Centre Français Fiabilité

**Regroupement d'experts
de la fiabilité des systèmes
et des composants électroniques**

Centre Français de Fiabilité

Les Rendez-Vous Fiabilité du CFF
10 mai 2022

Bienvenue à toutes et à tous !

NAE Normandie — next move — ASTech — Région Normandie — AD Normandie — Région Île-de-France — République Française

Centre Français Fiabilité

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La vocation du CFF

NAE NORMANDIE AEROSPACE • DEFENCE • SECURITY

next move collaboration is the driver

ASTech Paris Region

RÉGION NORMANDIE

Région îledeFrance

RÉPUBLIQUE FRANÇAISE

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Les vocations du CFF

Regroupement d'experts de la fiabilité des systèmes et des composants électroniques

Réseau « Fiabilité » et Expertise Technique

- Cartographie
- Expertise
- Plateforme

Temps Forts

- Symposium NRTW
- Séminaire CFF
- RdV Fiabilité du CFF

Ressources documentaires

- Projets
- Thèses
- Publications
- Formations
- Présentations

Faire émerger des projets structurants

Le Centre Français de Fiabilité

Structuration du CFF

CFF

Expertise technique du CFF

Les Thématiques prioritaires

- Fiabilité des systèmes mécatroniques
- Fiabilité des composants électroniques (puissance, RF, …) et leur packaging
- Fiabilité des technologies liées à la connectique et à l'assemblage

Les Domaines

- Modélisation et simulation (numérique, analytique, …)
- Expérimental (caractérisation et testing)
- Cycle de vie (R&D / Utilisation)

Les Expertises

- Connaissances et moyens d'investigations sur les matériaux « électriques » et les composants
- Ingénierie de l'environnement (mécanique, climatique et CEM)
- Management thermique
- DataScience, Statistique et IA
- Analyse de construction
- Analyse de défaillances

Une matrice de lecture cohérente du périmètre du CFF

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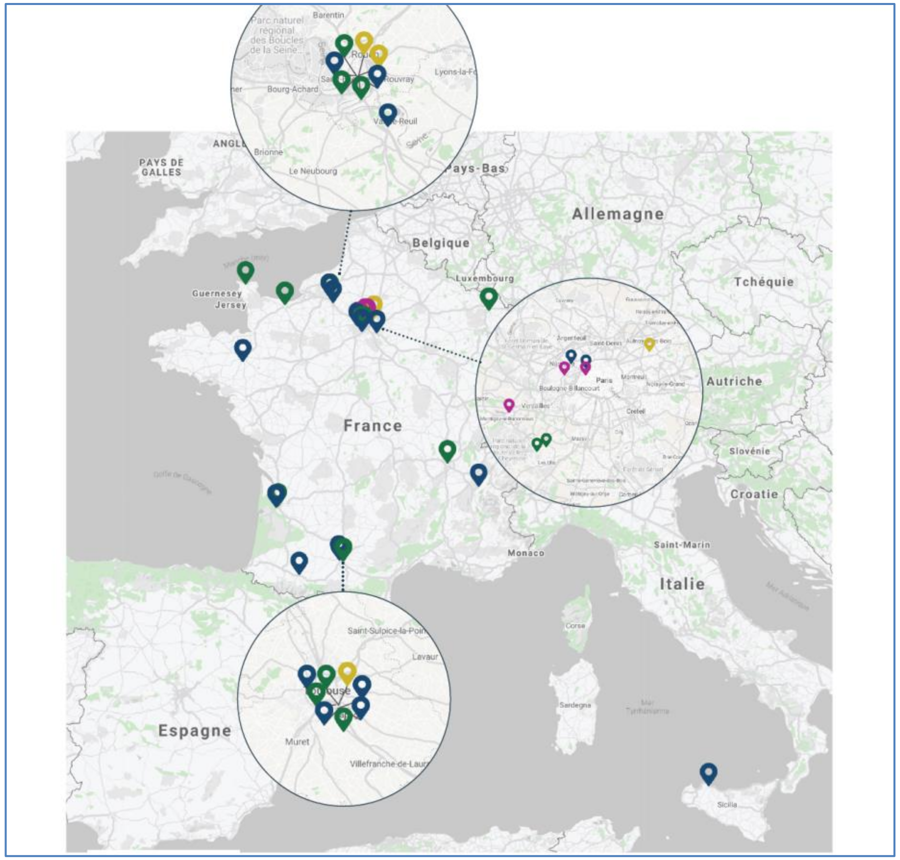
Structuration du CFF

Communauté CFF

- Près de 50 membres
- 9 partenaires : IMdR, ACSIEL, ANADEF, ASTE , CEEES, CNES-COMET, GDR Seeds, IEEE, SIA

Temps forts du CFF

SYMPOSIUM NRTW	Les Rendez-vous Fiabilité du CFF	Séminaire CFF
Le National Reliability Technology Workshop se veut un espace d'échanges et de rencontres des acteurs de la fiabilité. Il a lieu une fois par an. *Accès payant, ouvert à tous*	Les Rendez-Vous Fiabilité du CFF sont un évènement mensuel, organisé en visioconférence sur des travaux en lien avec les thématiques du CFF. *Accès gratuit en visioconférence, ouvert à tous.*	Le but de ce rendez-vous est de partager les compétences au sein de la communauté CFF. 3 rdv annuels : février – juin – octobre. *Accès gratuit en visioconférence et réservé aux membres.*



Une mobilisation concrète du réseau CFF à l'échelle nationale

Rejoignez la communauté CFF

Notre compte LinkedIn :	LinkedIn | Centre Francais de Fiabilite
Notre site internet :	www.cff-fiabilite.fr
Notre adresse email :	cff@nae.fr

Le Centre Français de Fiabilité

Structuration du CFF

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Nos ressources :

- Un site web : www.cff-fiabilite.fr
- Un compte LinkedIn | Centre Francais de Fiabilite
- Une adresse email de contact cff@nae.fr
- Un formulaire de candidature ici
- Une brochure des acteurs du CFF ici
- Mise en place d'un service « Ask the expert »

Formulaire de candidature

Brochure des acteurs du CFF

Regroupement d'experts de la fiabilité des systèmes et des composants électroniques

Une structuration de la communauté du CFF

NAE NORMANDIE · next move · ASTech Paris Region · RÉGION NORMANDIE · AD NORMANDIE · Région îledeFrance · RÉPUBLIQUE FRANÇAISE

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Agenda de la Saison 2022-23

CFF

Événements organisés par le CFF

Evènement	Date	Lieu	Thématique
RdV Fiabilité	10/05/2022	Visio	Radiations, impacts et évaluations Spatial, aéronautiques et automobile
Séminaire CFF *	14/06/2022	Visio	La température de jonction
Séminaire CFF *	11/10/2022	Visio	Sujet à confirmer
NRTW	15/03/2023	Rouen	La température dans la fiabilité des systèmes et des composants électroniques

Source : https://www.cff-fiabilite.fr/

* Exclusivement réservé aux membres CFF. ** Modalités à confirmer.

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Agenda de la Saison 2022-23

CFF

Événements relayés par le CFF

Evènement	Date	Lieu	Thématique
GDR SEEDS	Du 30-mai-22 Au 03-juin-22	Saint Géry - Vers, France	2e Ecole Thématique GDR SEEDS FiabSurf 30 mai 2022@8h00 - 3 juin 2022@17h00
ANADEF	Du 13-juin-22 Au 17-juin-22	Landes, France	**18e éd. Ateliers ANADEF**
IEEE	Du 24-août-22 Au 26-août-22	Paris, France	**7e éd. RTSI** (Research and Technologies for Society and Industry)
ESREL	Du 28-août-22 Au 01-sept.-22	Dublin, Ireland	**32e éd. conférence ESREL** = European Safety and Reliability Conference
EuWoRel	08-09 Sep 2022	Fraunhofer Forum Berlin, Germany	**10th Eu**ropean expert **Wo**rkshop on **Rel**iability of electronics and smart systems
ESREF	Du 26-sept.-22 Au 29-sept.22	Berlin, Germany	**33e éd. Symposium ESREF** = European Symposium on Reliability of Electron Devices, Failure Physics and Analysis
IMdR	Du 10-oct.-22 Au 13-oct.-22	EDF Lab Paris-Saclay , France	**23e éd. du congrès λμ (Lambda Mu)** « Innovations et maîtrise des risques pour un avenir durable »

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Regroupement d'experts de la fiabilité des systèmes et des composants électroniques

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Les Rendez-Vous Fiabilité du CFF

CFF

Sujet :	**L'impact des radiations sur les composants électroniques**

Date :	Mardi 10 mai 2022
Horaires :	13h00 - 14h00 | Durée : 60 min
Intervenants :	Marc MARIN — Airbus Defense & Space — (spatial) Jean-Claude LAPERCHE — Airbus Aircraft — (aéronautique) Arnaud CHAPON — ATRON Metrology — (essais)
Ordre du jour :	Quel type de radiations ? Rappel sur les notions de base Quelle influence des radiations sur les composants électroniques ? • Secteur Spatial • Secteur Aérospatial Comment évaluer les défaillances ? • Moyens d'essais et de mesures.

Intro	5'
Basics + Spatial	10' + 5' Q/R
Aeronautics	10' + 5' Q/R
Test	10' + 5' Q/R
Q/R	10'

Les Rendez-Vous Fiabilité du CFF

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AIRBUS Amber

Influence des radiations sur les composants électroniques

Radiation

From device to system levels

DEFENCE AND SPACE
EEE Parts Engineering and Radiation Team

Marc MARIN
HO EEE Parts Engineering and Radiation

Les Rendez-Vous Fiabilité du CFF - 10 mai 2022

AIRBUS

The space natural radiation environment

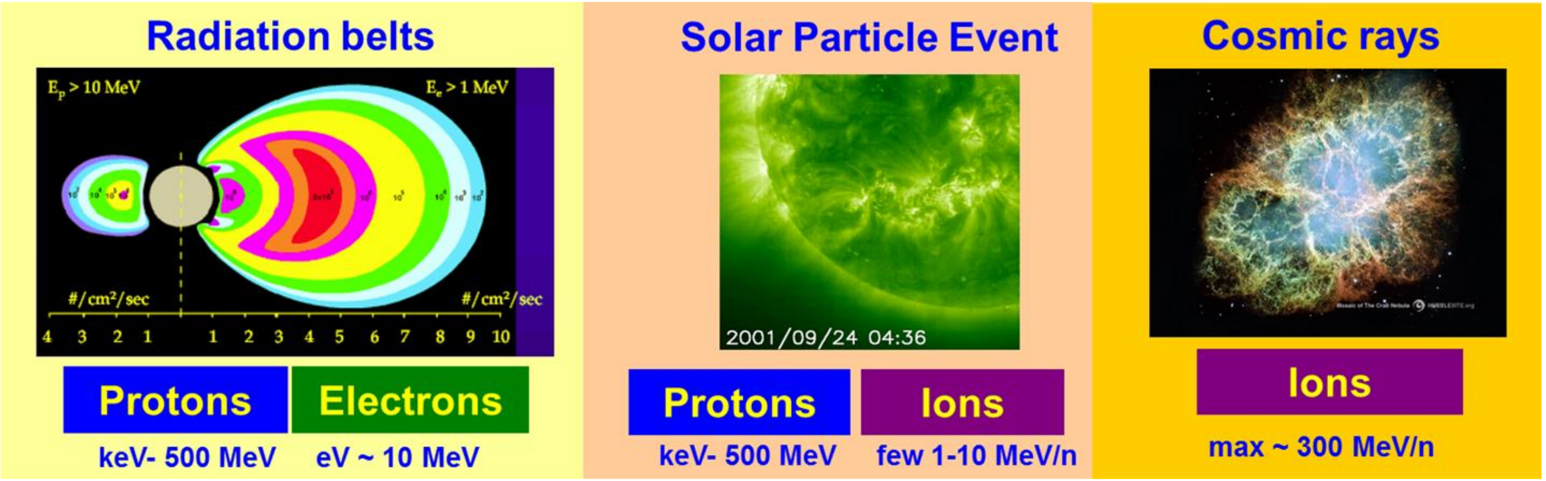
Radiation effects on electronic devices

Radiation Hardness Assurance (RHA)

Space radiation environment – 1/3

"There is no space system in which radiation effects can be neglected"

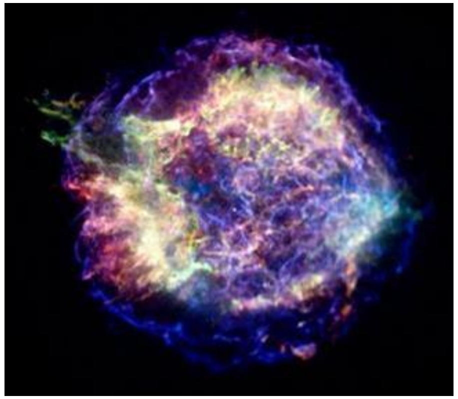
Underestimation of radiation induced degradation may endanger any space mission
Starting point : identification of the radiation environment, regarding to system and mission
Natural space environment is not radiation free



+ UV (for external materials)

Space system "designers" have to take it into account for radiation related risk analysis

Space radiation environment – 2/3



Galactic Cosmic Rays (GCR)

Coming either from Galactic and Extra Galactic origins

Composition: mostly protons, alpha and heavy ions (1%)

Energy up to 100 MeV/n ⇒ Very little effect of shielding

Relatively low Flux

Solar Particle Events (SPE)

Coming from the Sun

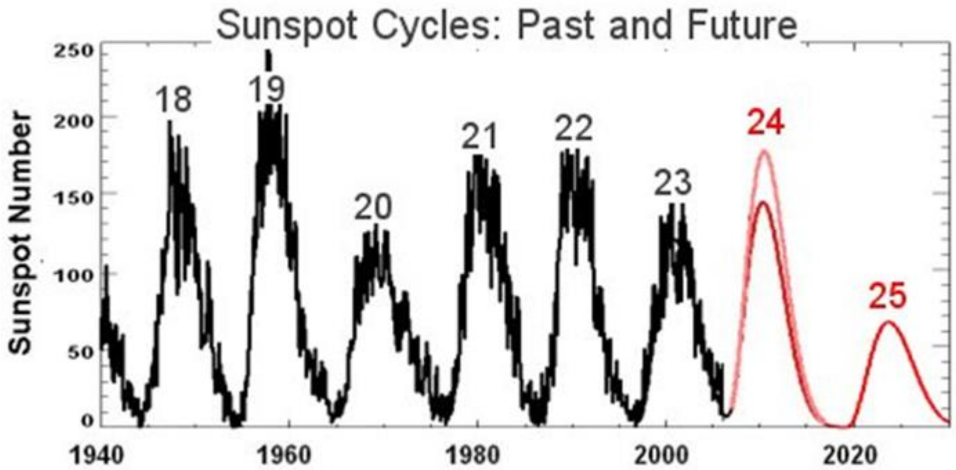
Composition

- Mainly Protons, Some Heavy Ions

Max intensity when solar max activity

- Solar max activity (7 years)
- Solar min activity (4 years)

Intense burst of a few hours to a few days



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Space radiation environment – 3/3

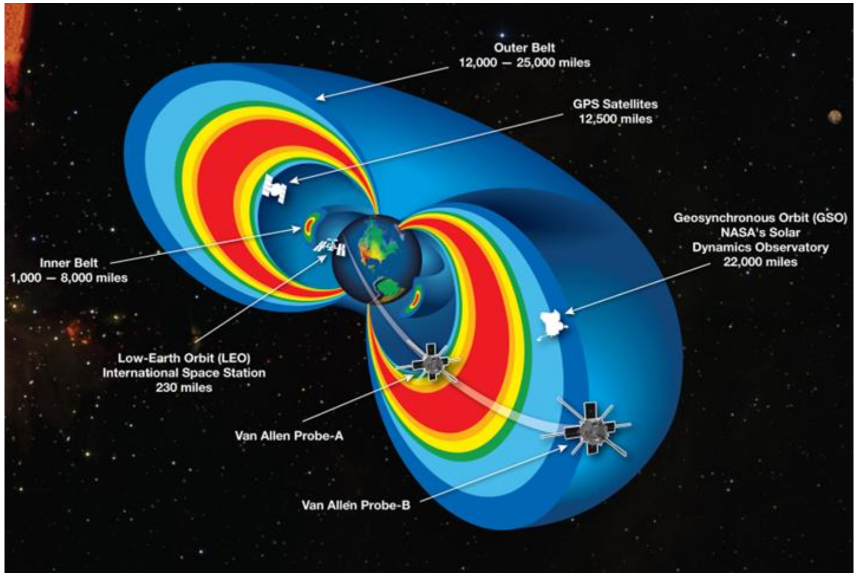
Particles trapped around the Earth radiation belts (Van Allen)

Composition

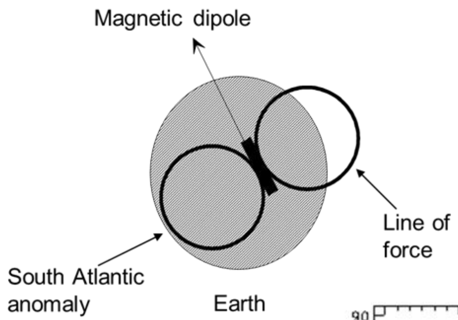
Protons (10 keV to 500 MeV), 1 max region

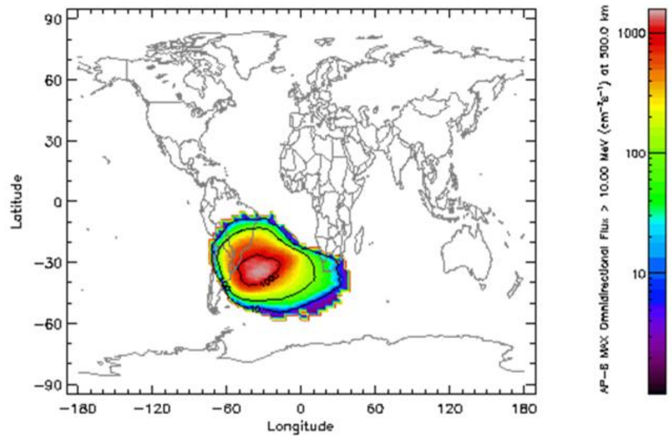
Electrons (< 5 keV to about 7 MeV), 2 max regions (inner and outer belts)

Fluxes intensity dependent of altitude and inclination



South Atlantic Anomaly (LEO, protons)





All this described in the radiation environment specification applicable to the program

The space natural radiation environment

Radiation effects on electronic devices

Radiation Hardness Assurance (RHA)

Radiation effects on electronics

Cumulative Effects

✓ Total Ionizing Dose (TID)

Effects: due to ionizing environment (electrons, protons), charges accumulate in device oxides and induce parametric drifts at EEE level.

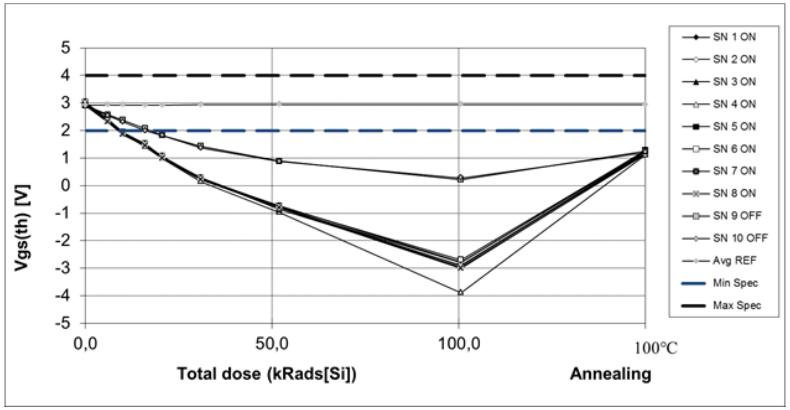
Affects all active EEE (diodes, transistors, ICs), also applies to some materials

✓ Total Non Ionizing Dose (TNID) or Displacement Damage (DD)

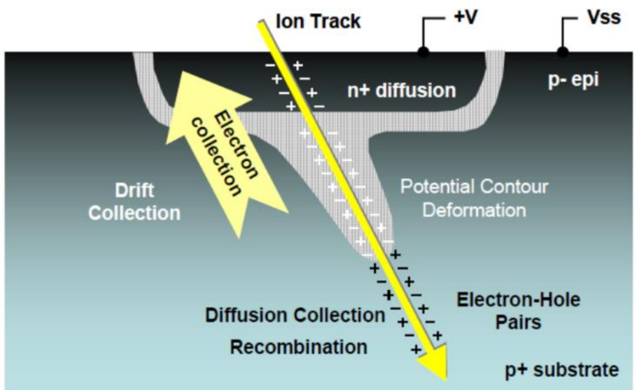
Modification of the lattice crystalline structure of semi-conductor devices, then device damages

Consequences in Optoelectronics, Detectors, and Bipolar Devices

Alteration of the electrical characteristics of electronic devices



Electrical parameter drift vs received TID



Heavy ion impact through PN junction

Instantaneous Effects

✓ Single Event Effects (SEL)

Very sudden ionization (<< 1 s) of the semiconductor bulk along particle track

- Transient current in the semiconductor bulk

SEE occurs randomly during the mission, stochastic nature

Destructive events

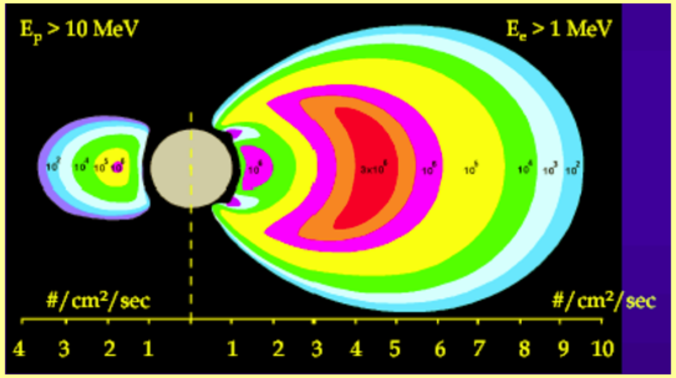
- SEL (Latchup) → CMOS and BiCMOS
- SEB (Burnout) → Power MOSFETs
- SEGR (Gate Rupture) → Power MOSFETs
- SEDR (Dielectric Rupture) → FPGA and Linear ICs

Non-destructive events

- SEU (Upset) → Memories and latches
- SET (Transient) → Analog and Mixed signal ICs, Photonics
- SHE (Hard Error) → Memories and latches
- SEFI (Functional Interrupt) → State/control sections of complex devices

Radiation effects on electronics w.r.t. space radiation environment

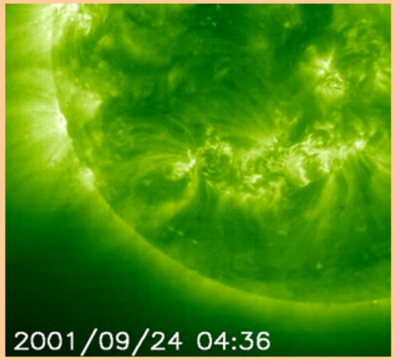
Radiation belts



Protons — keV- 500 MeV

Electrons — eV ~ 10 MeV

Solar Particle Event



Protons — keV- 500 MeV

Ions — few 1-10 MeV/n

Cosmic rays

Ions — max ~ 300 MeV/n

Total Ionising Dose (TID)

Displacement Damage (DD)

Single Event Effects (SEE)

The space natural radiation environment

Radiation effects on electronic devices

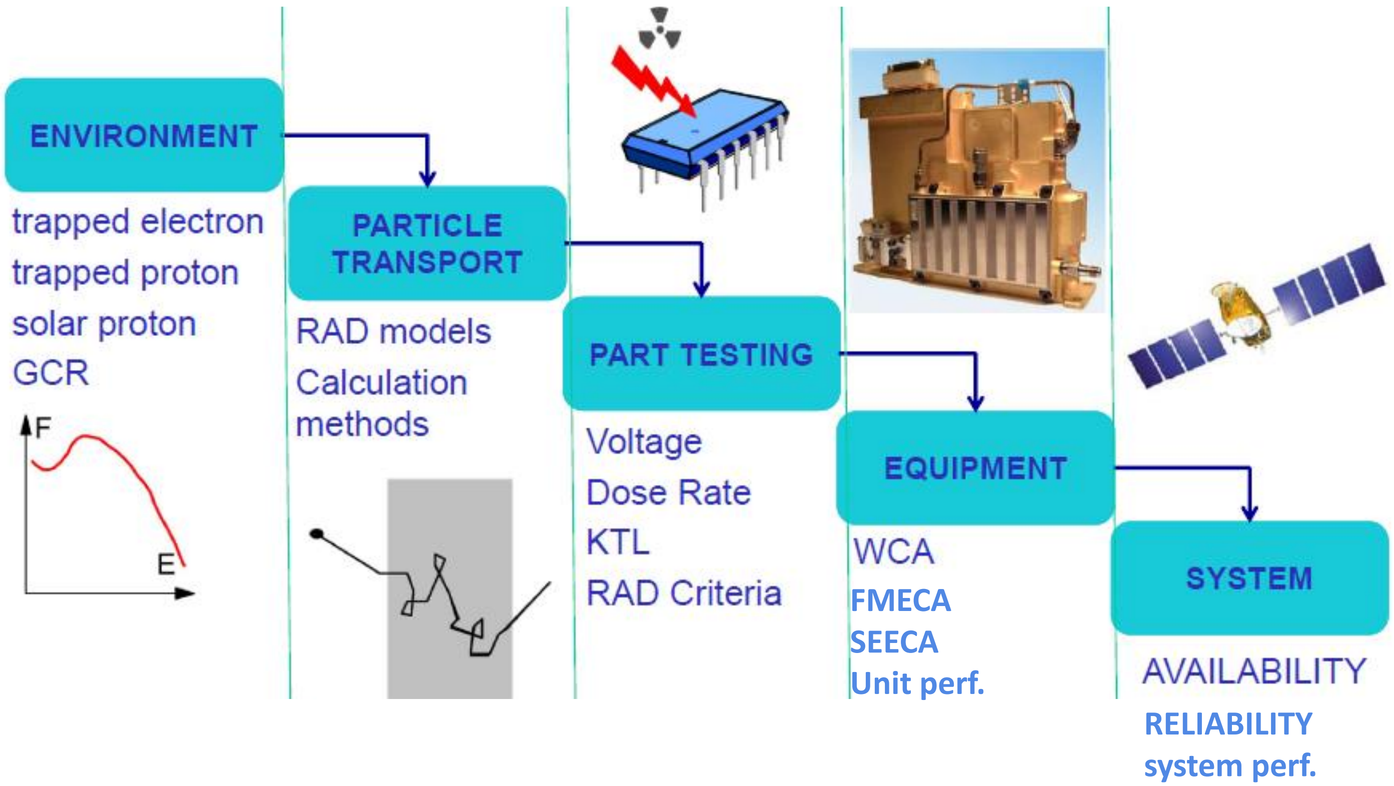
Radiation Hardness Assurance (RHA)

Radiation Hardness Assurance (RHA) – Basics

All activities to be considered to insure that all the radiation sensitive devices of a space system will meet their design specifications up to the end of a space mission

Dealing with

- Environment definition
- Devices selection and approval
- Devices testing methodologies
- Spacecraft Layout
- Design tolerance
- Mission/system and subsystems requirements



It goes well beyond EEE part level

Radiation Hardness Assurance (RHA) – TID / DD

Radiation Design Margin (RDM) defined as being the ratio between TIDS (TNIDS) and TIDL (TNIDL)

TIDL (TNIDL) and TIDS (TNIDS) shall be validated through compliance to requirements applicable in RHA specification

TIDL (TNIDL) : validation of calculation methodology, radiation tool, etc…

TIDS (TNIDL) : validation of radiation test data and test methodology (e.g. ELDRS), applicability of these data to used devices (traceability), etc…

Airbus DS method is the so called "categorization" method:

Airbus DS standard RDM policy:

- **RDM(low) < 1.2 device rejected**
- **1,2 ≤ RDM < 2 RADLAT required**
- **RDM(high) > 2 no RADLAT required**

TID and TNID RDM shall both be considered in case device is sensitive to both effect

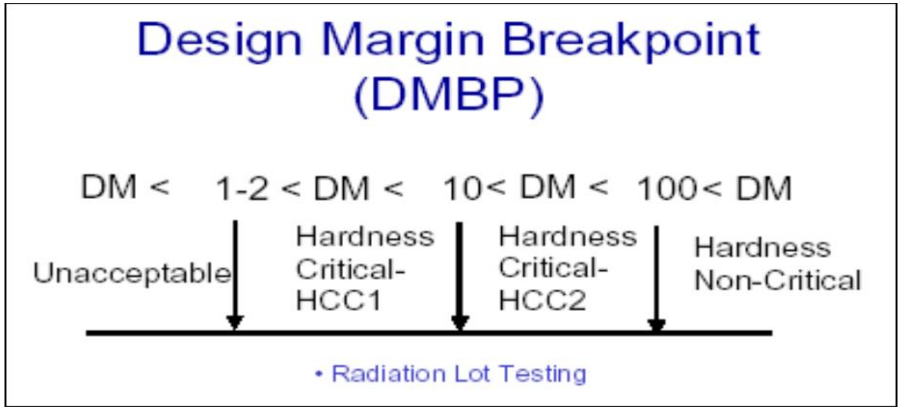
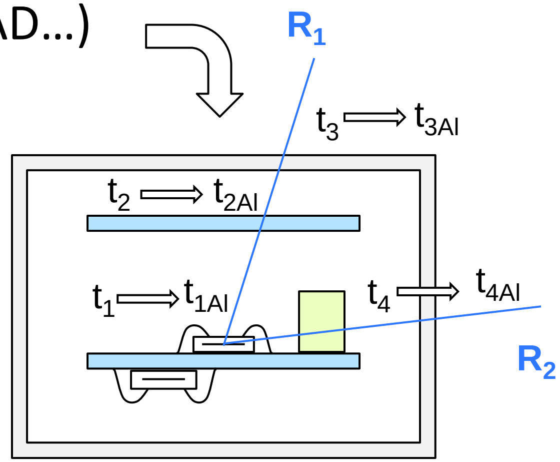


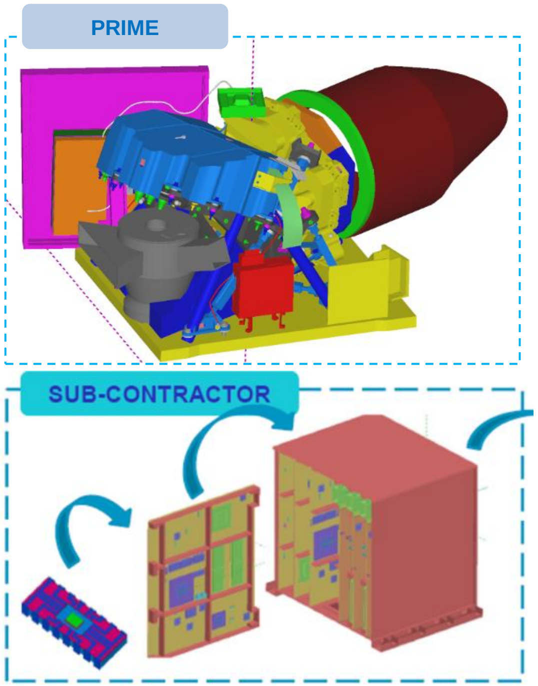
Figure : "categorization" method by AIRBUS DEFENCE AND SPACE

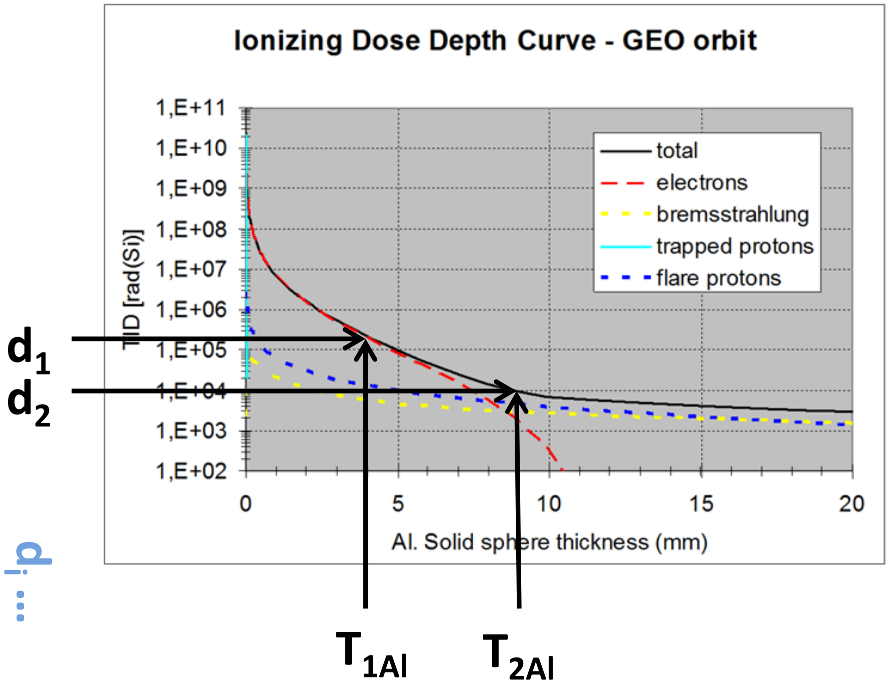
Total Ionising (Non Ionising) Dose calculation methods

Robustness of a device/subsystem/system evidenced thanks to comparison between expected in flight level and TID tolerable by the concerned device

- Expected in flight level shall be calculated
  - By Ray Tracing technique (NOVICE, FASTRAD, SYSTEMA/DOSRAD…) fast however limited accuracy
  - By Reverse Monte Carlo technique (NOVICE, GRAS…) complex, slower, but very accurate.







$R_1 \Longrightarrow T_{1Al} = t_{1Al} + t_{2Al} + t_{3Al}$

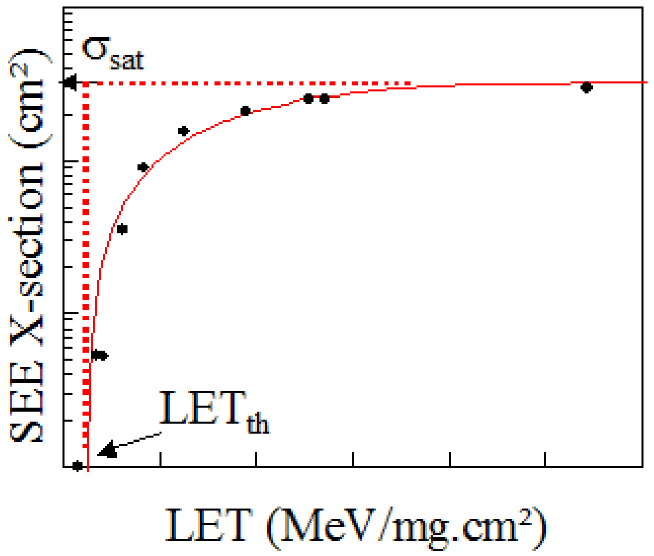
$R_2 \Longrightarrow T_{2Al} = t_{1Al} + t_{4Al} + t_{3Al}$

R_i …

d_i … $D = \Sigma\, d_i$

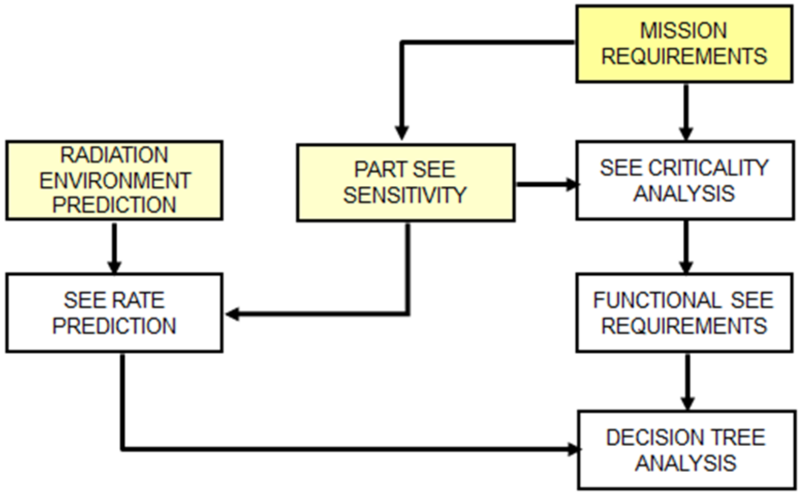
Radiation Hardness Assurance (RHA) – SEE

At EEE level, Airbus DS methodology relies on device SEE categorization



SEE LET threshold in MeV.cm²/mg	Analysis Requirement
> 60	SEE risk negligible, no further analysis needed
15 <LET_{th}<60	SEE risk, heavy ion induced SEE rates to be analyzed
LET_{th} < 15	SEE risk high, heavy ion and proton induced SEE rates to be analyzed

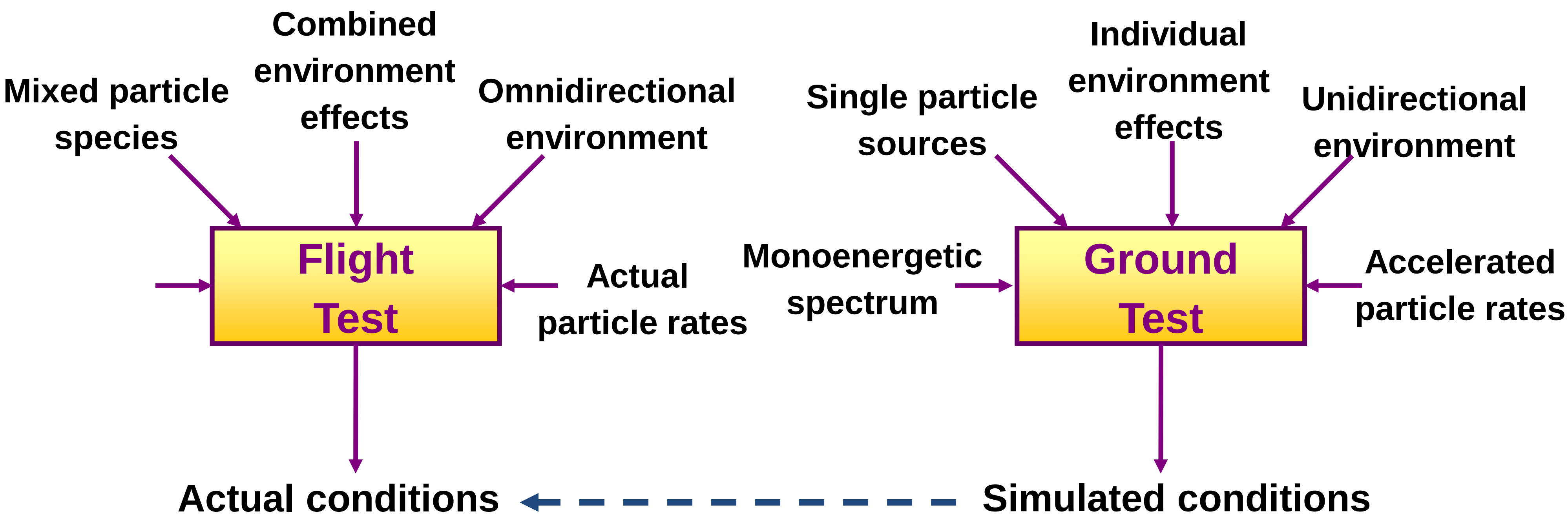
RHA process for SEE is based on the consideration of acceptable risks and rates and therefore involving equipment/system level considerations



Radiation Testing

To forecast the behaviour of devices for a specific mission

- Testing should mimic or bound the flight usage
- To deduce the impact on equipment and/or system performances for this mission
- To enlarge the knowledge to other missions in order to get a database usable for all projects.



Thank you

Marc MARIN
HO EEE Parts Engineering and Radiation

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AIRBUS Amber

Influence des radiations sur les composants électroniques

Impact sur les systèmes aéronautiques

Jean-Claude LAPERCHE

1 Cosmic Radiation Avionics environment (1/2)

GALACTIC COSMIC RAYS(GCR)
83% protons,16% alpha particles, < 2% heavy ions

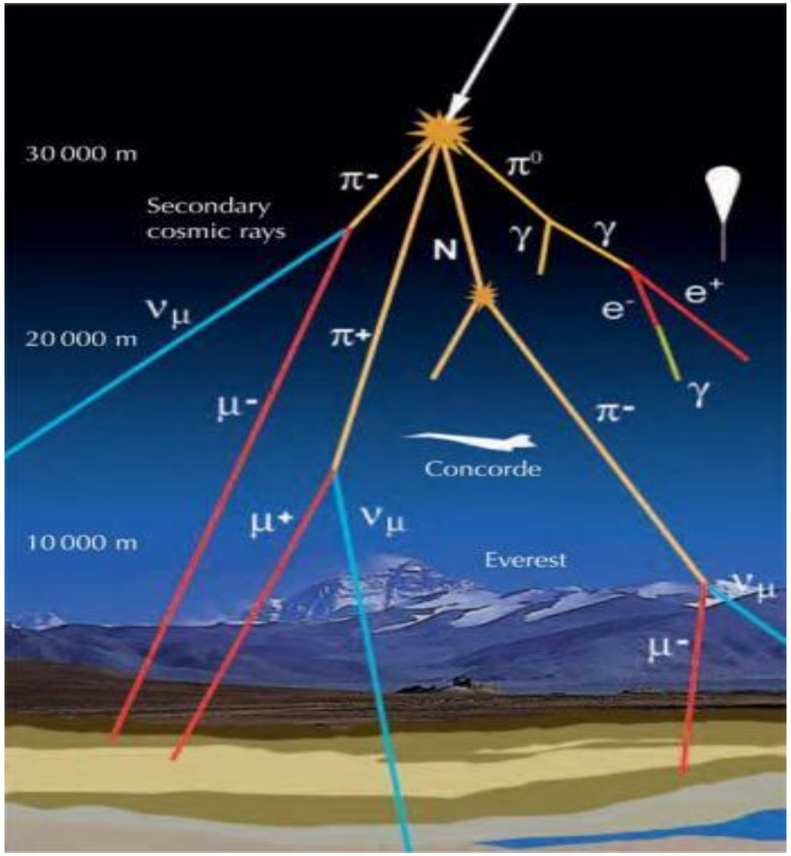
Interaction with the atoms in the atmosphere (Nitrogen and Oxygen)

SECONDARY PARTICLES
Neutrons, protons, pions, muons

Flux Aircraft altitude
10 particles/cm^2/sec

Flux Sea level
< 0.1 particle/cm^2/sec

Attenuation factor around 300 to 400 between aircraft altitude and sea level



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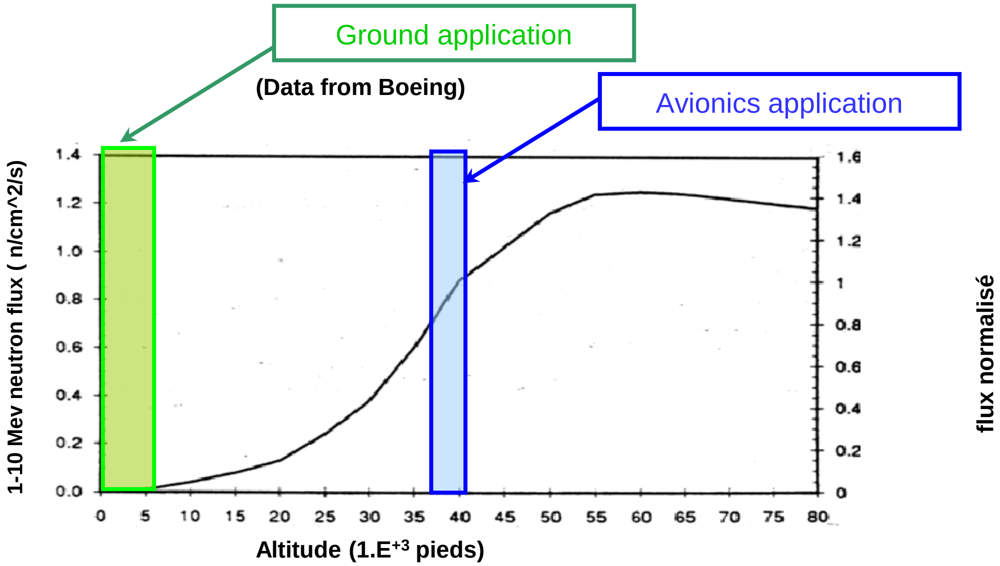
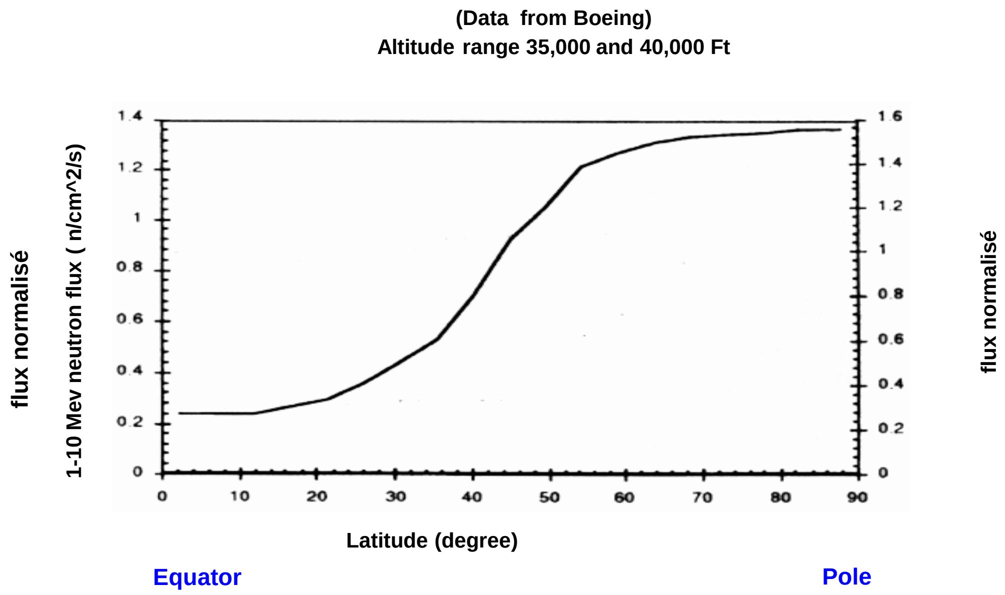
1 Cosmic Radiation Avionics environment (2/2)

- Neutrons are not uniformly distributed in the atmosphere.
- The neutron flow is strongly dependent of **ALTITUDE and of LATITUDE** (effects of the terrestrial magnetic field filter)





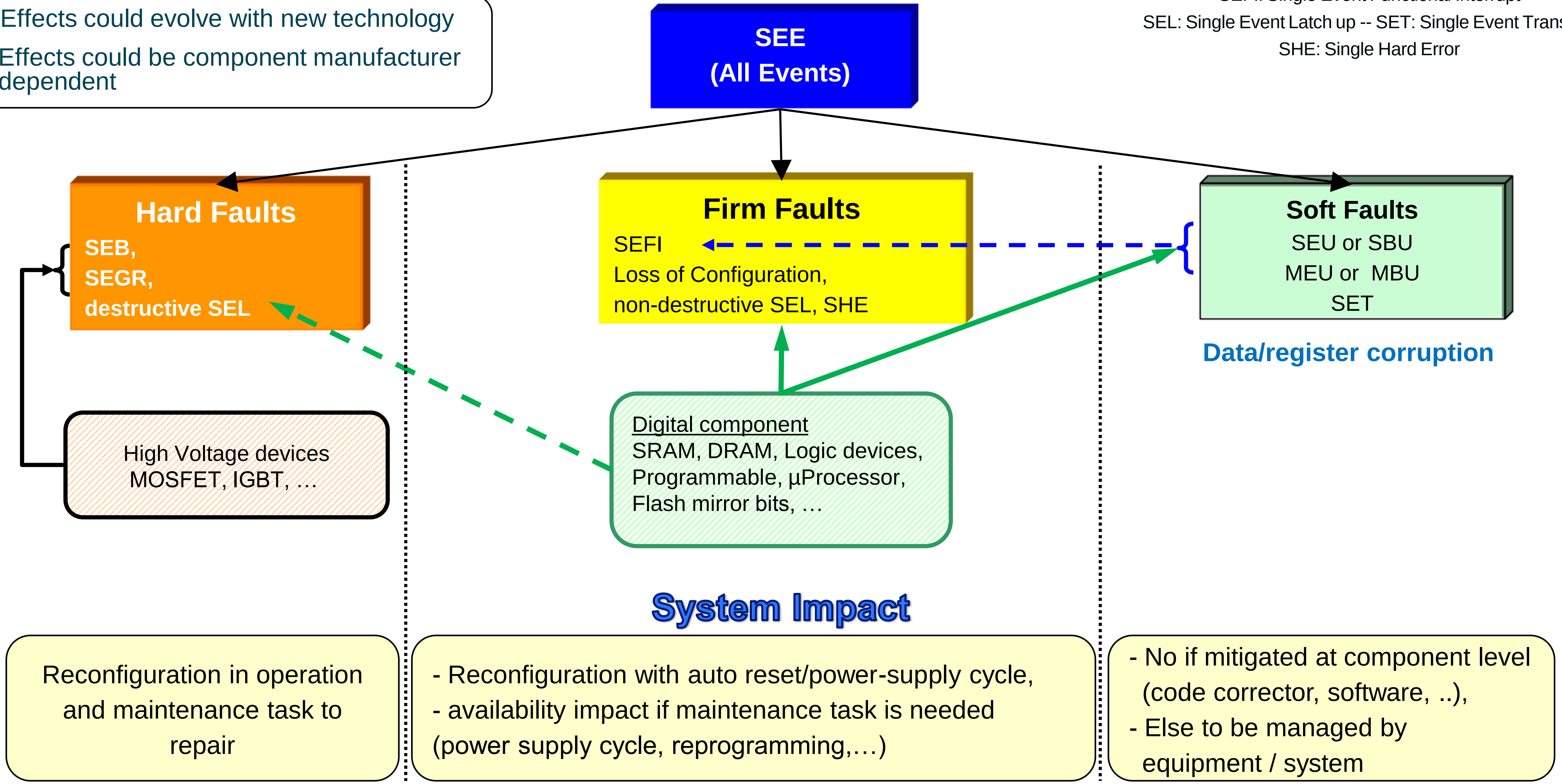
- The neutron flow for Avionics application is considered at: **8600 neutrons/cm^2/FH by AIRBUS**

Note: in IEC62396 neutron flow is 6000 n/cm^2/FH and 9200 for techno <150nm

2 Single Event Effect / System impact

SEU/MEU: Single/ Multiple Event Upset
SBU/MBU: Single/Multiple Bit Upset in the same word
SEB: Single Event Burn Out --- SEGR: Single Event gate Rupture
SEFI: Single Event Functional Interrupt
SEL: Single Event Latch up -- SET: Single Event Transient
SHE: Single Hard Error

⚠ Effects could evolve with new technology
Effects could be component manufacturer dependent



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3 SEE management objective

=

Failures

Designed to comply with

Safety
and Operational Reliability
Objectives

Mitigated with

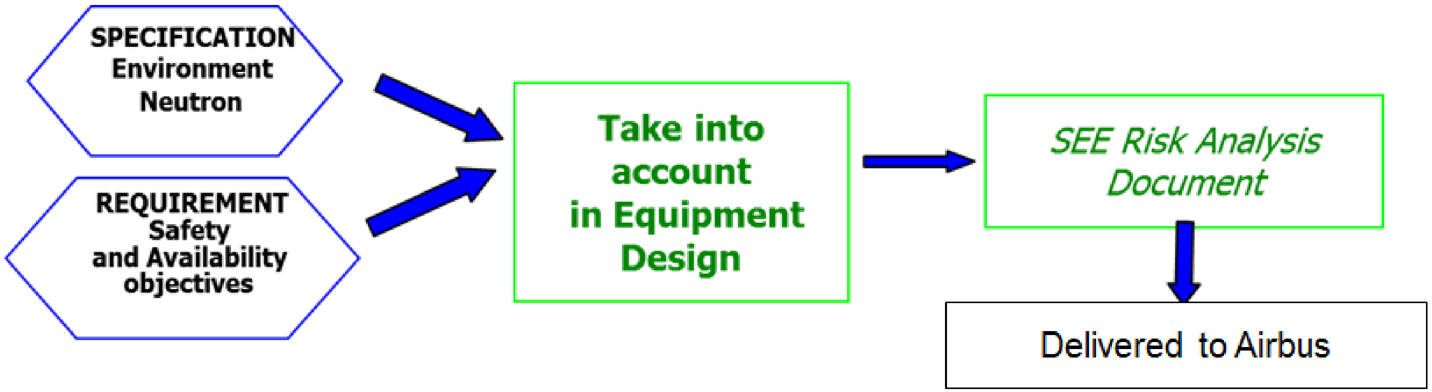
Command/monitor equipment,
Redundancies,
Triplex, dual architectures,
Backup systems,…

SEE Management Objective ➔ No system architecture modification

➔ SEE have to be mainly mitigated at equipment level

4 Requirements to Suppliers

- **Requirement for electronic equipment**:
  - ✓ SEE shall not affect equipment SAFETY requirements,
  - ✓ SEE consequence shall not impact the equipment MTBF,
  - ✓ SEE should not induce equipment removal and affect MTBUR , NFF, operational reliability,
  - ✓ SEE should not induce cockpit effect.
- **Suppliers have to provide a SEE risk analysis** (from DAL A to E) **:**



DAL: Design Assurance Level - MTBF: Mean Time Between Failure - MTBUR: Mean Time Between Unscheduled Removal - NFF: No Fault Found

5 SEE risk analysis

IEC/TS62396

Suppliers ← | → System designer

For all sensitive components of all boards of equipment,
- type of effects (SEU, SEFI, SEL, …), cross-section,
- affected functions

Quantitative analysis. For each function/sensitive components,
- "Worst cases" SEE rates

For 1Mbyte of SDRAM 210nm: 10^7 x 6.10^{-16}cross section(cm²/bit) x 8600 Flow (Neutron/cm²/FH) = 5.10^{-5} /FH → 1 SEE every 20.000FH

- Mitigation means description and performance (usage ratio, auto-correction,…)
- Remaining SEE rates with associated effects on function/board

SEE summary to demonstrate compliance with
- Safety requirements,
- Operational Reliability requirements & cockpit effects

Note: SEE events are considered independent

Results → OK

Results → KO

→ Equipment design modification

→ Or to be assessed on SSA (System Safety Analysis) with potential additional monitoring by A/C application (data confirmation, …).

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6 Conclusion & way forward

- SEE confirmed by in **service experience feedback**,
- SEE shall be **mainly mitigated at equipment level** with auto correction mechanisms if possible,
- SEE shall be analysed in case of **Equipment evolution** (use of new more sensitive component),
- Due to **technology evolution and component integration**, new digital electronic / power devices become **more and more sensitive** to cosmic radiations

  ➔ Sensitive component and appropriate mitigations have to be defined before development.

AIRBUS

Thank you

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Sûreté de Fonctionnement

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ATRON
METROLOGY

Effects of radiative environments on components

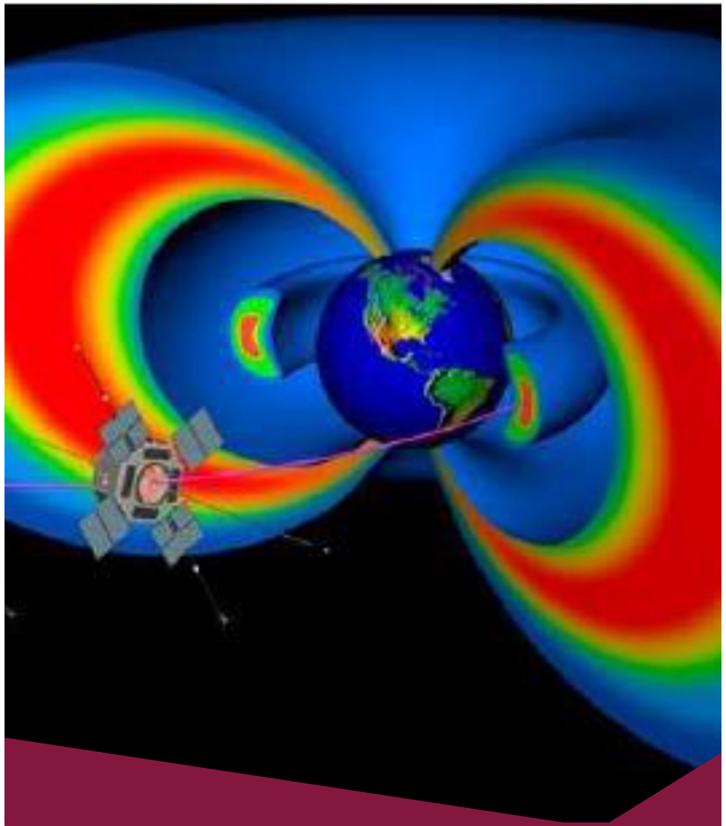
Effects of radiation on electronic devices and materials depends on:

- ✓ Type of radiation (photon, electron, proton, etc.)
- ✓ Rate of interaction
- ✓ Type of material (Silicon, GaAs)
- ✓ Component characteristics (process, structure, etc.)

CONSEQUENCES

- ✓ Single Events Effects (SEE)
- ✓ Displacement Damages (DD or TNID)
- ✓ Total Ionizing Dose (TID)

RADIATION EXECUTIVE TESTS



Electrons and protons trapped in

Earth magnetic field

(Lorentz force)

Single Events Effects

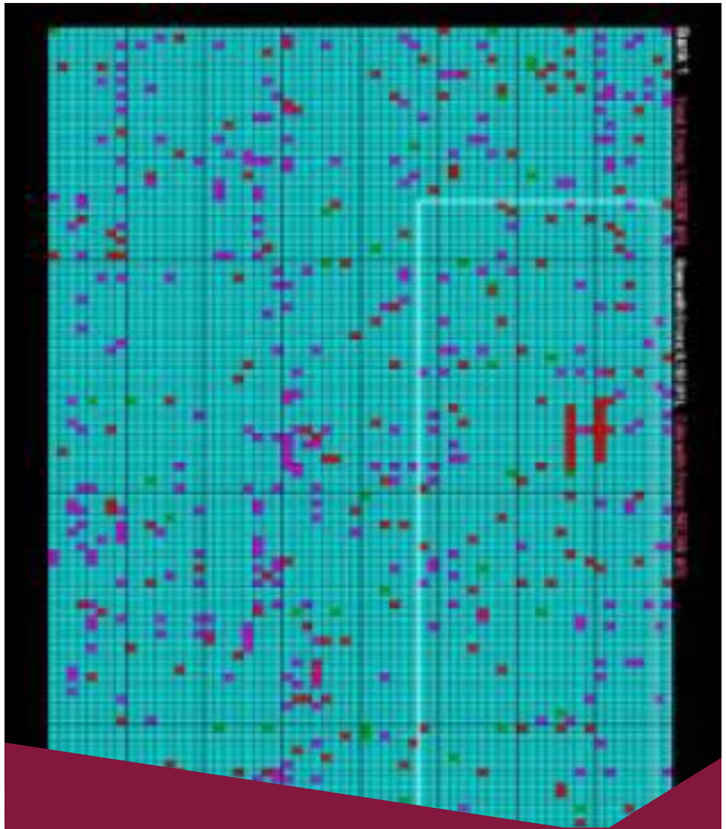
- ✓ SEEs are Random Events:
  1. Charge generation (direct orindirect ionization)
  2. Charge Collection and Recombination
  3. Circuit Response

- ✓ Many types of SEEs: SET, SEU, MCU, SEFI, ISB, SEL, SEB, SEGR/SEDR, etc.

- ✓ Single Events Effects (SEE) → LET ($MeV.cm^2/mg$)
  - ✓ Heavy ions

Ion	Total Energy (MeV)	LET ($MeV.cm^2/mg$)	Range in Si (µm)
^{84}Kr	1260	28.2	170
^{129}Xe	1935	52.1	156
^{165}Ho	2475	69.8	112

15MeV beams

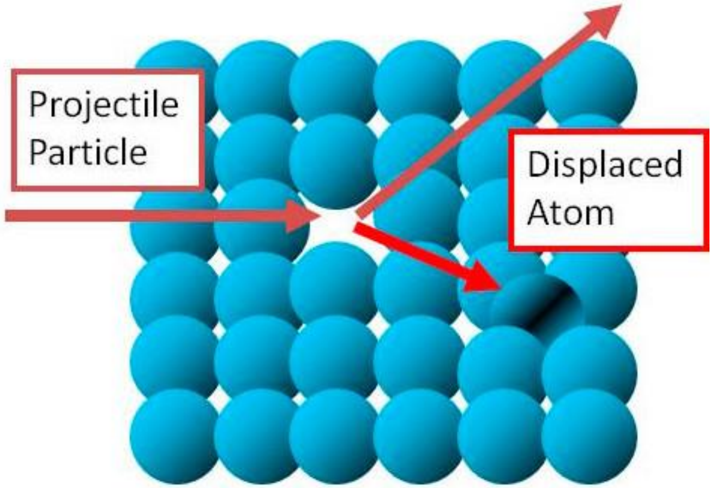


A SEE with a low probability of occurrence can occur the first day of a mission

Displacement Damages

- ✓ Sensor degradation is a significant constraint for payloads and star trackers (CCDs)
  - ✓ Increase of dark current (overall)
  - ✓ Hot pixels (→ reduction at low temperatures)
  - ✓ Charge Transfer Efficiency (CTE) degradation

- ✓ Displacement Damage (TNID) → NIEL ($MeV.cm^2/g$)
  - ✓ Protons (most often in 40-60 MeV range)
  - ✓ Flux generally in the range of 10^7 to 10^8 $p/cm^2/s$
  - ✓ Up to a fluence based on NIEL:
    - ✓ target material,
    - ✓ particle type and energy.



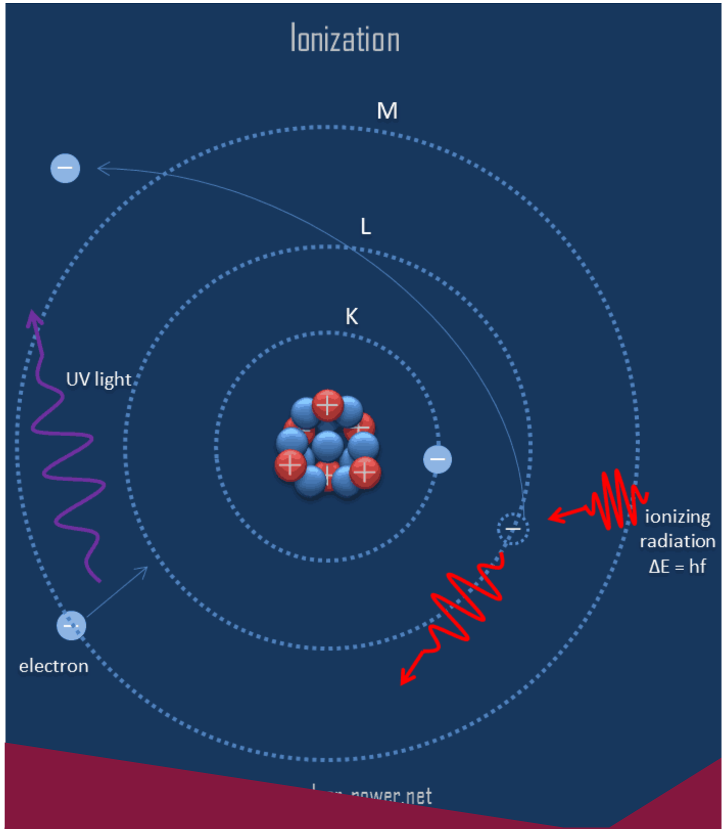
Frenkel pair after stable migration of vacancies and interstitials

Total Ionizing Dose

- ✓ Component degradation is very much dependent on a device technology, process and bias conditions

- ✓ TID is mainly a semiconductor oxide effect → $E_{EH}(SiO_2)$ = ~17 eV

- ✓ Total Ionizing Dose (TID) → D (Gy)
  - ✓ 60-Co Gamma rays, X-rays from ebeam
  - ✓ Dose rates significantly higher than the actual space dose rates



Excited electrons are freed from their bound state and create electron-hole pairs

ATRON, a technological platform at Cherbourg-en-Cotentin

FELIX: Faisceau d’Electrons et Ligne d’Irradiation X

- ✓ Calibration of radiation survey meters
- ✓ Treatment of materials
- ✓ Qualification of electronic devices for nuclear or space applications

CALIBRATION OF SURVEY METERS

- ✓ calibration without radioactive source
- ✓ 3000 devices per year
- ✓ High metrological requirements
- ✓ COFRAC accreditation n° 2-6778 (ISO 17025)

Since 2018

2 PhDs

Turnover: 0,5 M€

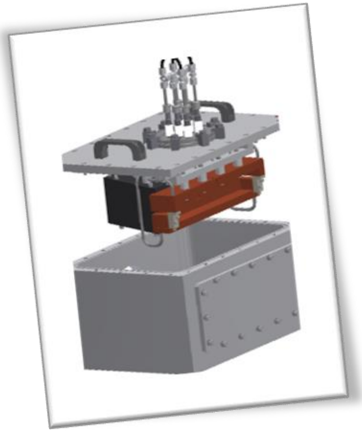
Electrons accelerator datasheet

ENERGY RANGE OF ELECTRONS

- From 0.2 to 3.5 MeV

ELECTRONS BEAM CURRENT

- From ~1 pA to 1 mA



X conversion target

E-BEAM

- Up to 6×10^{15} e^-/s
- Beam spot size ~1 mm²

X-RAYS

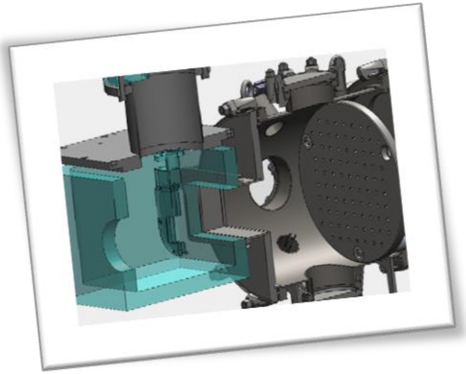
- From 10 µrad/h to 50 krad/h
  = 0.1 µGy/h – 500 Gy/h
- Volumes up to few m³
  (irradiation room size is 3×6 m²)

Electrostatic accelerator

Removable X-target

→ X-rays or ebeam

Irradiation chamber datasheet



internal cold plate

TEMPERATURE CONTROL

- From -200 °C to +300 °C

ATMOSPHERE CONTROL

- Under vacuum,
- In N_2, Ar, Air, etc.

VACUUM-TIGHT FEEDTHROUGHS

- Instrumentation during irradiation
- Window and camera available

EFFECTIVE SURFACE

- 300 mm in diameter for X-rays irradiations
- up to 40×220 mm² in e-beam

Simulation of extreme environmental conditions

Irradiation services

ATRON METROLOGY ADVANCE ENGINEERING SEFC FORMATION CERAP RADIOPROTECTION

TREATMENT OF MATERIAL BY IRRADIATION

- ✓ Innovation capabilities, scientific collaborations
- ✓ Extreme environmental conditions

ACCELERATED AGEING UNDER IRRADIATION

- ✓ Various applications in space or nuclear domains
- ✓ From coatings (ebeam) to full systems (X-rays)

INFORMATION SYSTEMS RELIABILITY

- ✓ TID effects on components and systems
- ✓ Continuity of service during equipment lifetime

Easy availability

Strong reactivity

Confidentiality culture

Example of applications

CARACTERISATION OF RADIATION DETECTORS

- ✓ 3.5 MeV X-rays at 50 krad/h (500 Gy/h) for 20 hours to reach a total dose of 1 Mrad (10 kGy)
- ✓ Dose detectors used in space missions

QUALIFICATION OF RF CABLES

- ✓ 240 keV ebeam scanned on a 16×16 cm^2 area for 10 hours at 80 nA/cm^2
- ✓ Qualification for space applications

RADNEXT CONTRIBUTOR (H2020 PROGRAM)

- ✓ WP7-JRA3: cumulative radiation effects on electronics:
  - ✓ Determination of ^{60}Co / X-ray comparison,
  - ✓ Provision of expertise for simulations (Geant4)

Representative spectrum

Wide ranges of energy

Temperature control

DEFENCE AND SPACE

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Le Centre Français de Fiabilité

Les Rendez-Vous Fiabilité du CFF

CFF

Avez-vous des questions complémentaires ?!

Sujet : **L'impact des radiations sur les composants électroniques**

Date :	Mardi 10 mai 2022
Horaires :	13h00 - 14h00 | Durée : 60 min
Intervenants :	Marc MARIN — Airbus Defense & Space — (spatial) Jean-Claude LAPERCHE — Airbus Aircraft — (aéronautique) Arnaud CHAPON — ATRON Métrology — (essais)
Ordre du jour :	Quel type de radiations ? Rappel sur les notions de base Quelle influence des radiations sur les composants électroniques ? • Secteur Spatial • Secteur Aérospatial Comment évaluer les défaillances ? • Moyens d'essais et de mesures.

Intro	5'
Basics + Spatial	10' + 5' Q/R
Aeronautics	10' + 5' Q/R
Test	10' + 5' Q/R
Q/R	10'

Centre Français Fiabilité

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Severine COUPE

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