Impact des radiations sur les composants et systèmes électroniques pour l'espace:

de la prédiction à l'analyse

Denis LAVIELLE,

Responsable Développement & Innovation TRAD

www.trad.fr

OBJECTIFS

- Décrire la démarche assurance radiation spatiale dans un cadre plus global (lien entre analyse , tests et exploitation des essais, composants et ….. matériaux)

- Illustrer la démarche en identifiant quelques outils et mots-clés

- Mentionner les sujets « émergents »

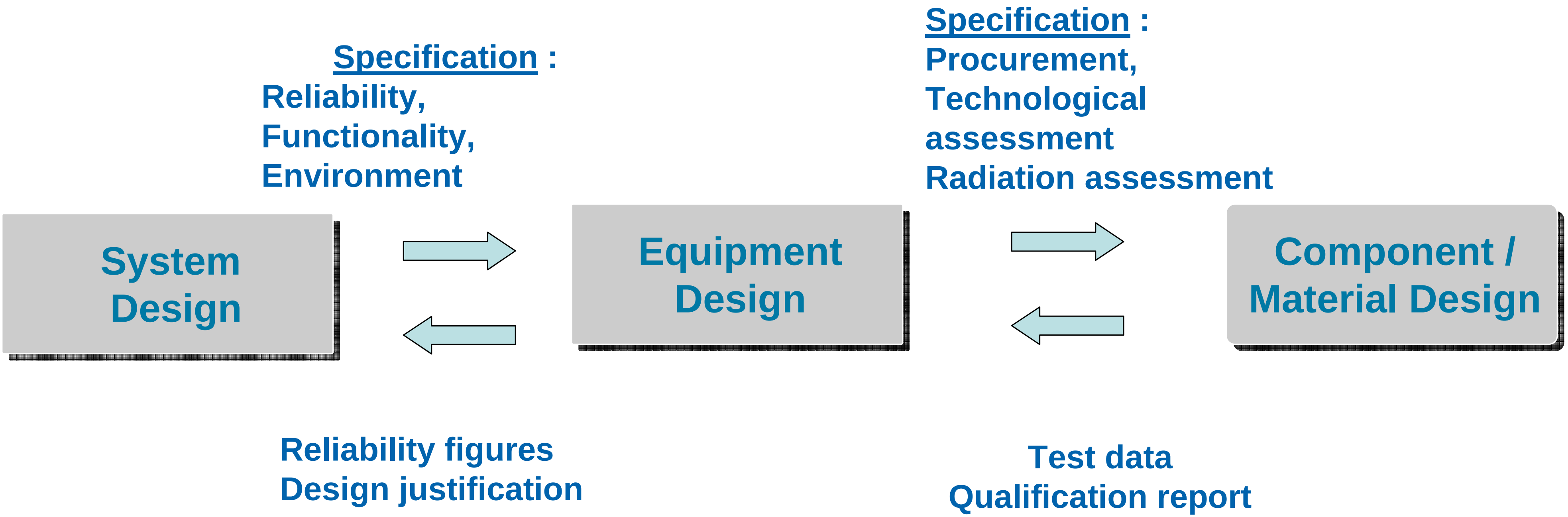
Space Environment

Space environment is a harsh medium for technologies

- Radiation
  - Alpha particles & Protons
  - Electrons
  - Photons
- UV
- Temperature
  - Thermal Cycling under Vacuum
- Atomic Oxygen
  - Erosion of surfaces
- Debris
  - Impacts
  - Mechanical damage

Need to ensure reliability at an acceptable cost

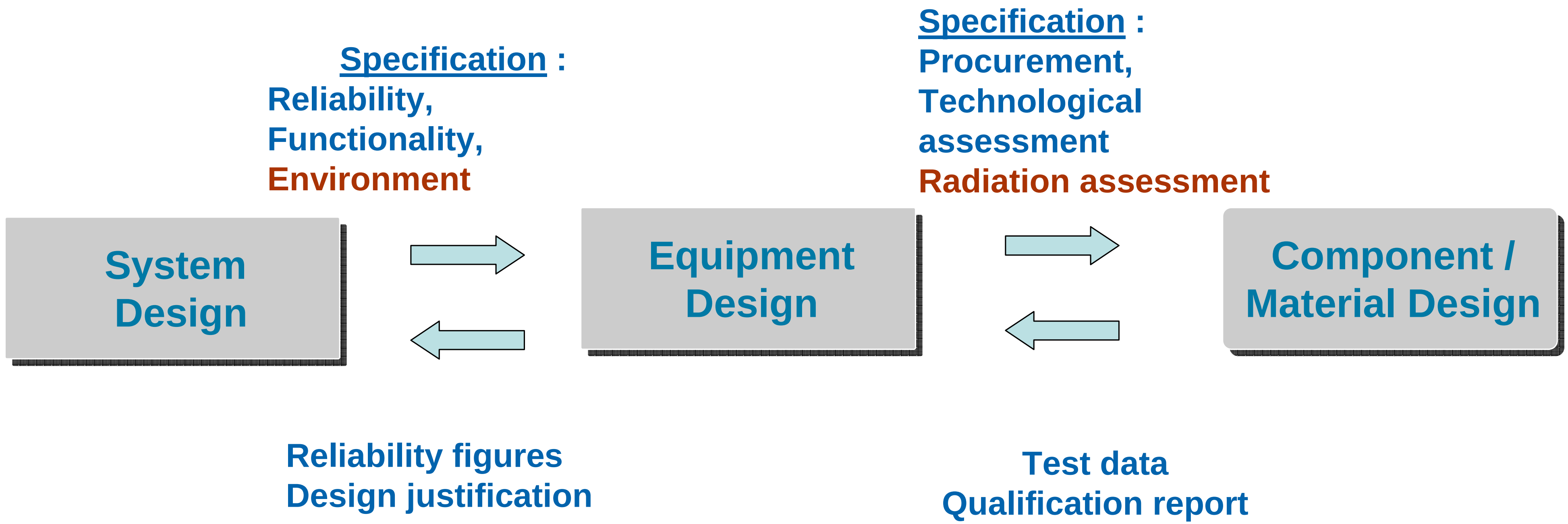
Radiation Assurance Process*…



…Aims at ensuring the ability of technologies (Components, Materials) to comply to radiation requirements

*refer to ECSS-Q-ST-60-15

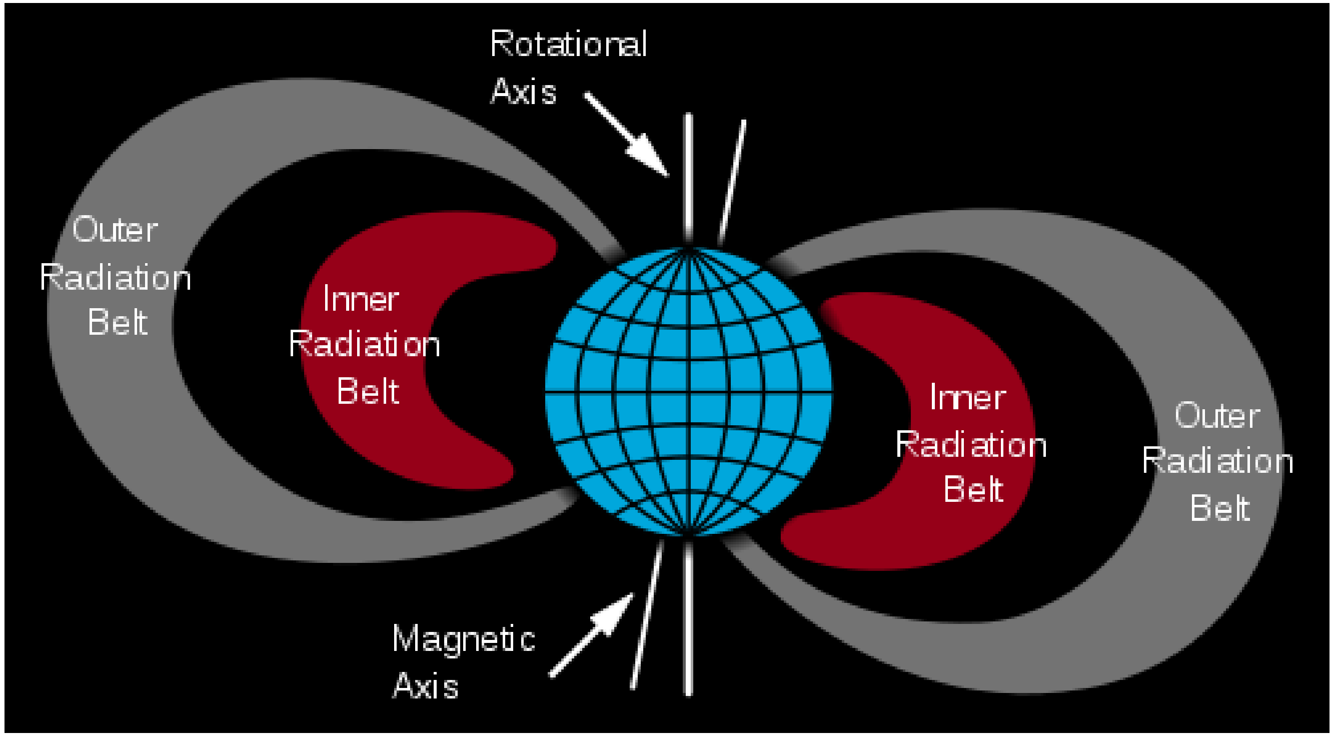
STEP 1 : Define Radiation Environment



Calculation of Space Environment

- Depends on the mission: LEO, GEO*, Interplanetary, Near Sun,…
  - Trapped Particles / Solar particles / Cosmic ray (ECSS-E-ST-10-04)

*Generally
Industrial specifications

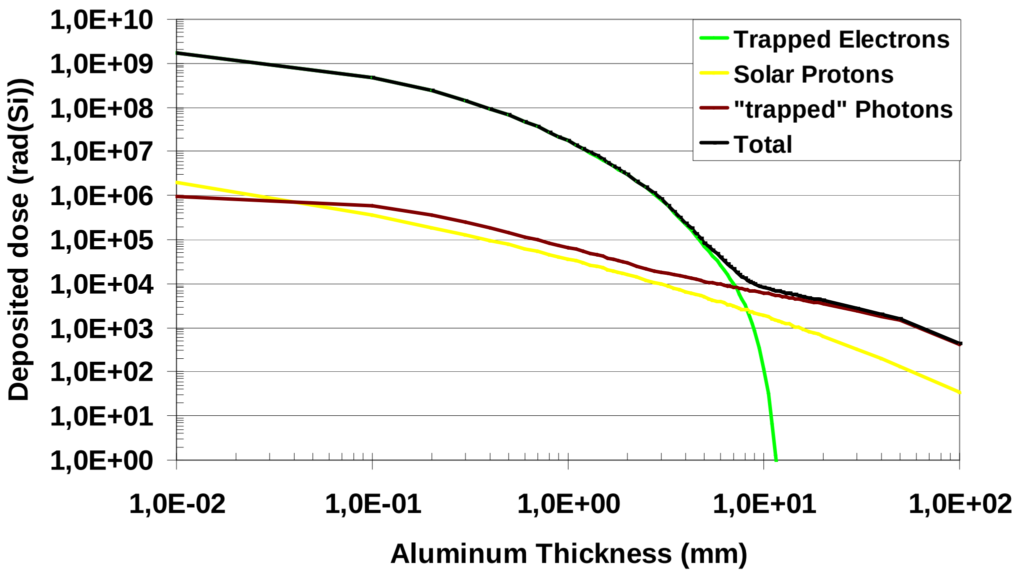


PARTICLE FLUX Calculation tools :

OMERE (TRAD with CNES support : more than 500 users in the world)

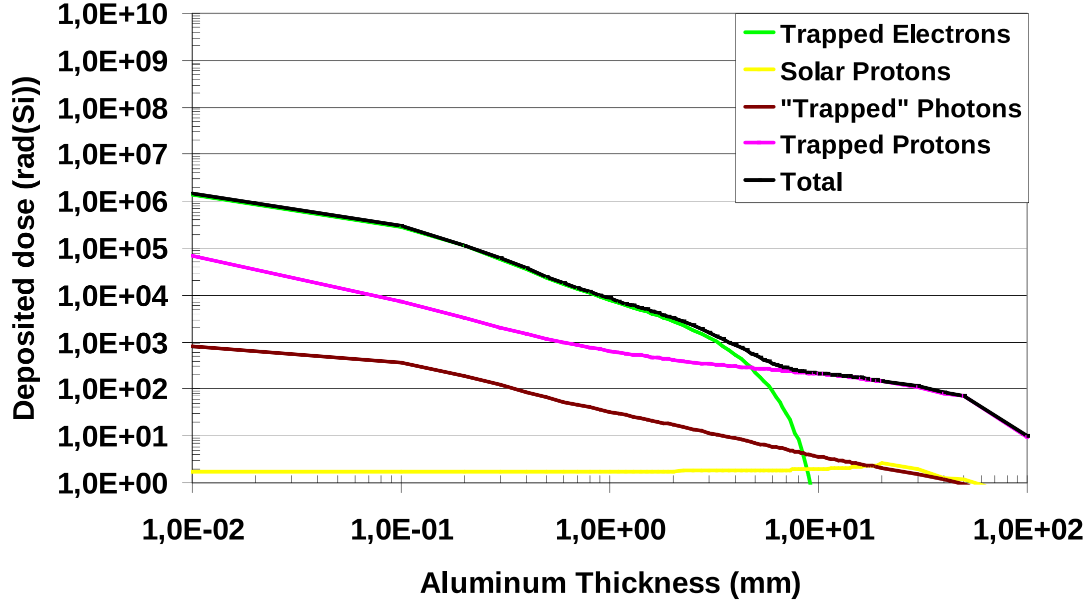
Calculation of Space Environment

DOSE-DEPTH CURVE : e.g OMERE OUTPUT



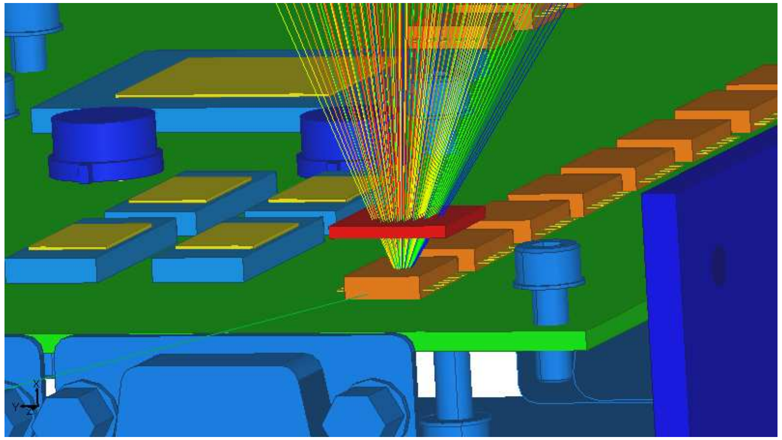
15 Years GEO

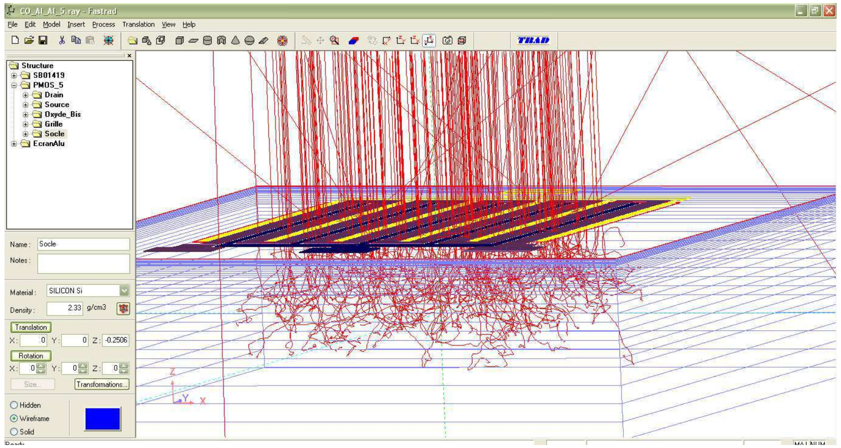
5 Years LEO ISS



Calculate expected orbit dose

- Components
  - Ray-tracing for quick calculation
  - Reverse Monte Carlo for critical cases
- Materials
  - Direct Monte Carlo
  - RayTracing only for “internal” materials



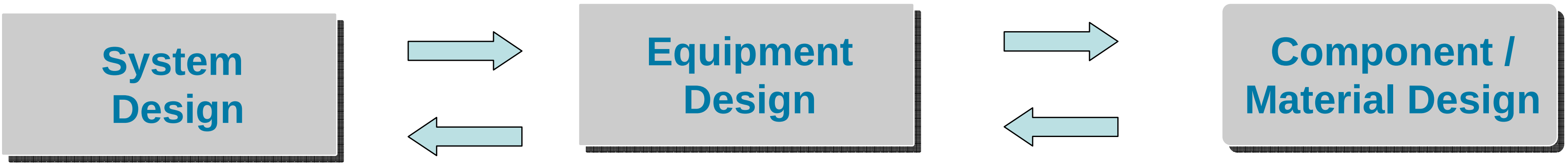


- FASTRAD TRAD’s tool has become a standard in Europe (Thales, Astrium, ESA,..) but it is also used by NASA JPL, MIT, JAXA

STEP 2 : Technological Assessment

Specification :
Reliability,
Functionality,
Environment

Specification :
Procurement,
Technological assessment
Radiation assessment



Reliability figures
Design justification

Test data
Qualification report

Summary of radiation effects

Total Ionizing Dose (TID)

Potentially all components & Materials

Cumulative effects

Displacement damage

Bipolar technologies

Optical Devices & Materials

Permanent SEEs

SEL

CMOS technologies

SEB

Power MOSFETs, BJT and diodes

SEGR

Power MOSFETs

Single Event Effects (SEE)

Static SEEs

SEU, SEFI

Digital ICs

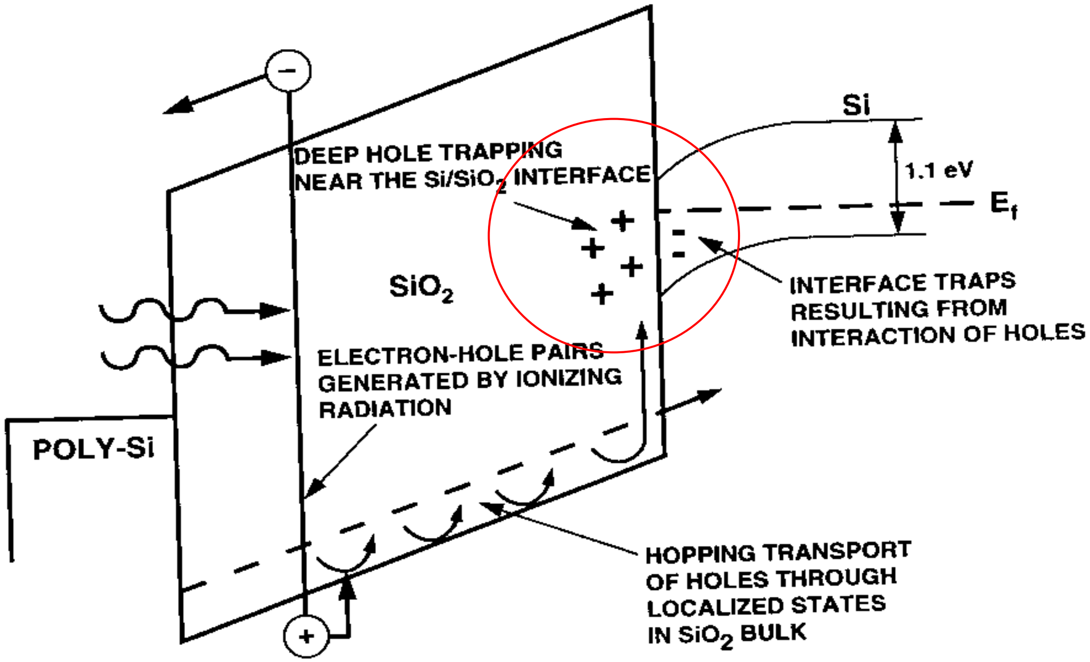
Transient SEEs

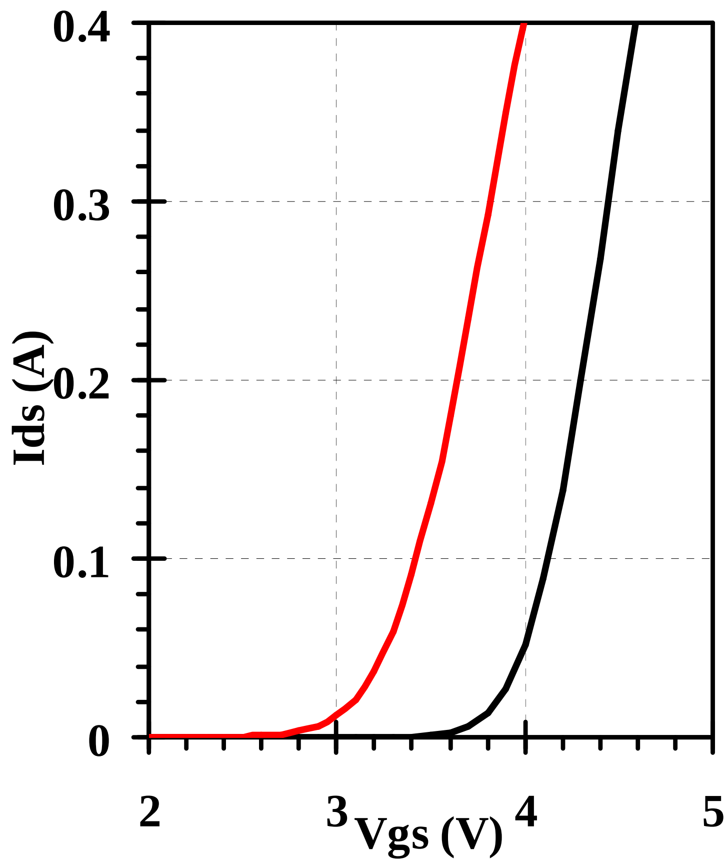
Combinational logic

Operational amplifiers

Total Ionizing Dose

- MOS technology :
  - Voltage drifts due to oxyde traps
  - Std by currents -> leakage -> consumption





F.B.McLean et al., HDL-TR-2129 internal report, 1987

Total Ionizing Dose

- Bipolar technologies :

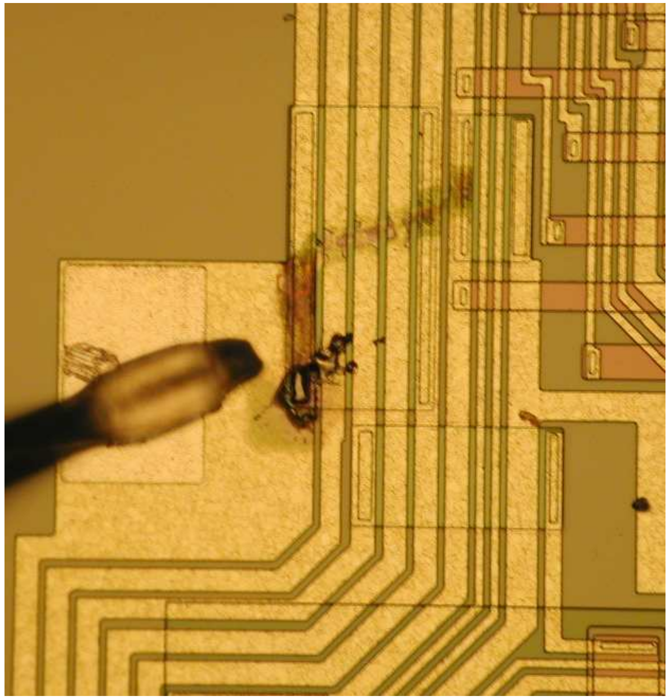
  - Main effect at transistor level :
    - <u>reduction of gain</u> $\Delta(1/\beta)=K.D^N$ with N#1at a low level of dose.

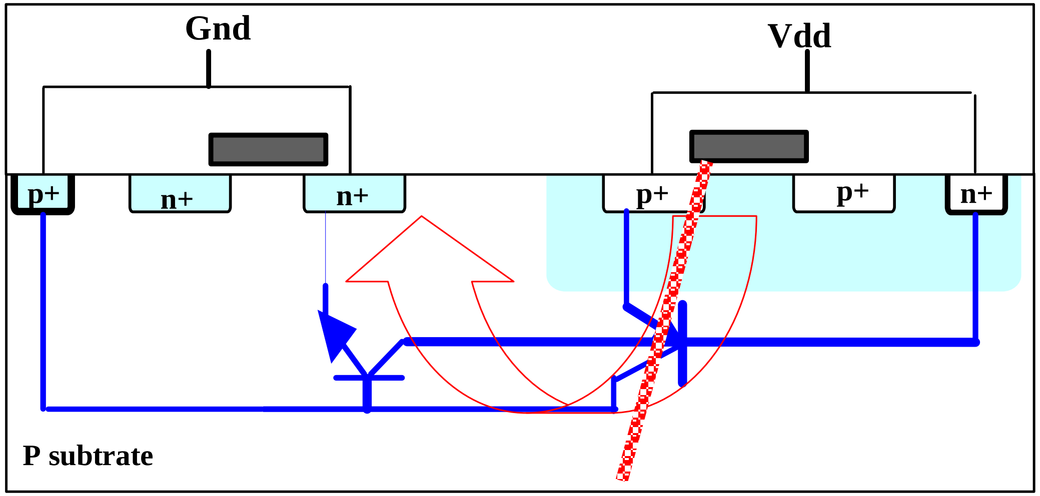
  - Bias & offset currents, increase of offset voltages

  - Potential dose rate effects (low dose rate sensitivity enhancement)

SEL Single Event Latch-up

Destructive effect (and bulk structures)





- *Potential Destruction if no delatcher*

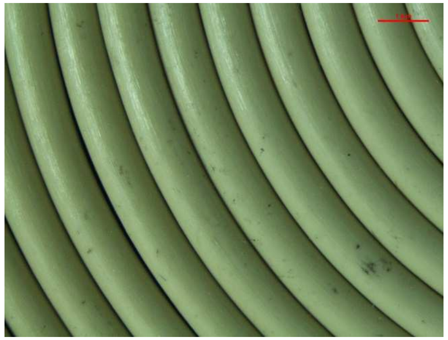
Radiation Effects on Materials

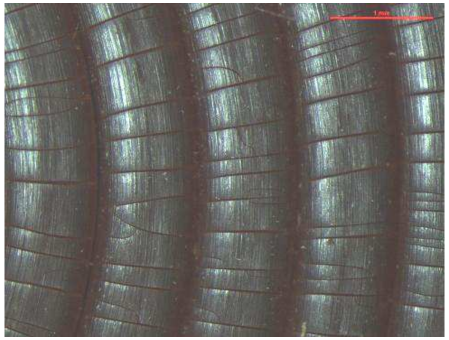
Ageing of thermal protection materials

Absorptivity increase

Failure of external jacket cable material

Insulation leaks





STEP 3 : Test Definition & Realization

Specification :
Reliability,
Functionality,
Environment

Specification :
Procurement,
Technological assessment
Radiation assessment

System Design ⇄ **Equipment Design** ⇄ **Component / Material Design**

Reliability figures
Design justification

Test data
Qualification report

Radiation Testing of components

Total Ionizing Dose (ESCC 22900)

- Dose level (dose rate x time / Co60)
- Dose rate effect

Single Event Effects (ESCC 25100)

- Decapsulation / active zone (cf heavy ions penetration depth)
- Cf to pre-test, Laser

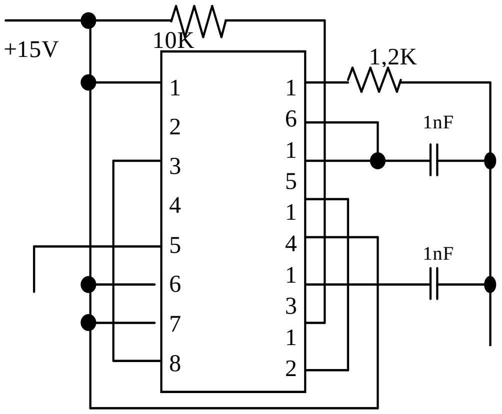
Define an irradiation test plan (ITP)

- Device configuration and Tested parameters

Irradiation Test Plan

TOTAL DOSE IRRADIATION TEST PLAN DATA SHEET			
PART :	**UC1834**	MANUFACTURER :	UNITRODE
FUNCTION:	REGULATOR		
SOURCE :	Co 60	DOSE RATE :	< 360rad(si) / hour
STEPS :	0,10,20,30,50,70,100 (krad(si))	SPECIFICATION :	ESA SCC 22900
ANNEALING:	Under bias 24Hrs / 25°+ 168 Hrs / 100°C		

BIAS CONDITIONS UNDER TEST :

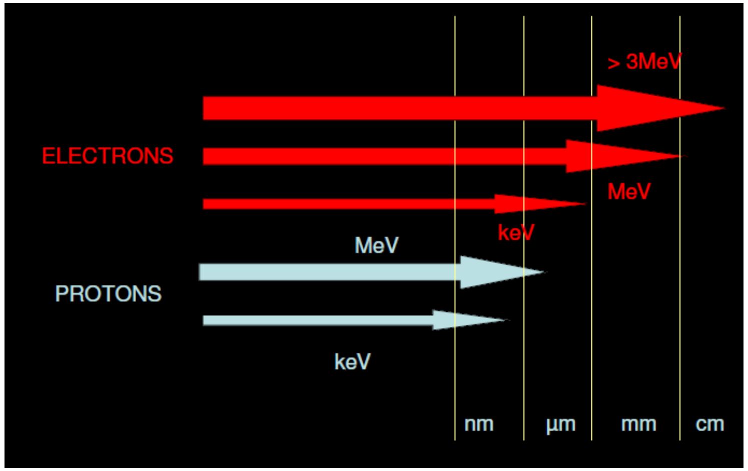


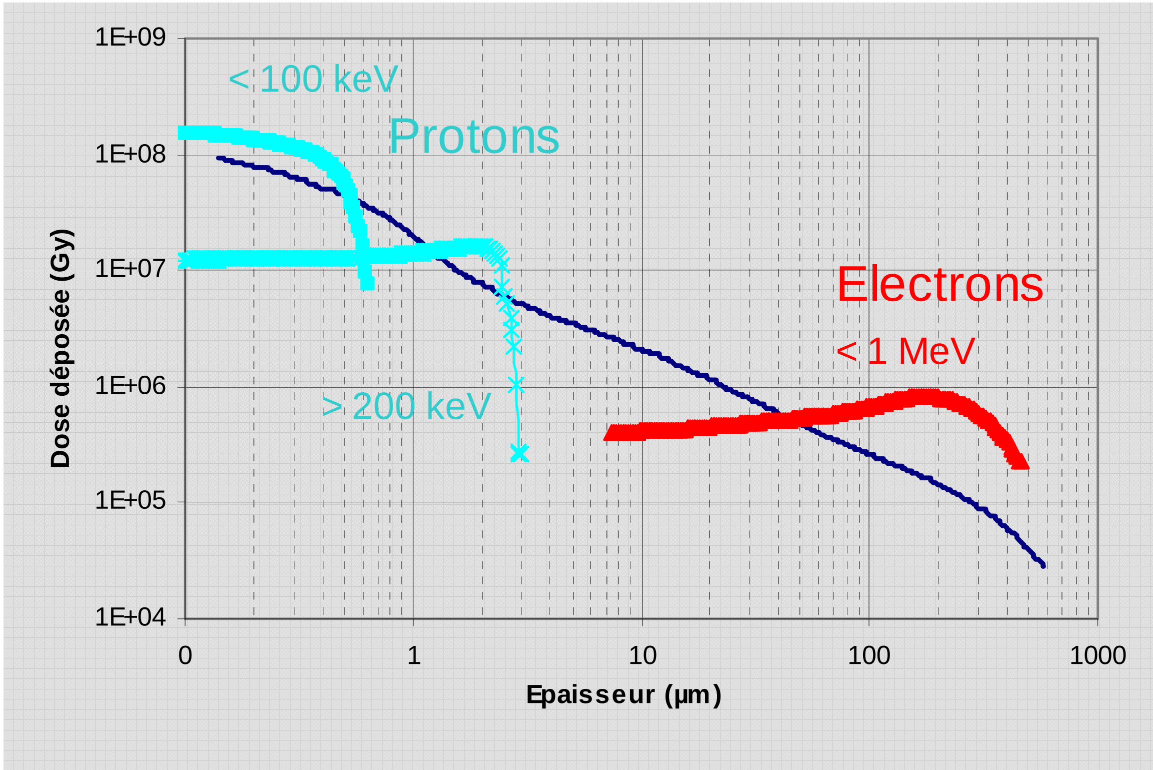
PARAMETERS TO MEASURE PRE AND POST RADIATION :

CHARACTERISTICS	SYMBOLS	TEST CONDITIONS
Standby Supply Current	Icc	
+ 1,5 Volt reference :		
Output Voltage 1	Vout 1	
Line Regulation 1	Kvi1	Vin = 5 to 35V
Load Regulation 1	Kvo1	Iout = 0 to 2 mA
-2 Volt reference :		
Output Voltage 2	Vout2	
Line Regulation 2	Kvi2	Vin = 5 to 35 V
Error Amplifier section :		
Input Offset Voltage	Vos	Vcm = 1.5V
Input Offset Current	Ios	
Bias Current on + of Error Amplifier	IbiasE+	Vcm = 1.5V; vdm = 5 mV
Bias Current on - of Error Amplifier	IbiasE-	Vcm = 1.5V; vdm = 5 mV
Current sense amplifier section :		
Open Loop Gain		Output @Pin 14, Pin 12 = Vin+
Bias Current on + of Sense Amplifier	IbiasSh+	Vin = 15V
Bias Current on - of Sense Amplifier	IbiasSh-	Vin = 15V
Bias Current on + of Sense Amplifier	IbiasS1+	Vin = 0V
Bias Current on - of Sense Amplifier	IbiasS1-	Vin = 0V
Threshold Voltage		
0,5 V Threshold Voltage	Vth	Pin 4 open Vcm = Vin+ or Vin-
Adjustement Input Current	Iadj	Vin = 0,5V
Driver section :		
Driver Saturation Voltage	VDsat	Iout = 100 mA
Maximum output current	Idout	
Driver Leakage Current	IDleak	Dvout = 30V
Fault amplifier section :		
Saturation Voltage	VFsat	Iout = 1 mA
O.V. Latch Saturation Voltage	VLsat	Iout = 1 mA
Crowbar Gate Current	Icgc	Vcg = 0V
Crowbard Gate Leakage Current	Iclc	Vcg = 0V
OV Latch Output Current	Ilout	
Alert Output Current	Ifout	

Radiation Testing of Materials

- Test Definition -> DOSE PROFILE
  - Necessity to combine different particles and energies to fit as good as possible the calculated dose (ECSS Q 70 06)
  - A test covering one year in orbit for “volume effect” could represent less than one day for “surface effects”



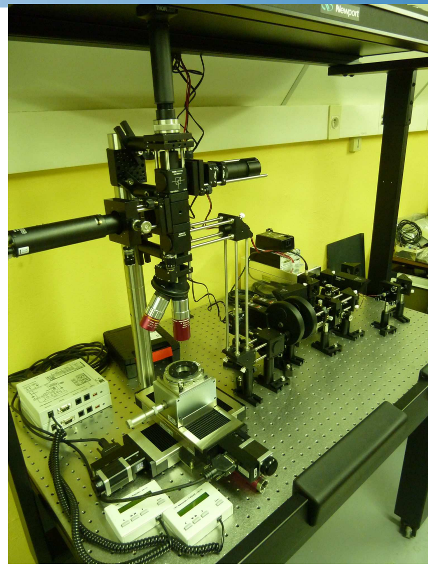


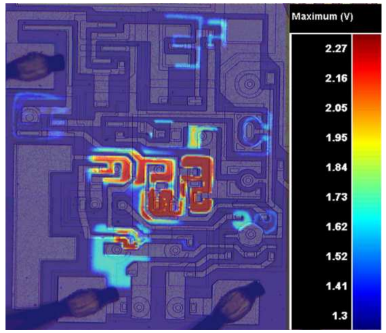
Dose profile for kapton (d=1.42g.cm^{-3}) for 1year GEO and comparison with simulated dose profile

Tests Facilities & Equipments

- Maintenance of test equipments
  - Regular controls by certified authority
- Adequation of test benches to application
  - Cable length (accuracy, signal/noise ratio)
  - Vacuum
    - ❑pre-test using Cf source, laser
- Device preparation
  - Decapsulation / Identification of active zone
- Dosimetry of sources/accelerators & Radioprotection
  - TRAD has developed its own electronic dosimeters for Co60
  - TRAD has its own Co60 source with independent customer room
  - Entries controlled by alarms and operators follow-up / Security system

TEST FACILITIES





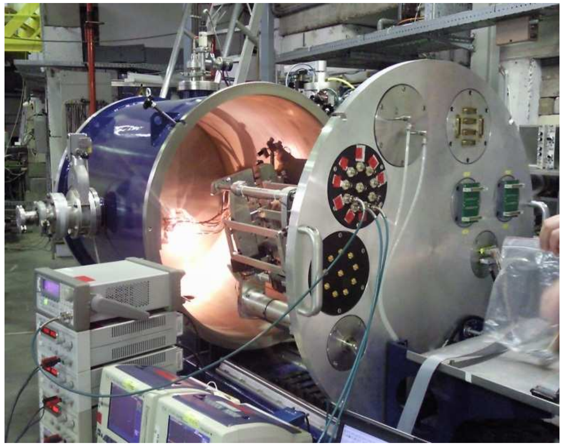
Cobalt 60 source

- Photonic dose
- 45m^3 irradiation volume
- 7.4 TBq, beam dose rate from 10rad(Si)/h to1krad(Si)/h, operating temperature at room temp

Laser

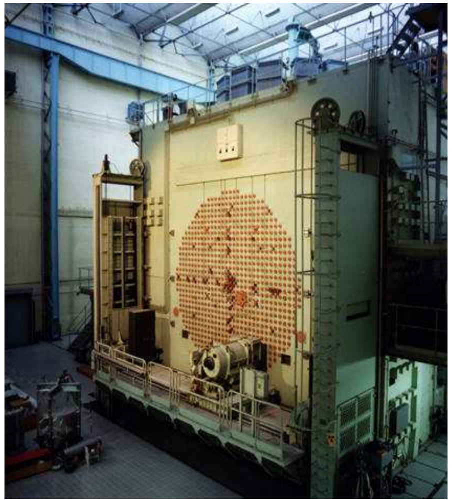
- SEE Simulation
- DUT cartography

HEAVY IONS-PROTONS-NEUTRONS



Cyclotrons (HIF/RADEF)

- Ions HIGH LET value
- 67,7 MeV/mg/cm^2 up to 80 with 45° angle
- Ions High Range (92 µm)



Neutrons

- High energy 1 MeV

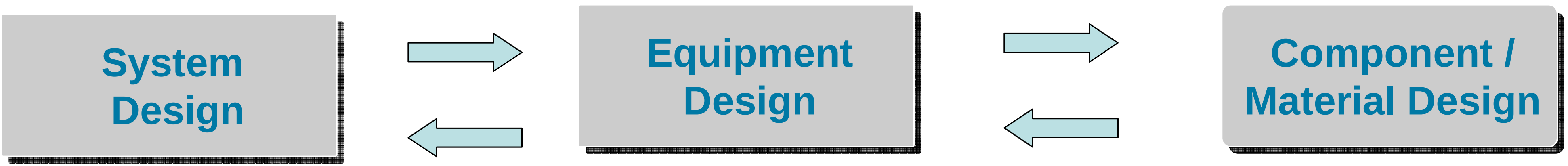
Protons

- Energy up to 200 MeV
- Flux : 2E8 p/cm^2/s

STEP 4 : Radiation Test Data Management

Specification :
Reliability,
Functionality,
Environment

Specification :
Procurement,
Technological assessment
Radiation assessment

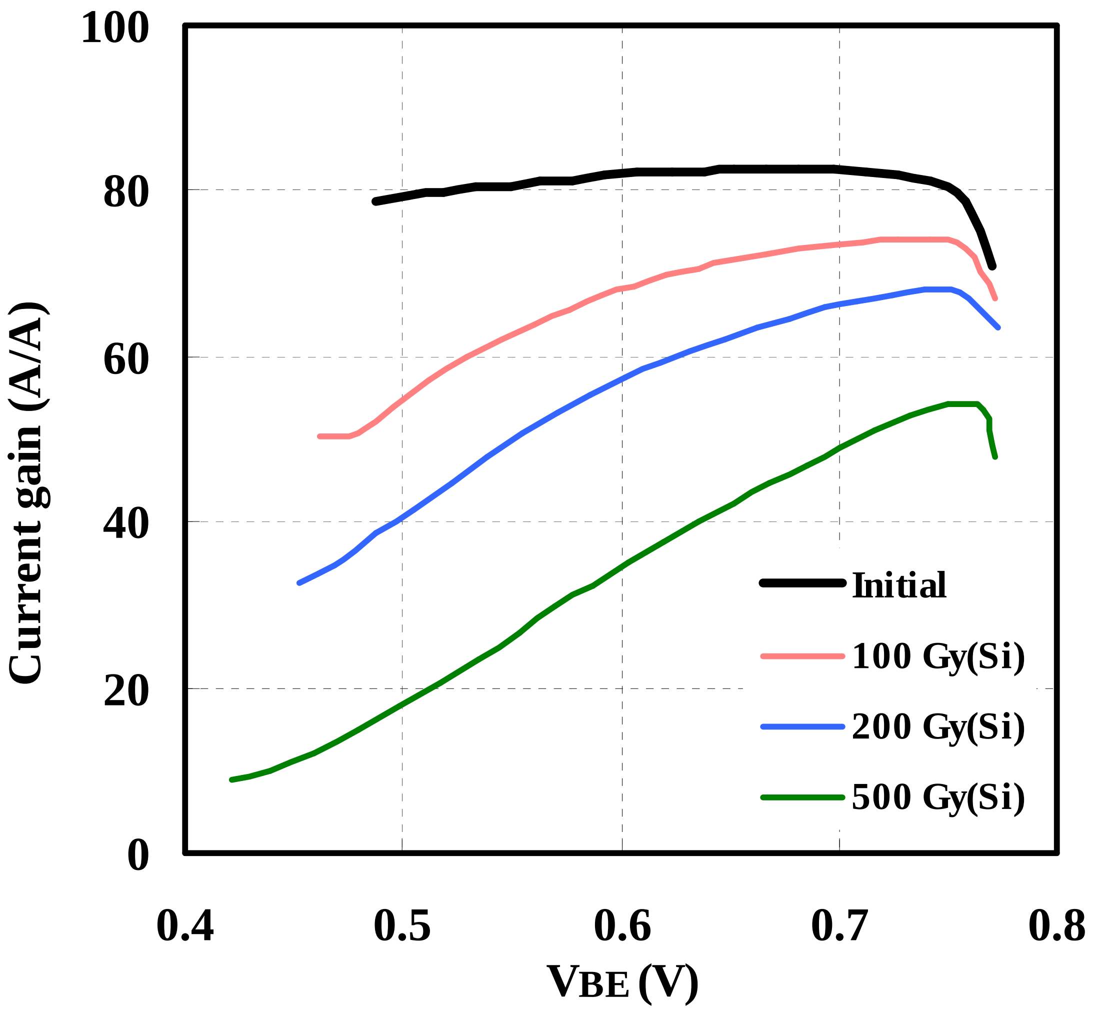


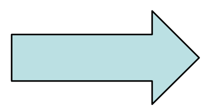
Reliability figures
Design justification

Test data
Qualification report

Supply Data to system engineer

- TID : Test report with impacted parameters

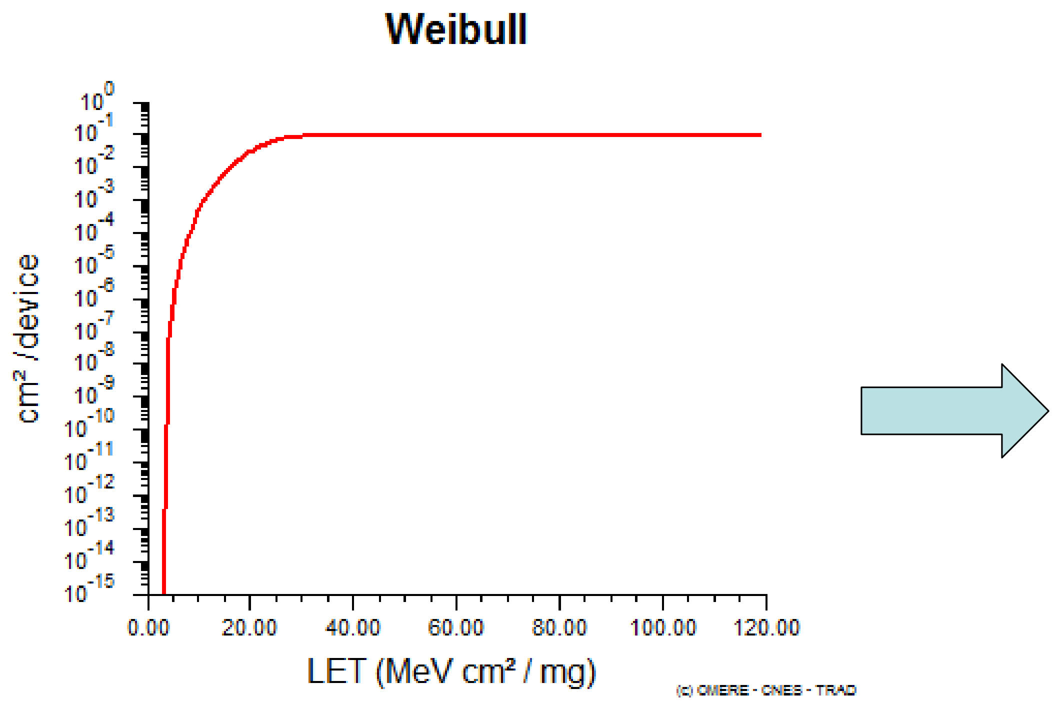




Electrical drifts

Supply Data to system engineer

- SEE : Weibull fit of cross-section

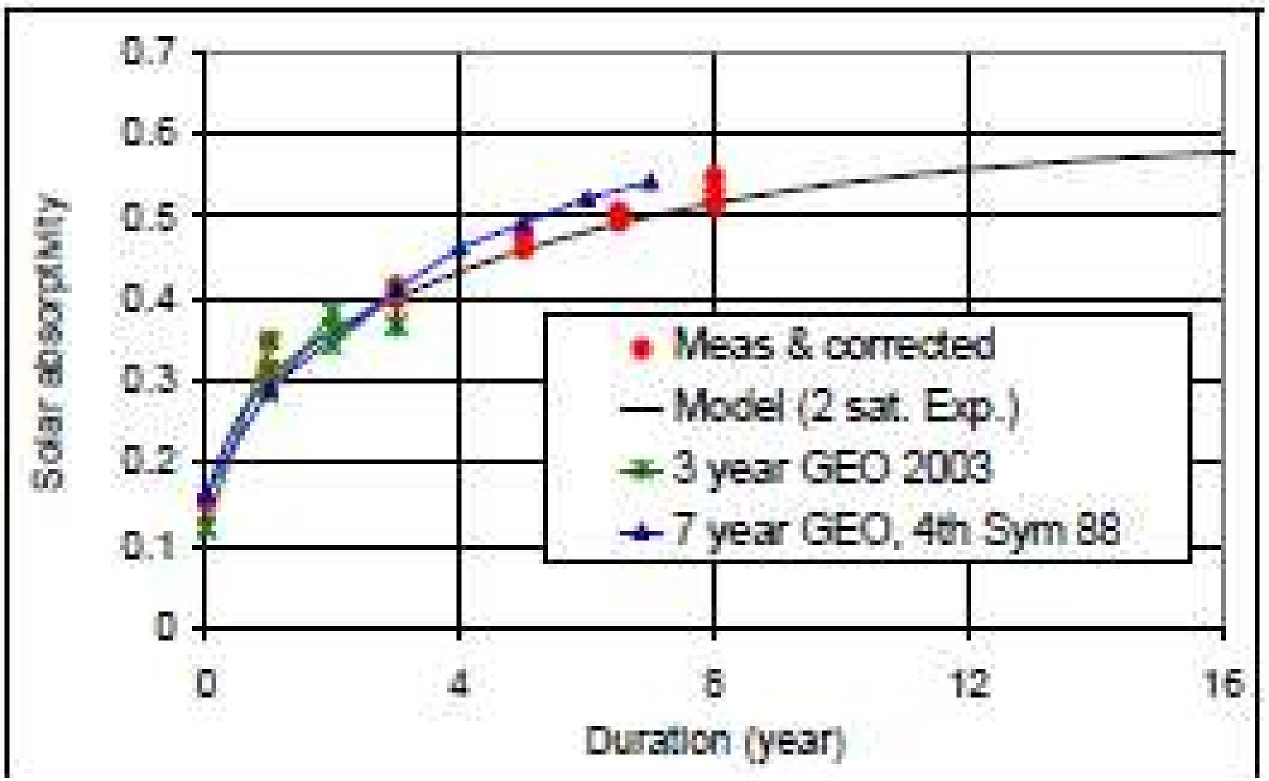


Single Event Rate

(#events /device/day)

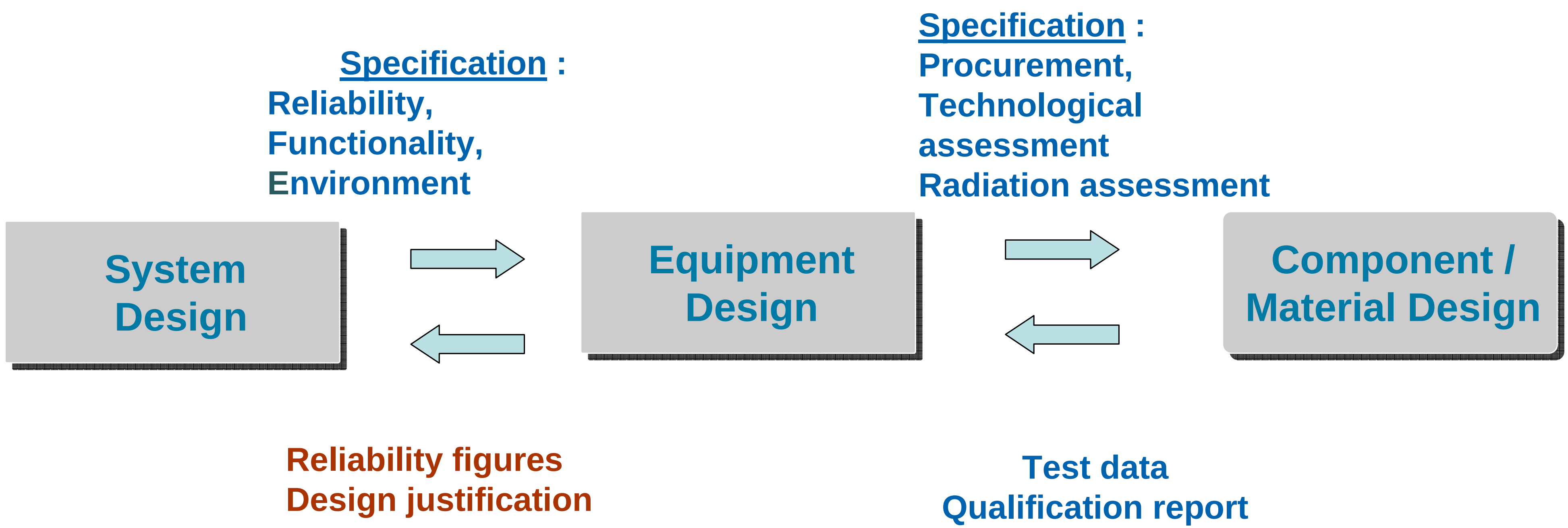
Supply Data to system engineer

- Change of solar absorptivity

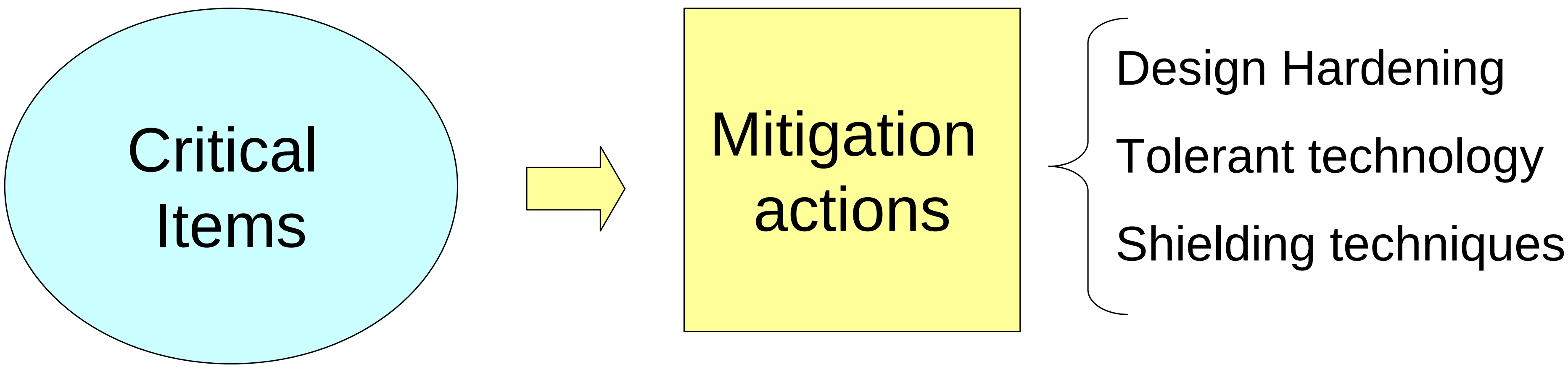


Thermal equilibrium impact

STEP 5 : Radiation Test Data Analysis



Radiation risks mitigation



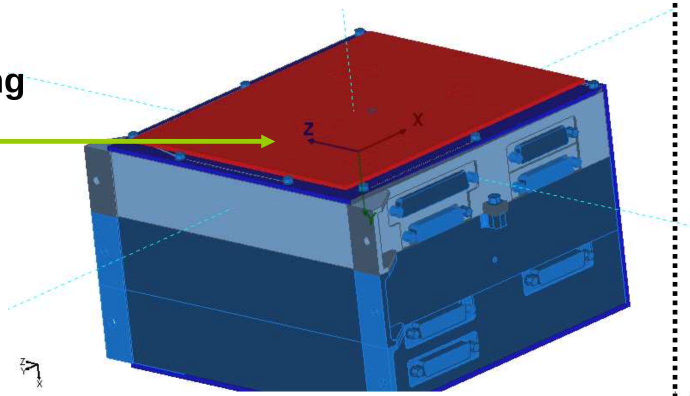
Radiation risks mitigation examples

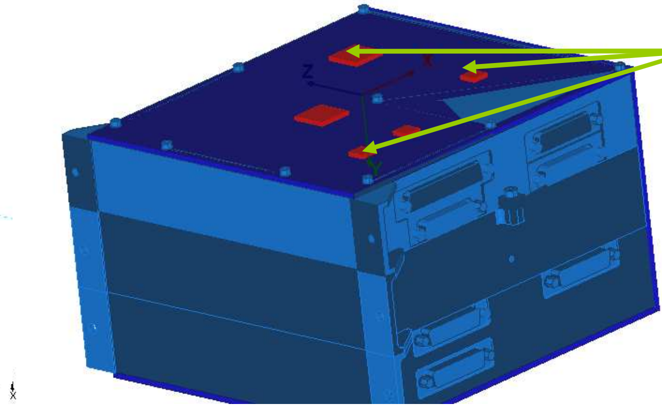
- Optimize shielding

Example : Shielding of one equipment for a geostationnary mission

Without FASTRAD	With FASTRAD

Uniform shielding on cover





Spot Shielding

	Without FASTRAD	With FASTRAD
Additional Shielding	**360 g**	**12 g**

You save 350 g/equipment

Tests & radiations

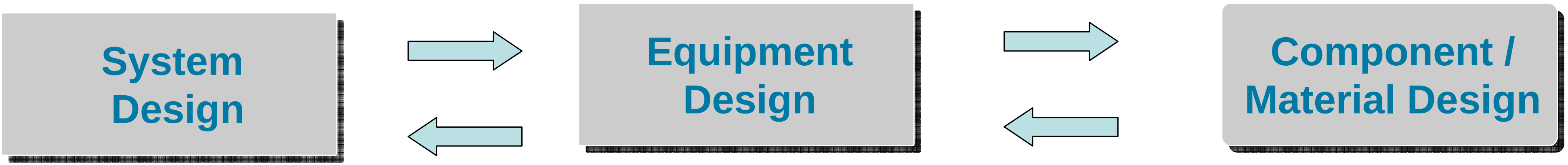
Radiation risks mitigation examples

- Optimize design
  - Adapt configurations (electronic, thermal)
  - Adapt derating rules (e.g. Power MOSFET) → ECSS Q 30 11
- Reject some technologies…. And re-qualify good ones !
- Electronics :
  - SEE or SEL rate not acceptable
  - Unacceptable drifts
- Materials :
  - Adhesive weakness
  - Radiation induced Optical absorption too high for glasses

STEP 6 : « Sustainable » Hardening

Specification :
Reliability,
Functionality,
Environment

Specification :
Procurement,
Technological assessment
Radiation assessment



Reliability figures
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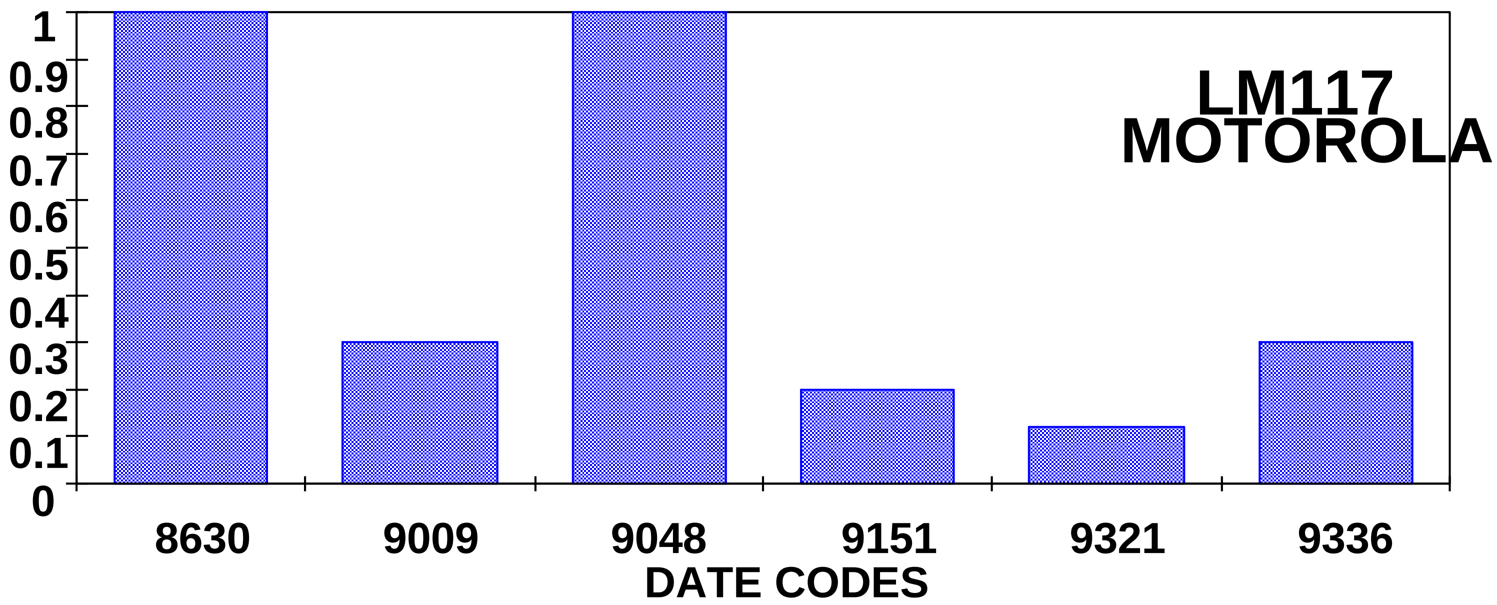
Optimize procurement

- Avoid sensitive technologies
  - ❑Updated Expert judgement
    - Critical Review of Declared Material and Declared Component Lists
    - Bibliographic studies (e.g RADECS, NSREC)
    - Field return based on background

- Test <u>every</u> flight lot of sensitive technologies (RVT)



« Emerging » topics

- Laser / SEE
  - Alternative to heavy ions ?
- New technologies (MEMS, Opto, RF,…)
  - New degradation mechanisms
  - New test techniques
  - Dose rate ?
- « New » missions
  - Interplanetary (Jupiter -> High Energy Electrons)
- Sequenced / Synergetic effects (UV, Radiation, Thermal)
  - JUICE, Solar missions

E-mail denis.lavielle@trad.fr

Web site http://www.trad.fr

Phone +33 (0)5 61 00 95 60

TRAD

907 voie l'Occitane

31670 Labège France