Irradiation test facilities for COTS EEE components

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7 November 2019

Outline

A _Introduction

1. Radiation space environment
2. Radiation effects

B_Radiation Testing

1. TID testing with Co60 gamma rays
2. DD testing with protons
3. SEE with heavy ions
    a) Heavy ions facilities overview
4. Board level test with protons

Part A

INTRODUCTION

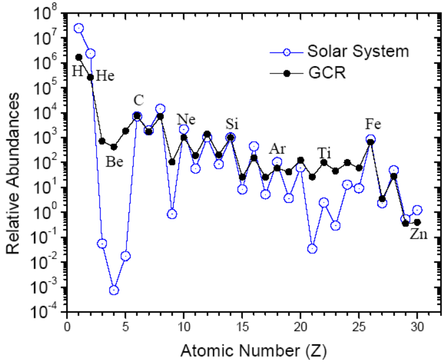
Ionising radiation in the space environment

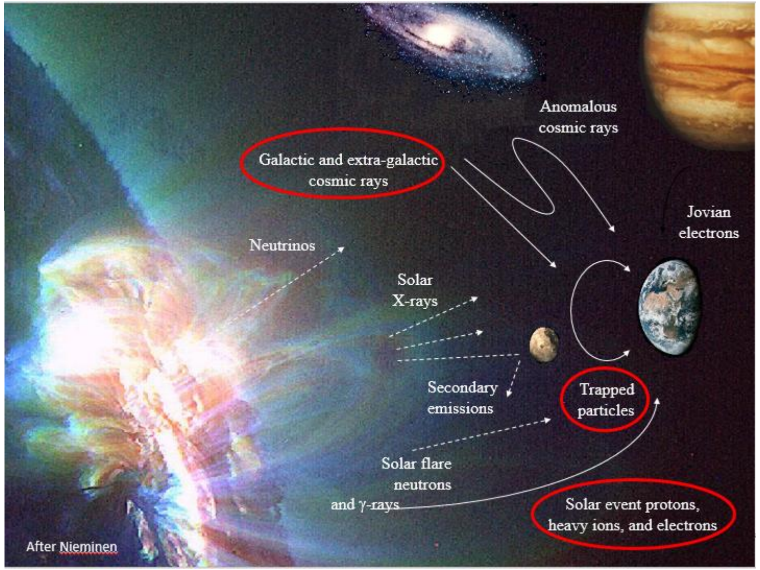
- **Protons and electrons** trapped by planets' magnetospheres in radiation belts

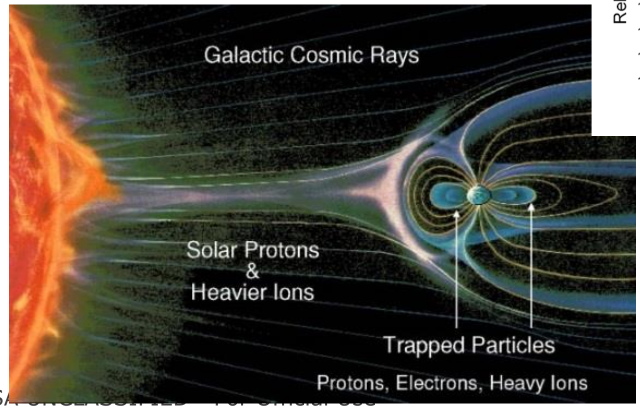
- Particles originating from the activity of the Sun, which include also **heavy ions**

- And **cosmic rays** with very high energy

http://www.srl.caltech.edu/ACE/ACENews/ACENews83.html







Solar system : space and time variability of the environment

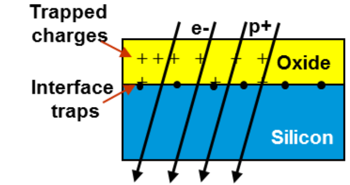
- Magnetosphere
- Solar cycle
- Coronal mass ejections and solar flares

Ionising radiation effects on EEE components

Ionising radiation in space

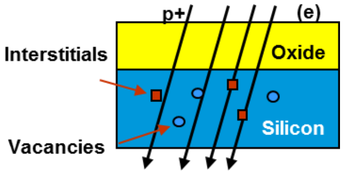
		Energy range					
		ev	kev	10Mev	100MeV	500MeV	GeV
Particle	Electrons		<-------TID-------->				
				<--DD-->			
				<-SEE->			
	Protons		<-----------------------TID----------------->				
				<---------DD------->			
					<--SEE-->		
	Heavy ions			<-------------------------TID------------------------->			
				<-------------------------DD------------------------->			
				<----------------------SEE------------------>			

Effect on the component



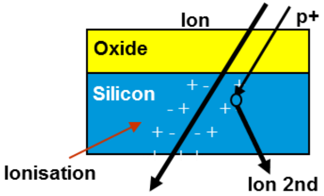
Total Ionising Dose

Electron-hole pairs generation in semiconductor oxides



Displacement Damage

Lattice Displacement Damage caused by energetic particles



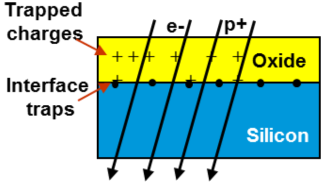
Single event effects

Ion deposits significant charge within device that directly affects its operation

Ionising radiation effects on EEE components

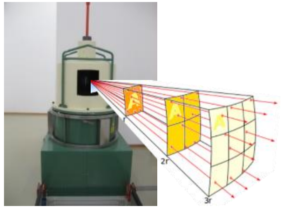
Effect on the component

Source used



Total Ionising Dose

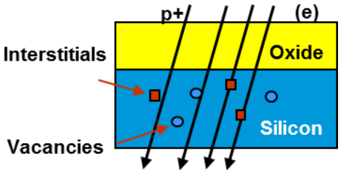
Electron-hole pairs generation in semiconductor oxides



Total Ionising Dose

Co-60 gamma ray irradiation

or X-rays, Electrons, Protons



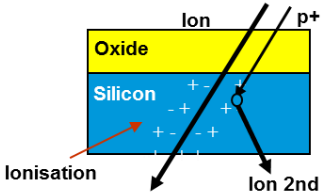
Displacement Damage

Lattice Displacement Damage caused by energetic particles

Displacement Damage

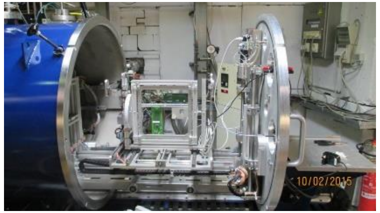
High energy protons (10-200MeV)

or Neutrons



Single event effects

Ion deposits significant charge within device that directly affects its operation



Single event effects

High energy ions

or Laser, Cf252, electrons

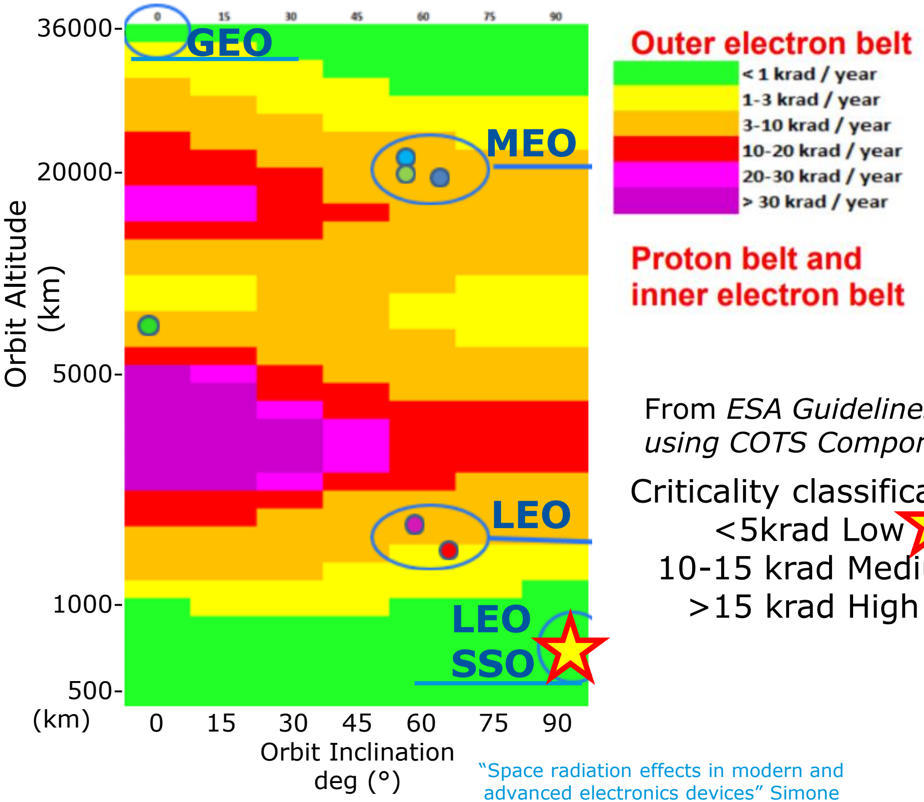
Part B

TESTING

Part 1

TID TESTING

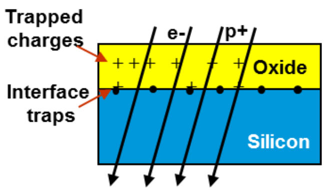
Total ionising dose



From *ESA Guidelines for using COTS Components*

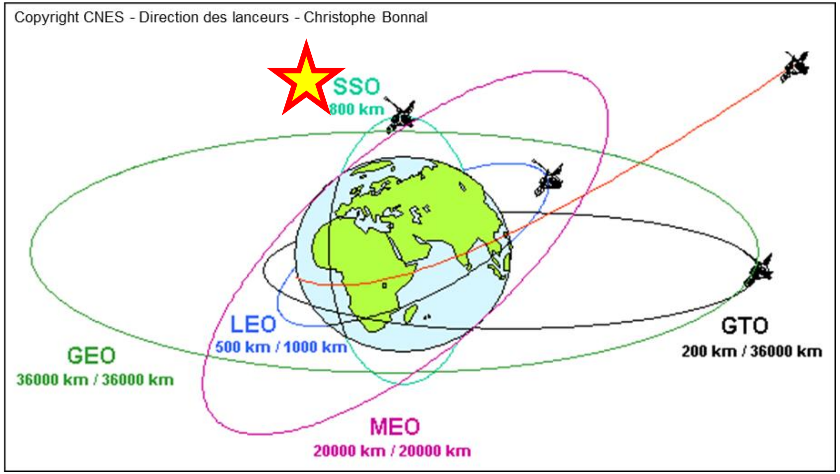
Criticality classification
<5krad Low
10-15 krad Medium
>15 krad High

"Space radiation effects in modern and advanced electronics devices" Simone Gerardin, RADECS 2015 Short course



Total Ionising Dose

Electron-hole pairs generation in semiconductor oxides



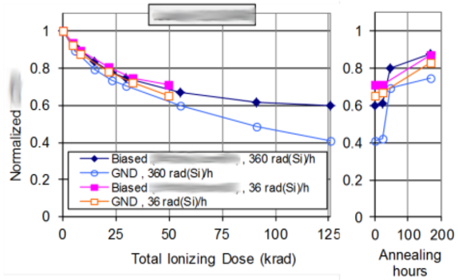
TID - Co60 gamma ray irradiation

TID Test strategy:

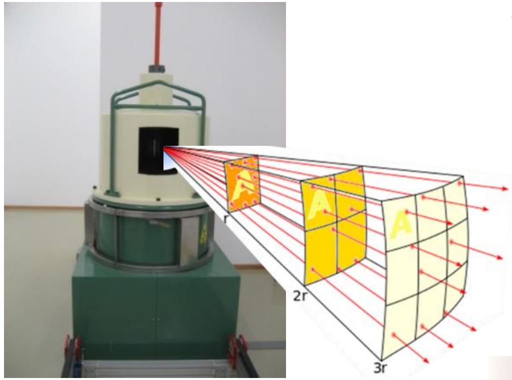
Cumulative effect:
Gradual global degradation of device parameter

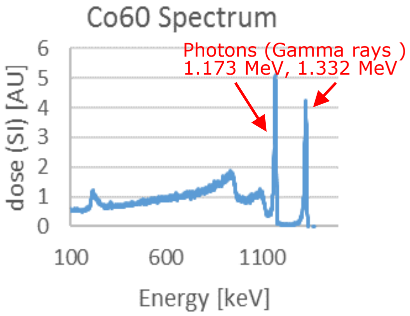
The PERFORMANCE DEGRADATION is estimated as function of :

Total dose [rad(Si)] [Gy(Si)]



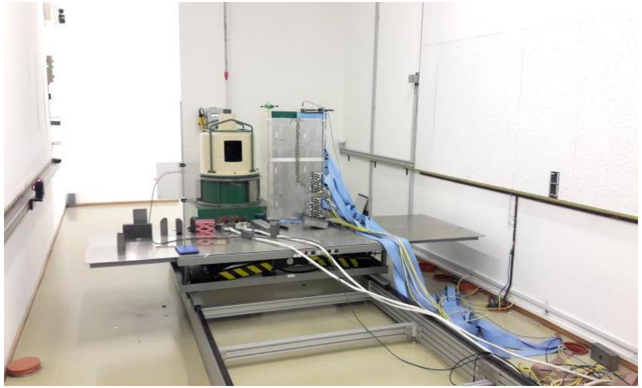
Test methods:
ESCC 22900
MIL-STD 883 TM1019





Irradiations are executed exposing the DUT to the photons emitted by the decay of Cobalt 60 isotope

- the irradiated parts do not become radioactive,
- to produce the beam we do not need an accelerator,
- we can have wide irradiation area,
- different dose rate are available simultaneusly,
- ….etc



Part 2

DD TESTING

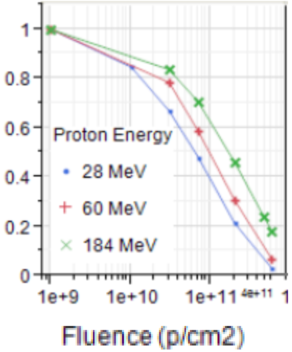
Displacement Damage – proton irradiation

Test strategy:

Cumulative effect:
Gradual global degradation of device parameter

The PERFORMANCE DEGRADATION is estimated
as function of :

Fluence [p/cm^2] (@Energy [MeV])



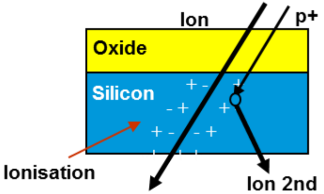
	PSI (Switzerland)	RADEF (Finland)	UCL (Belgium)
Proton Beam	74 - 230 MeV	0.5 - 52 MeV	14 - 62 MeV

For a list of facilities available worldwide:
https://irradiation-facilities.web.cern.ch/

Part 3

SEE TESTING

Single Event Effects



Single event effects

Ion deposits significant charge within device that directly affects its operation

Examples of SEE type

SEFI: functional interruption

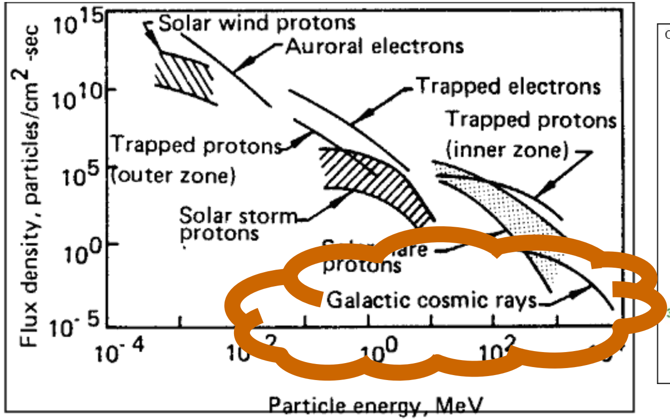
SET: transient

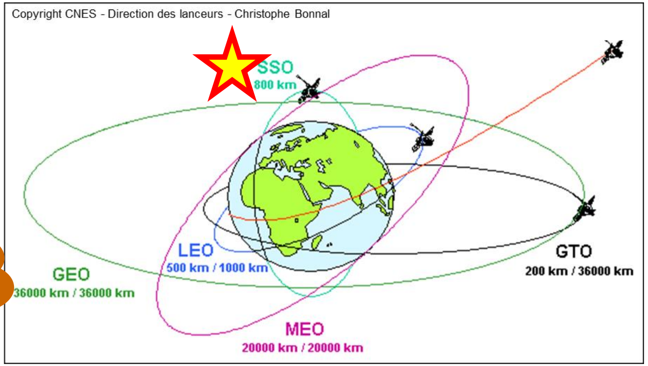
SEU: upset

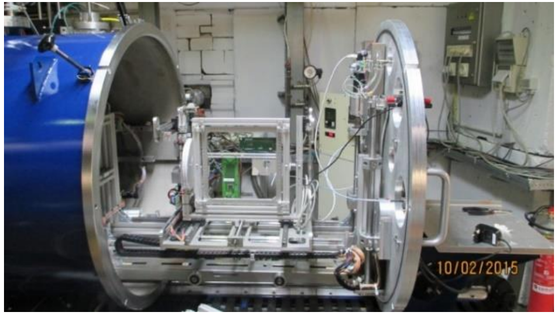
SEL: latch-up

SEB: burn-out

SEGR: gate rupture





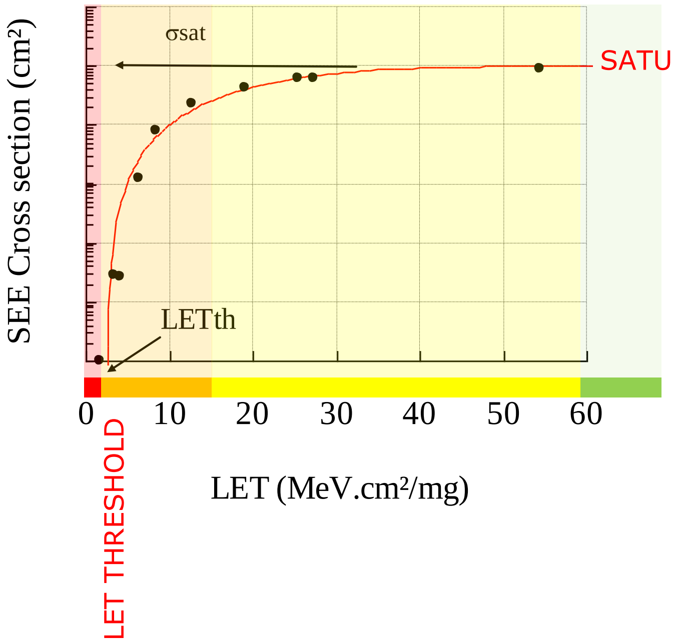


SEE probability

EEE part test:

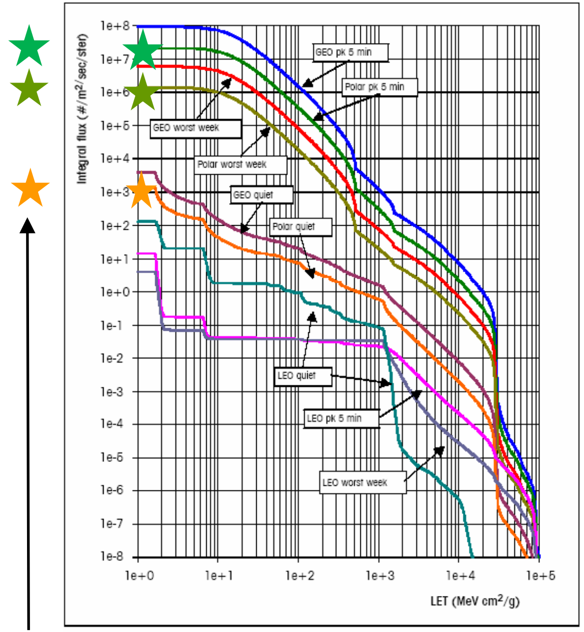
Characterisation of the cross section

(probability of event as function of LET on the die)



SEE LET Threshold MeVcm²/mg	SEE severity risk
> 60	negligible
15-60	to be analyzed
<15	high
<1	Very high

Mission integral flux vs LET



Polar SSO (quiet, worst week, pk5min)

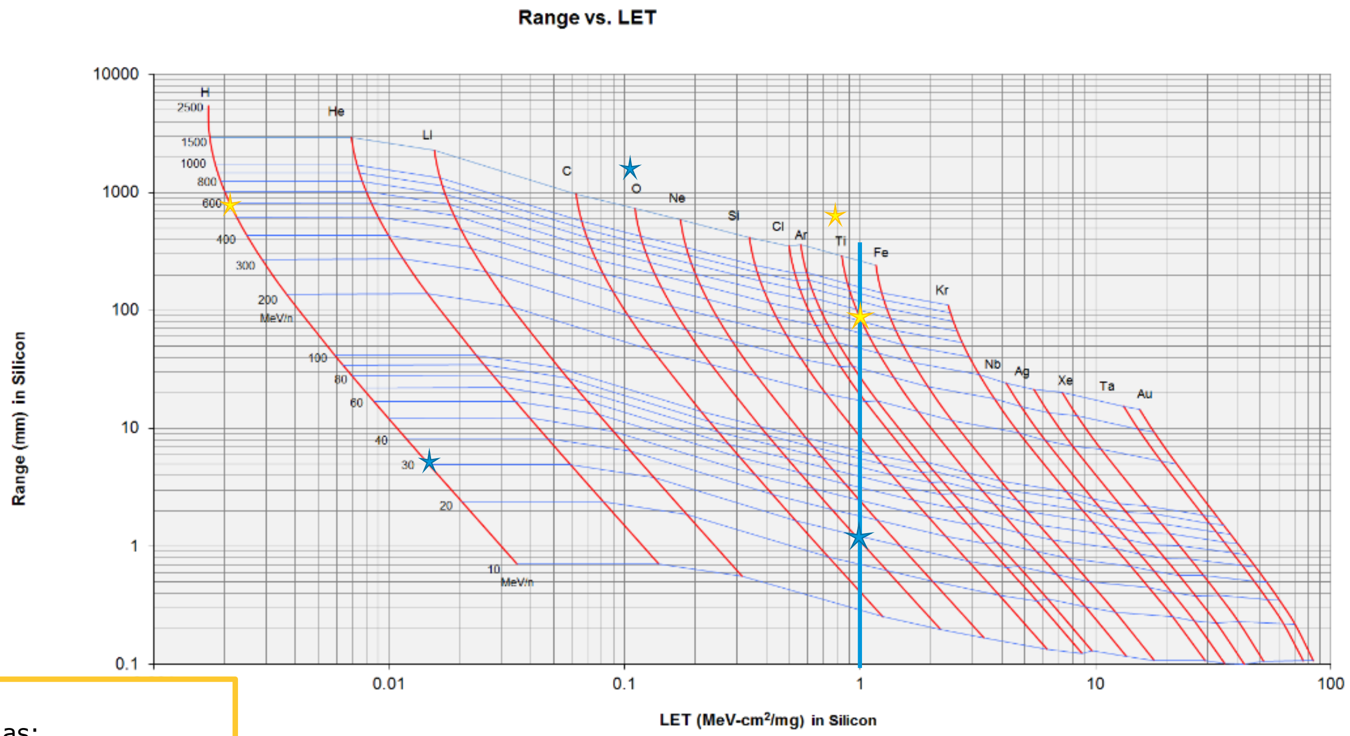
Beam energy and Linear energy transfer

LET is a measure of the amount of energy, **dE,**
lost by a particle in a specific material
as it travels an incremental distance, **dx,**
through that material.
expressed in (MeV-cm^2/mg)

Different combination of
(Ion, energy)

⇓

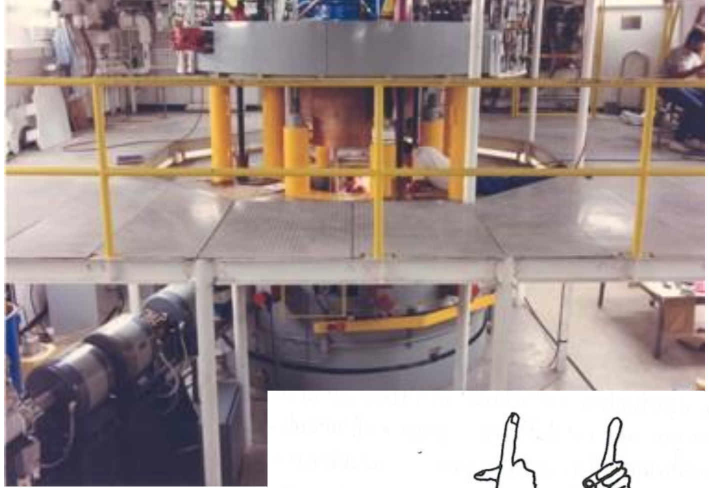
same LET
with different range

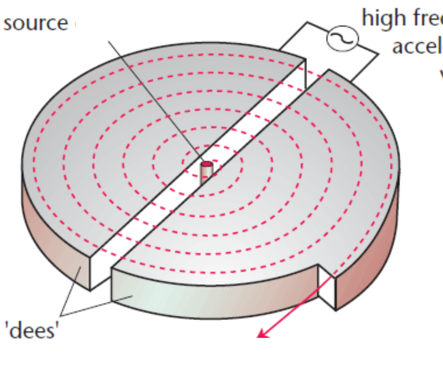


“Introduction to NSRL Heavy Ion Facilities Comparison LBNL/TAMU/NSRL”
Michael Sivertz, NASA Space Radiation Laboratory

Note:
Heavy ion beam energy can be expressed as:
energy per nucelon (MeV/n) or Ion energy (MeV)

Ion energy = energy per nucleon * (protons+neutrons)

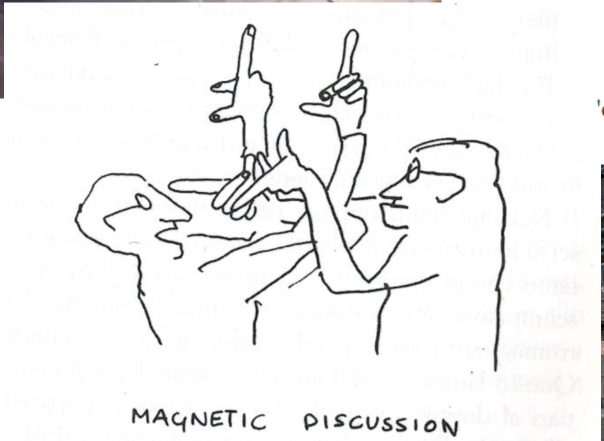


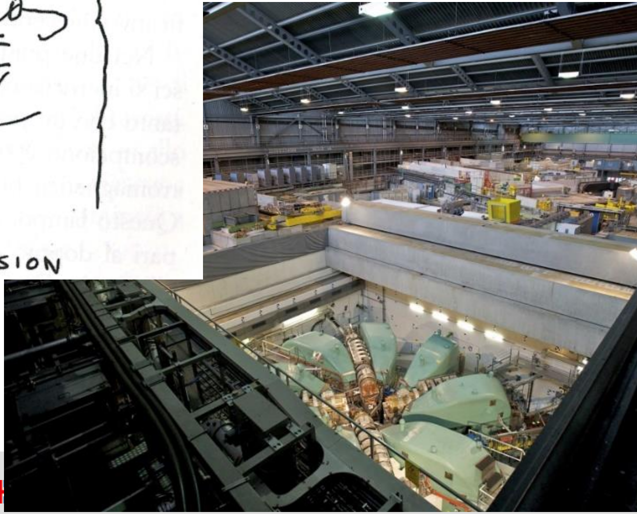


Part 3b

SEE TESTING

TEST FACILITIES

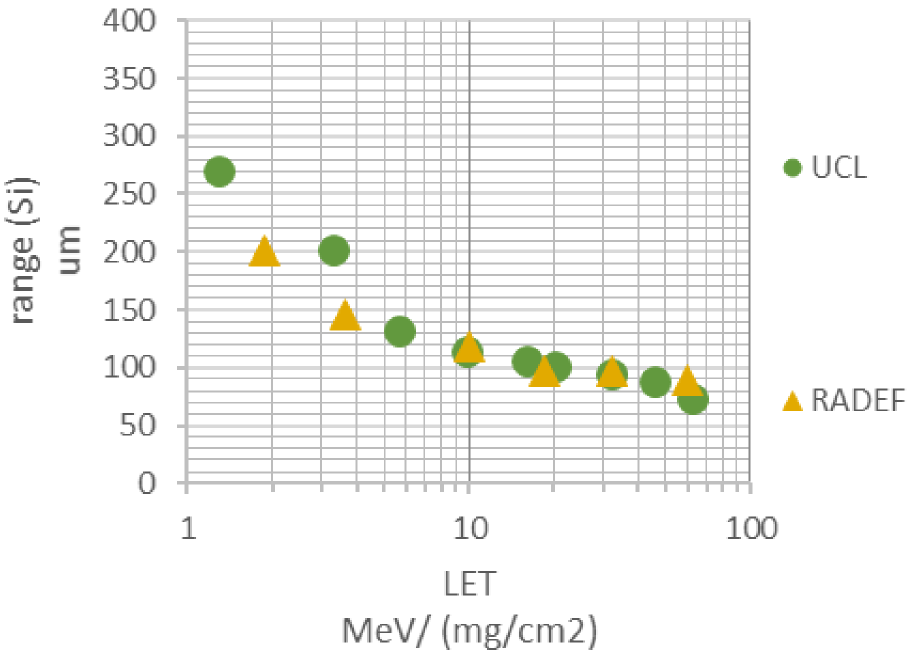




Heavy ion beams

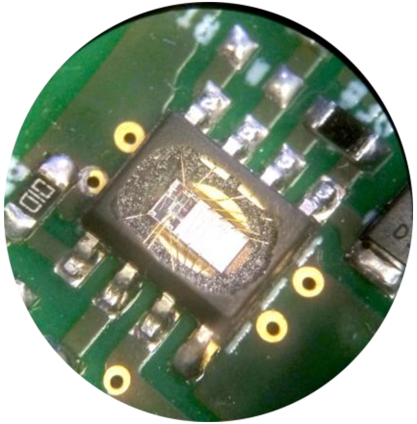
Standard Energy (SE)	< 10 MeV/n
High Energy (HE)	10-100 MeV/n
Very-High Energy (VHE)	100 MeV/n-5 GeV/n
Ultra-High Energy (UHE)	5-150 GeV/n

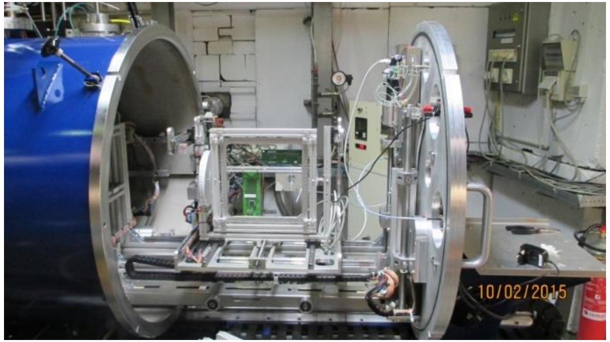
Facility	Ion	Beam energy [MeV]	Range [μm Si]	LET at surface [MeV/(mg/cm²)]
UCL	13 C 4+	131	269.3	1.3
	22 Ne 7+	238	202	3.3
	27 Al 8+	250	131.2	5.7
	36 Ar 11+	353	114	9.9
	53 Cr 16+	505	105.5	16.1
	58 Ni 18+	582	100.5	20.4
	84 Kr 25+	769	94.2	32.4
	103 Rh31+	957	87.3	46.1
	124 Xe 35+	995	73.1	62.5
RADEF	15 N 4+	139	202	1.87
	20 Ne 6+	186	146	3.63
	40 Ar 12+	372	118	10.1
	56 Fe 15+	523	97	18.6
	83 Kr 22+	768	97	32.2
	131 Xe 35+	1217	89	60



Heavy ion beam energy can be expressed as:
energy per nuclon (MeV/n) or Ion energy (MeV)
Ion energy (MeV) = energy per nucleon (MeV/n) * (protons+neutrons)

Range of heavy ions





For 10MeV/n beam => 10-300um range

- Delidding (chemical etching)

to reach the active area of the die

- Test generally executed in vacuum

COTS EEE components

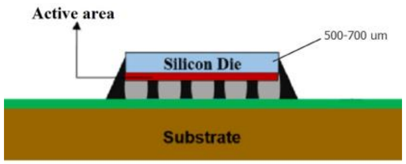
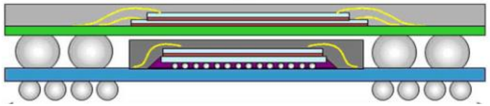
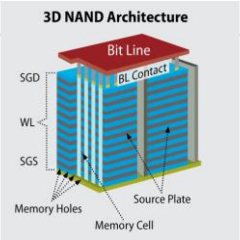
One common particularity of EEE COTS components is the dense packaging

Examples:

- Multi chip modules
- Flip chip construction
- Hybrids
- Plastic package with Cu bondwires

The exposure of either the dies of such packages is eiter impossible or difficult,
And there is the risk to modify the device response.

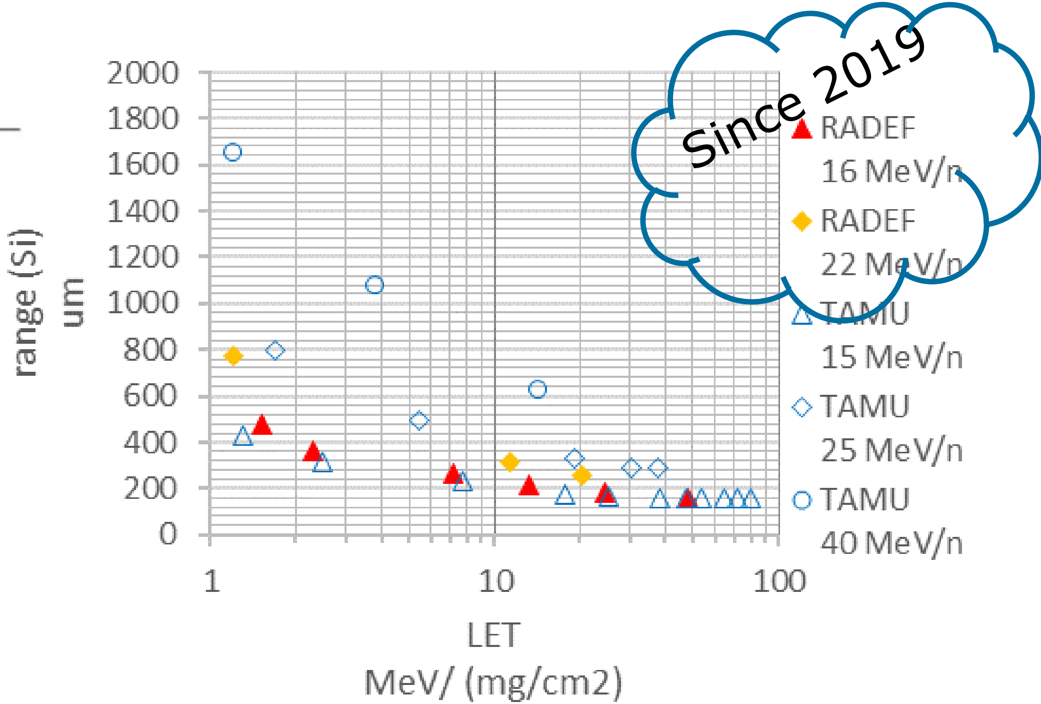
need of more enegetic particles to have more range (despite lower LET)

		
Flip chip: Active area facing package Backside irradiation -> die thinning to ~200 um	**System in package:** Test separately	**Dense structure:** Higher beam penetration range

High energy beam

Standard Energy (SE)	< 10 MeV/n
High Energy (HE)	10-100 MeV/n
Very-High Energy (VHE)	100 MeV/n-5 GeV/n
Ultra-High Energy (UHE)	5-150 GeV/n

	Ion	Beam energy [MeV]	Range [μm Si]	LET at surface [MeV/(mg/cm²)]
RADEF 16 MeV/n	$^{17}O^{6+}$	284	481	1.52
	$^{20}Ne^{7+}$	328	360	2.3
	$^{40}Ar^{14+}$	657	264	7.2
	$^{57}Fe^{20+}$	941	214	13.3
	$^{83}Kr^{29+}$	1358	185	24.5
	$^{126}Xe^{44+}$	2059	157	48.5
RADEF 22 MeV/n	$^{17}O^{7+}$	374	770	1.2
	$^{56}Fe^{23+}$	1230	315	11.3
	$^{78}Kr^{32+}$	1714	257	20.5



Very High energy beam

Standard Energy (SE)	< 10 MeV/n
High Energy (HE)	10-100 MeV/n
Very-High Energy (VHE)	100 MeV/n-5 GeV/n
Ultra-High Energy (UHE)	5-150 GeV/n

Facilities	Energy	Range of heavy ion species in Si	Availability per year
GSI SIS18 (Darmstadt, Germany)	50 MeV/n to 1-1.5 GeV/n	2.4 mm to 7.8 cm	Less than 1 week or scientific proposals
NSRL (Brookhaven, USA)	1500-217 MeV/n (light to heavy ions)	16 mm (350 MeV Xe)	~20 weeks NASA funded or scientific proposals

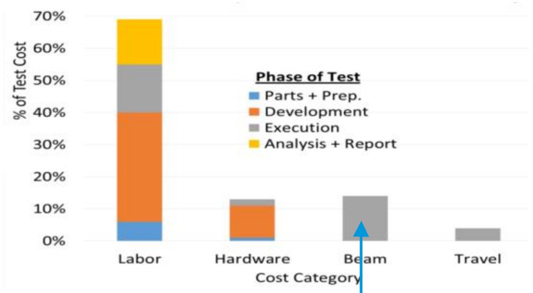
Ultra High energy beam

Standard Energy (SE)	< 10 MeV/n
High Energy (HE)	10-100 MeV/n
Very-High Energy (VHE)	100 MeV/n-5 GeV/n
Ultra-High Energy (UHE)	5-150 GeV/n

Facilities	Energy	Range of heavy ion species in Si	Availability per year
CERN CHARM or North Area (Geneva, Switzerland)	6-160 GeV/nucleon	meters	Less than 1 week ; ~2 year shutdown after 3-4 years of operation

Very and Ultra high energy beams

Standard Energy (SE)	< 10 MeV/n
High Energy (HE)	10-100 MeV/n
Very-High Energy (VHE)	100 MeV/n-5 GeV/n
Ultra-High Energy (UHE)	5-150 GeV/n



"Introduction to NSRL Heavy Ion Facilities Comparison LBNL/TAMU/NSRL"
Michael Sivertz, NASA Space Radiation Laboratory

Limitations:

- Few facilities worldwide that provide such beams

beam time scarce and expensive
or not available for commercial purposes

- High penetration linked to relatively low LET values;
  high LET values reachable near Bragg peak

Advantages:

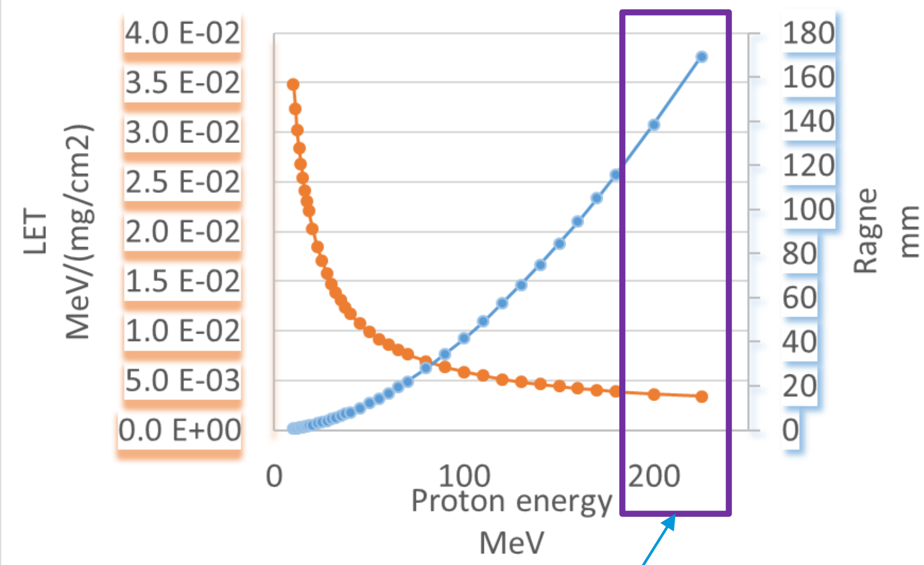
- Energies closer to actual GCR space environment, therefore tests are potentially more representative (i.e. for cases in which LET is not an appropriate figure of merit)
- High penetration: testing in air, at constant LET and with packaged components/boards

"Achieved results and perspectives in CERN-ESA cooperation Projects"
Presentation by R.Garcia Alia, 16 Oct 19

Part 5

BOARD LEVEL SEE TESTING WITH PROTONS

Board level SEE testing with protons



"Board Level Proton Testing Book of Knowledge for NASA Electronic Parts and Packaging Program"
Steven M. Guertin

Energy: 200MeV
fluence :10E10

Go-no go screen for soft errors

- Higher range (mm-cm), Lower LET….
  …with production of spallation reactions
- From these reactions, secondary particles with linear energy transfers (LETs) significantly higher than the incident protons are produced

Facilities:

PSI (Switzerland)
KVI (Netherlands)
…etc

"Test what you fly"

With an irradiation run

Energy: 200MeV fluence : 1E10 p/cm²

the deposited dose is small,

less than 0.6 krad(Si).

The board tested may be used as flight board

(after nuclear activation is decayed !!!)

" ESA COTS INITIATIVE WG 2/3 work synthesis"
Presented by F.Tonicello

Non-exhaustive list of test facilities

Facilities	Energy (MeV/nucleon)	Range of heavy species (Xe) in silicon	Available cocktail	Availability per year
UCL HIF (Louvain-la- Neuve, Belgium)	8-10 MeV/n	73 µm	9 species from C to Xe	About 16 weeks
RADEF (Jyväskylä,Finland)	from 2019 22 MeV/n , 16.3 MeV/n, (9.3 MeV/n before)	255 µm 155 µm (92 µm)	O, Fe, Kr 6 ion species, from O to Xe (7 ion species,from N to Xe)	About 12 weeks
KVI CART (Groningen, Netherlands)	30 MeV/n	333 µm	4 species, from Ne to Xe	1-2 weeks
GANIL G4 (Caen, France)	27 to 50 MeV/n possible degrading to few Mev/n	50 µm to 685 µm	One species per experiment, Ar, Kr, Xe or Pb	1-2 weeks
TAMU (College Station, TX, USA)	15 MeV/n 25 MeV/n 40 MeV/n	156 µm -286 µm 622 (Kr)	3 cocktails, from 12 to 4 species for resp. 15-40 MeV/n	About 20-25 weeks
GSI SIS18 (Darmstadt, Germany)	50 MeV/n to 1-1.5 GeV/n	2.4 mm to 7.8 cm	One species per experiment, can be from proton to U	Less than 1 week
NSRL (Brookhaven, US)	1500-217 MeV/n (light to heavy ions)	16 mm (350 MeV Xe)	One species per experiment, can be from proton to Th	~20 weeks NASA funded or scientific proposals
CERN CHARM or North Area (Geneva, Switzerland)	6-160 GeV/nucleon	meters	One species per experiment	Less than 1 week

For a list of facilities available worldwide: https://irradiation-facilities.web.cern.ch/

Thank you

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Memo from V.Ferlet-Cavrois, 20 Feb 2019

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