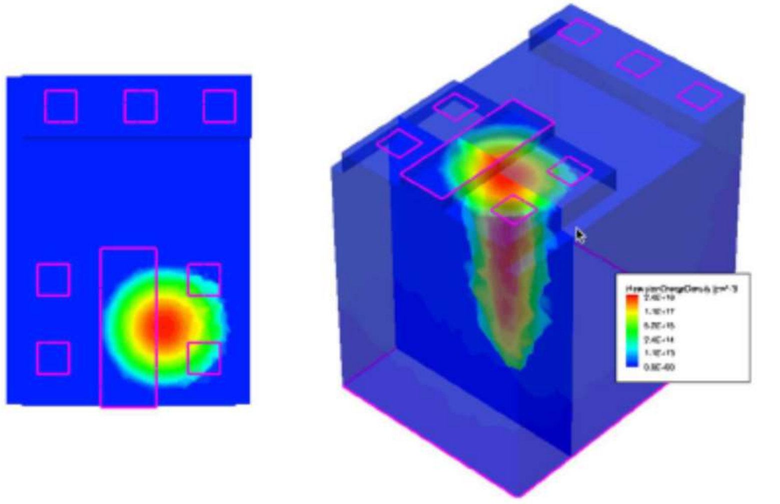


Fig. 3. Ion charge track in a 3D NMOS transistor model: LET profile has been previously estimated by SRIM.

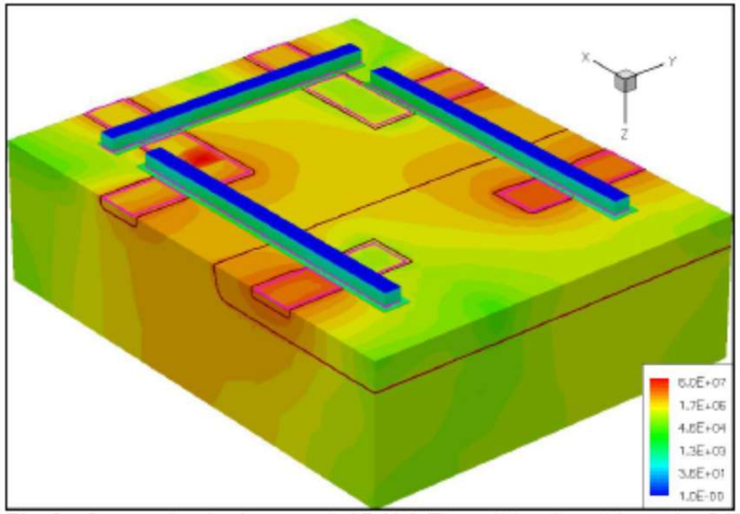
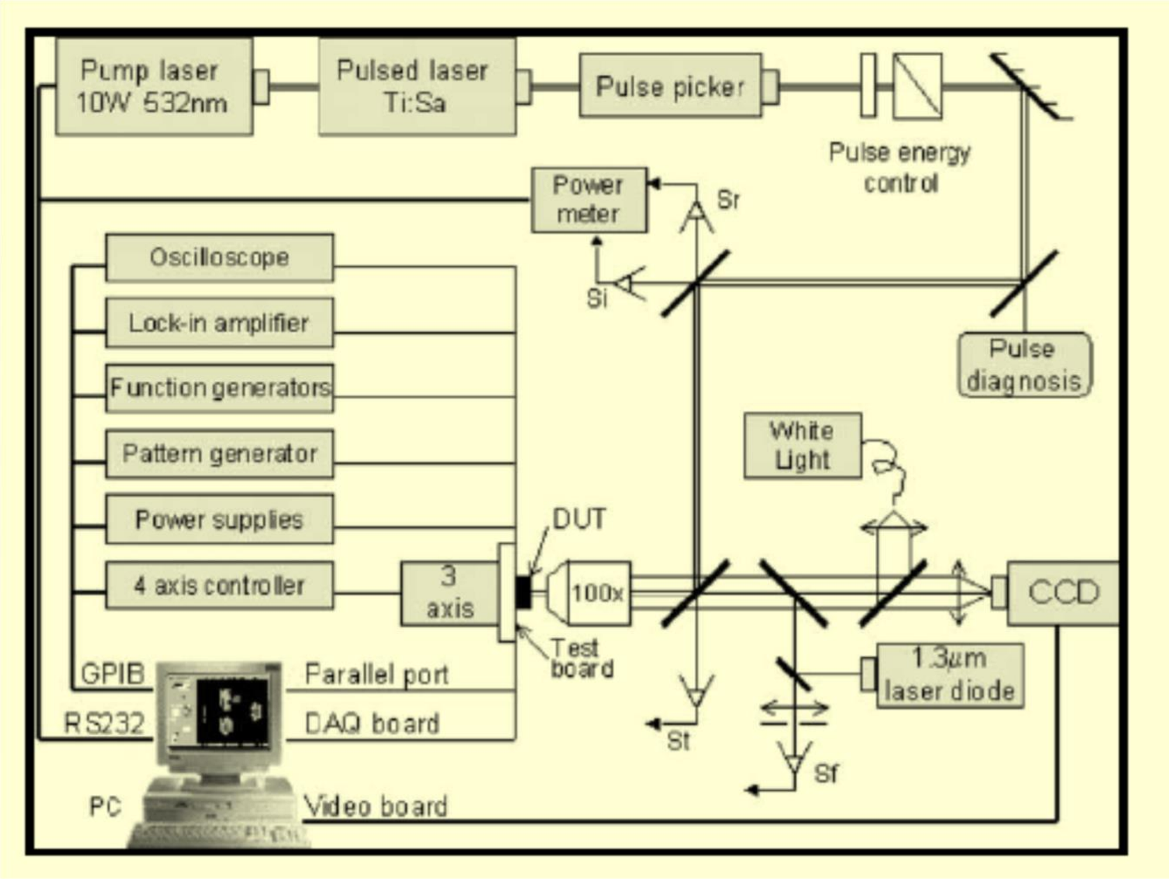


Fig. 9. Current density in a struck SRAM. The cell has been hit on the Off-NMOS; the current paths and coupling effects between adjacent devices can be observed

Simulation Methods for Ionizing Radiation Single Event Effects Evaluation
P. Fernández-Martínez1, J.M. Mogollón2, S. Hidalgo1, F.R. Palomo2, D. Flores1, and M.A. Aguirre2
1 Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Campus UAB, 08193 Bellaterra, Barcelona
Departamento de Ingeniería Electrónica, University of Sevilla, Camino de los Descubrimientos S/N, 41092, Sevilla, Spain

SEE Laser Testing



Generic Laser Test Set-up

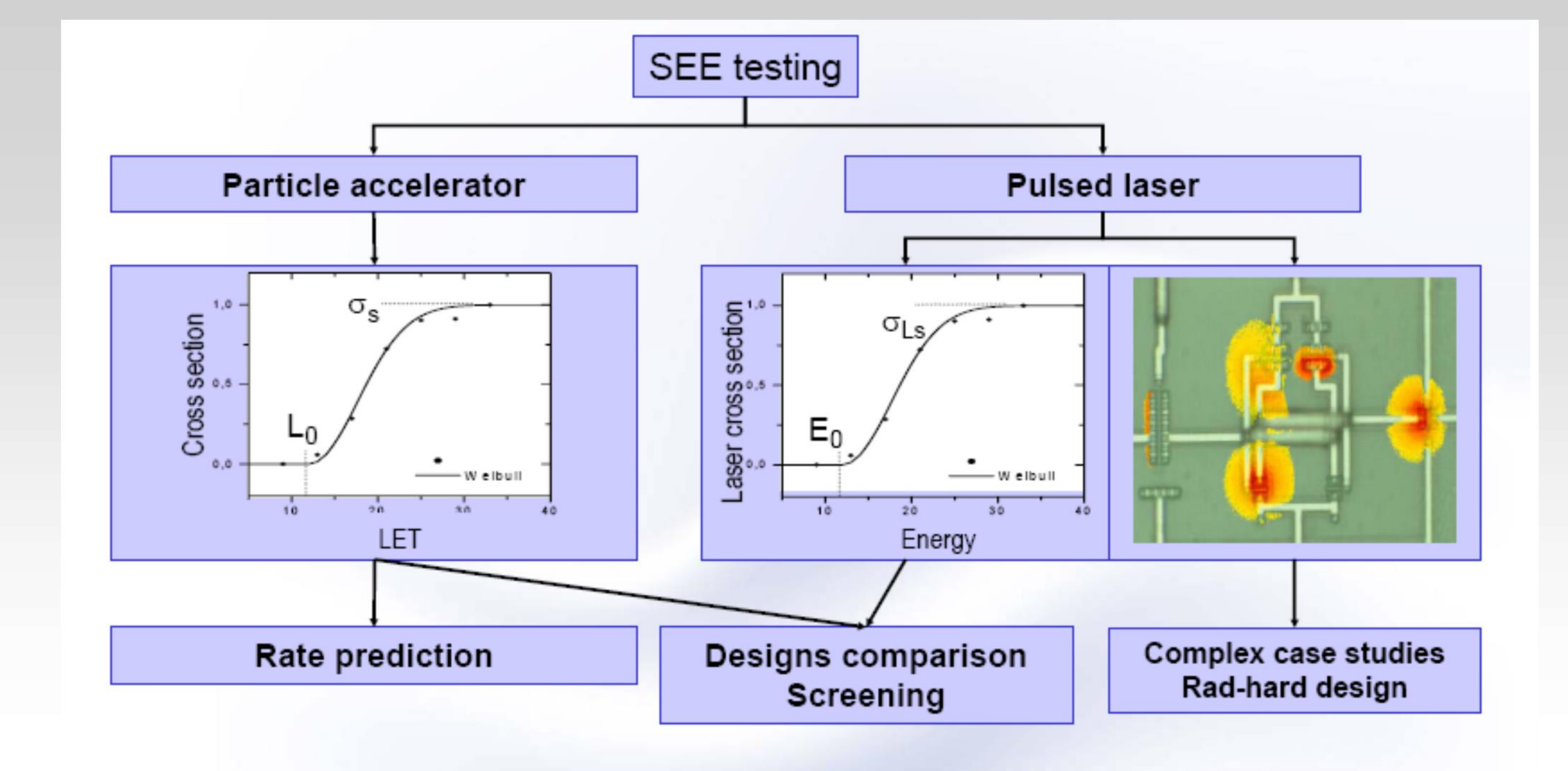
Advantage:

- Cheaper than accelerator
- Easy to handle
- Laser beam and trigger control

Disadvantage

- Special sample preparation required
- Lack of correlation with particle testing
- Low penetration

SEE Laser Testing



SEE testing

Particle accelerator

Pulsed laser

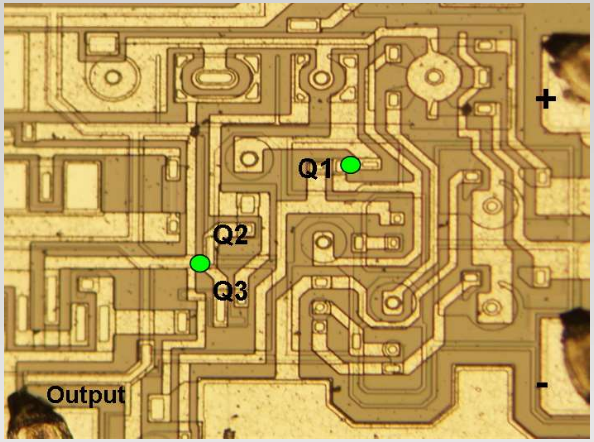
Rate prediction

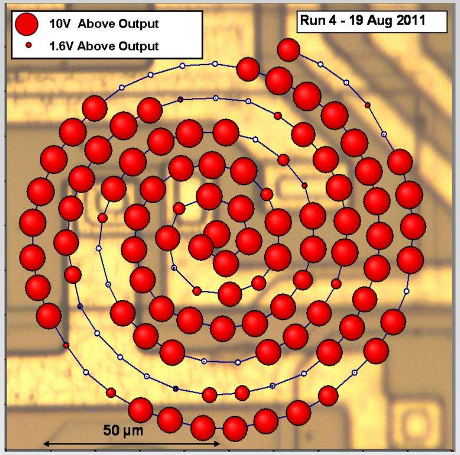
Designs comparison
Screening

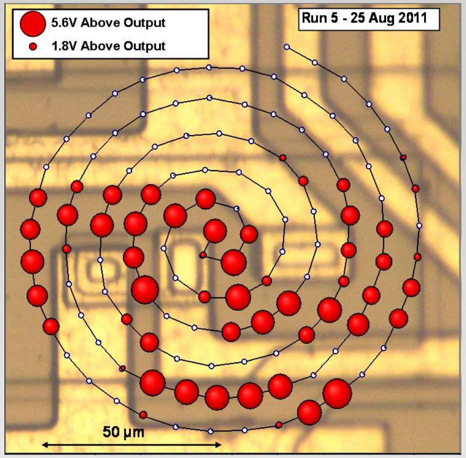
Complex case studies
Rad-hard design

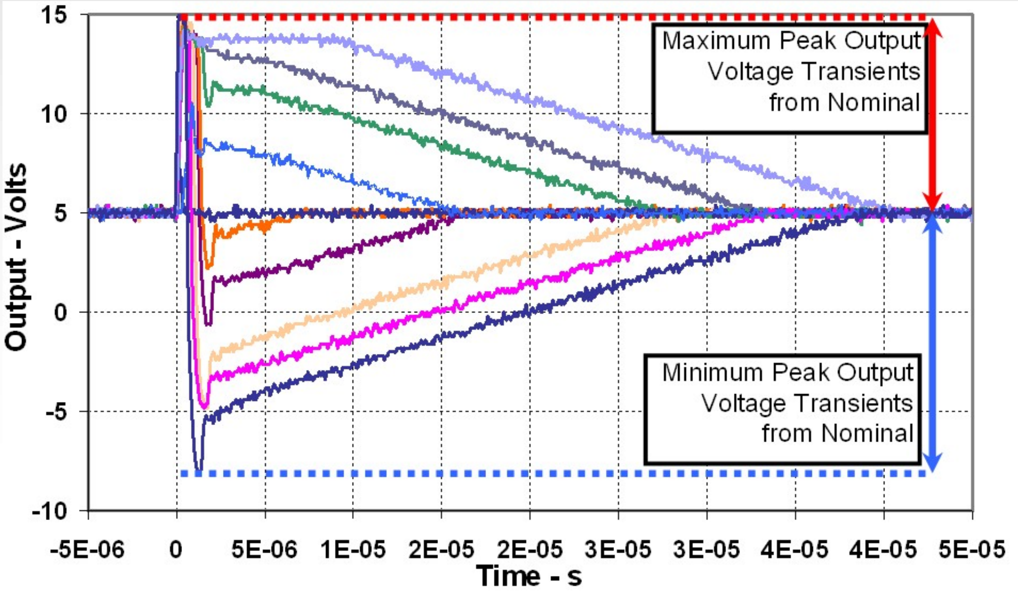
Laser Beam Testing and Analysis of Integrated Circuits
Vincent POUGET IMS Lab - University of Bordeaux, CNRS, ENSEIRB, France
vincent.pouget@ims-bordeaux.fr

SET Laser Testing Example - LM124









Final Report on Laser SET Testing of Analog Integrated Circuits. Ref: DR 39811
MBDA - Andrew Chugg Head of Radiation Effects & EMC

Simulation and other radiation assessments Emulation Hardware / Software

Fault injection (FI) tools try to emulate the device response to a perturbation, producing a change in one or several logical states, and assessing the impact in the device functioning. Several effects can be studied: SEU, MBU and also SET in digital devices.

These tools are normally used to debug device design errors and hardening the design to certain situations.

The FI tools look for: controllability, observability, low intrusiveness, speed and cost.

Síntesis del Estado del arte: Emulación Hardware de SEU y Transitorios Mediante Inyección de Fallos. Proyecto EMULASER Universidad de Sevilla M.A. Aguirre, J.M. Mogollón

Simulation and other radiation assessments
Emulation Hardware / Software

There are two main FI simulation techniques:

Simulation base on software Fault injection (SBFI):

The simulation is made with a computer using the DUT description in VHDL. It has the following advantages of:

- high observability
- high controllability
- flexibility
- no prototype needed

In general is a slow process.

Hardware Fault injection (HWFI):

The simulation is made using a hardware platform, in which the perturbed device functioning is simulated and compared with a gold device. It has de advantage of:

- high speed

But you need to have at least a prototype, and its structure is more rigid.

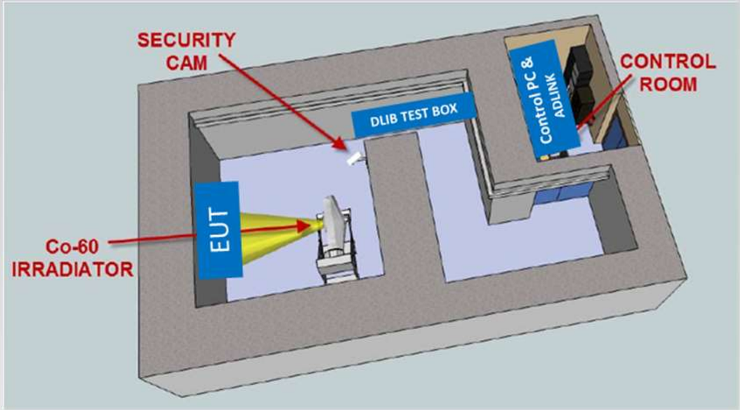
Síntesis del Estado del arte: Emulación Hardware de SEU y Transitorios Mediante Inyección de Fallos. Proyecto EMULASER Universidad de Sevilla M.A. Aguirre, J.M. Mogollón

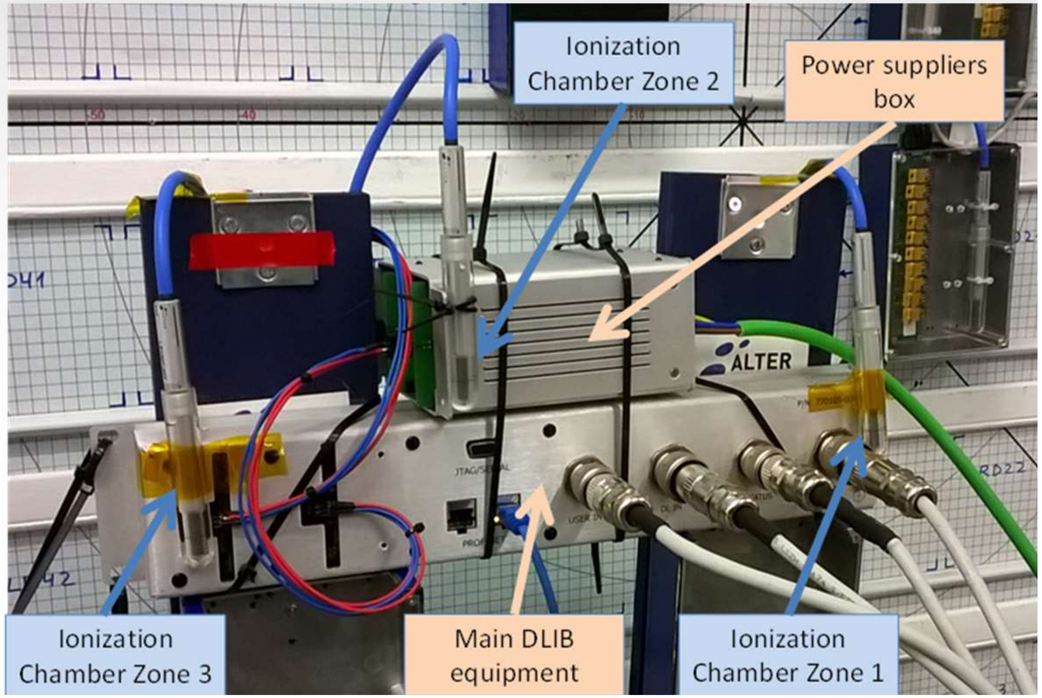
Radiation Test at Equipment Level.

ITER DLIB EXAMPLE

Followed process:

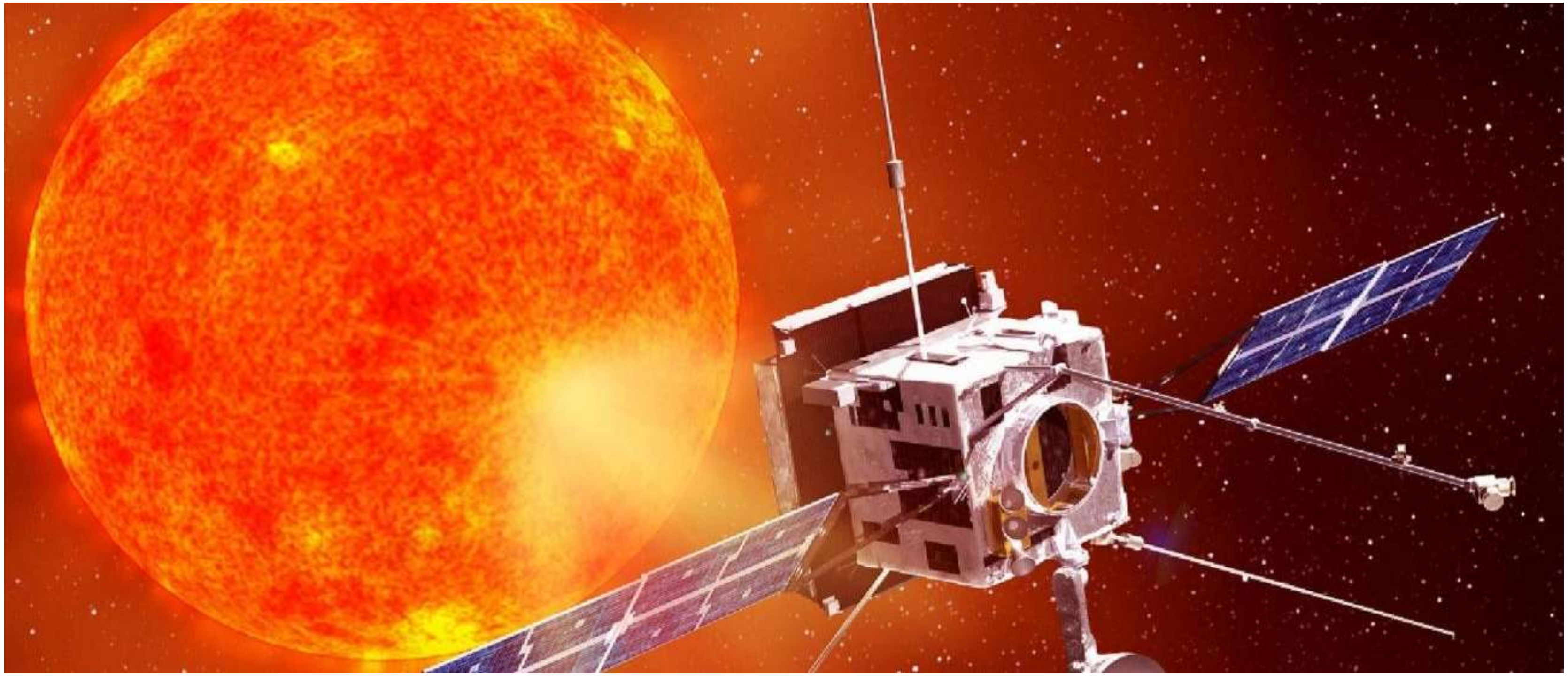
- Initial review od BOM list regarding radiatin.
- Some test at component level
- Radiation test plan after assessment of DLIB structure and project requirements.
- Electrical test set-up
- Irradiation test and annealing.
- Data collection and analysis





Some Conclusions.

1. The Radiation Effects are a set of phenomena of increase importance.
2. The TID, DD and SEE are key factors to determine the electronic system reliability in certain applications / environments, especially for Space.
3. To improve the radiation hardness at component level, we should use all the available techniques: part selection, TCAD, emulation, radiation testing,….
4. The easier and faster way to gather the desired device radiation information, when design / technology information is not available, is to perform radiation testing with the specific application conditions (test it as you flight it).



THANK YOU FOR YOUR ATTENTION

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¿Any question?