Radiation effects

in aircraft equipment

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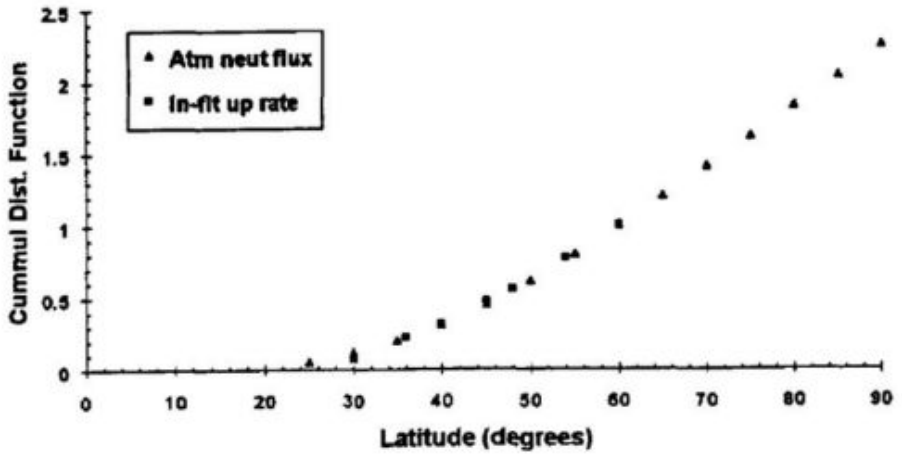
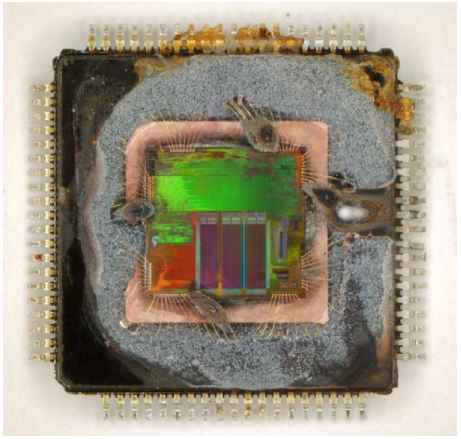
Flight Experience of SEE

Impact of SEE on safety & availability

- The first dysfunctions at aircraft altitudes were registered by E. Normand (1992 / Boeing).
- More than one upset per flight in 280 64K SRAMs on Boeing E-3 AWACS and NASA ER-2.
- Autopilot design altered after faults (every 200 flight hours) shown to correlate with altitude and latitude.

Normand & Baker (1993) observed correlation between SEU rates and neutron flux (latitude)





SEL in microcontroller

Outline

1. Standards
2. Atmospheric environment
3. Radiation testing
4. Summary & needs

Standardization

Strong cooperation on SEE standards in avionics

Standardization Work :

IEC TC107 “Process Management for Avionics”

- Elaborated by Aerospace Industry (AIRBUS, BOEING, GOODRICH, HONEYWELL, SMITHS, GE, THALES, SAFRAN, ...)
- EASA & ABD-100 (Airbus Directives) recommendations based on IEC standard

IEC 62396-1

Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment

Part 2 SEE testing	**Part 3** System optimization
Part 4 Power	**Part 5** Thermal Neutrons
Part 6 Extreme space weather	**Part 7** Design process
Part 8 Low energies particles	

Requirements

Airbus suppliers must provide a SEE risk analysis document

- At equipment level, SEE shall not affect SAFETY requirements or affect MTBUR [Mean Time Between Unscheduled Removal]

SEE risk analysis document

List of sensitive components (X-section) and affected functions	List of worst case SEE impact and mitigation means (Hardware, Software)	Quantification to demonstrate compliance with safety and availability requirements

- Systems are classified by the failure effects of the functions they implement

Functional failure condition classification (AC 23.1309-1C, AC 25.1309-1A and ARP4754)	System development assurance level (ARP4754)
Catastrophic	Level A
Severe major/hazardous	Level B
Major	Level C
Minor	Level D
No effect	Level E

Radiation effects in aircraft equipment, G-RAD(NEXT) 2022.

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Atmospheric Environment

Neutrons are communally considered as the main concern

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

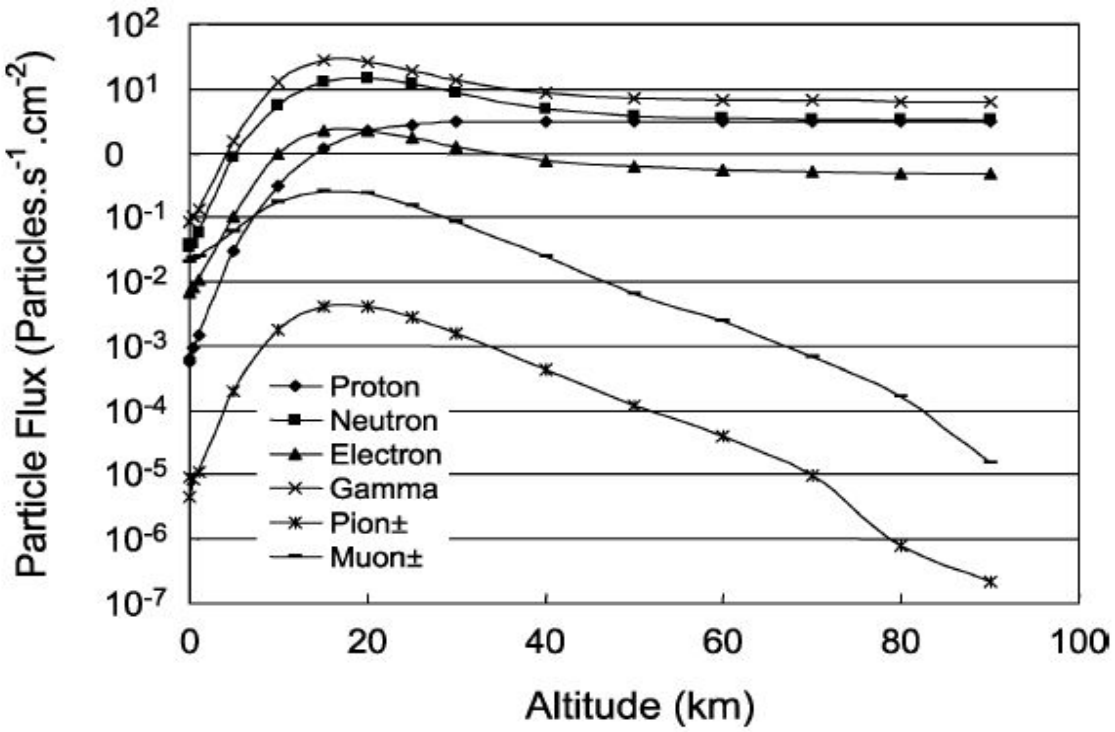
\+

ATMOSPHERE
Nitrogen, Oxygen

=

SECONDARY PARTICLES
<u>Neutrons</u>
Protons, Pions, Muons

Above 18 km (60 000 feets),
heavy ions can not be neglected.



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Atmospheric Environment

Variations of neutron flux with altitude & latitude

A chip in an aircraft may be struck by a neutron every few seconds.

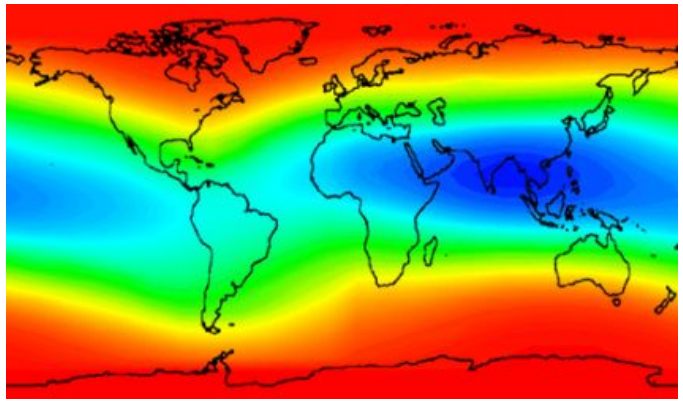
Flux at 12 km & 45° of latitude (standards)

8600 n/cm²/h (Airbus ABD) for E>1 MeV

6000 n/cm²/h (IEC) for E>10 MeV

Conservative values

Increase 300X



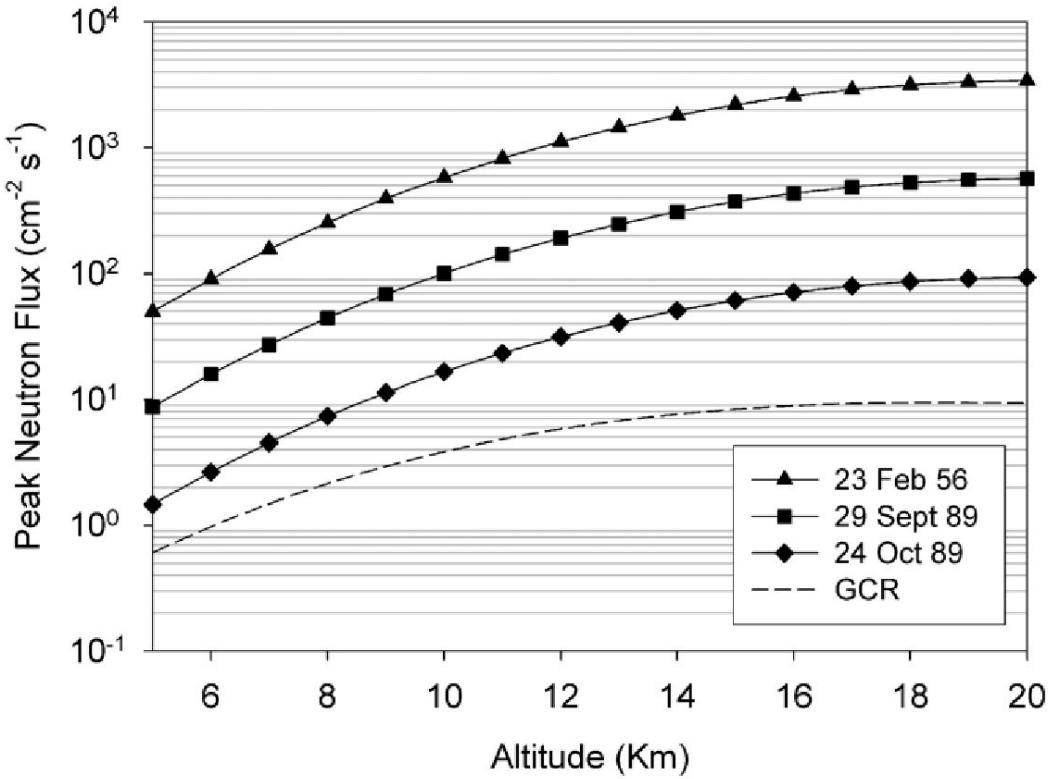
Flux at Sea Level

~20 n/cm²/h for E>1 MeV

Extreme Space Weather

Many solar storms, a few are severe

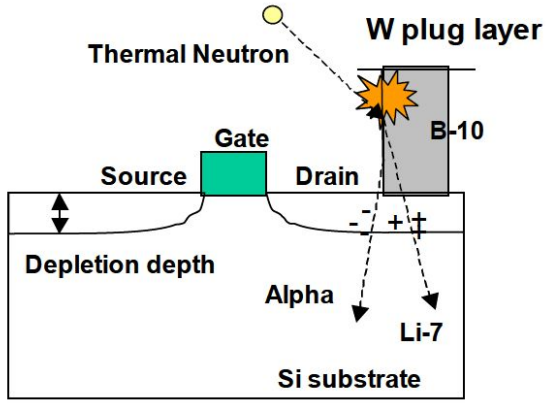
- Relative low modulation with solar cycle
- Some solar particle events, called Ground Level Enhancements (GLE), can exceptionally enhance by a large factor the neutron flux received on-board aeroplane.
- 100X increase in the neutron flux for the solar flare on February 23, 1956.

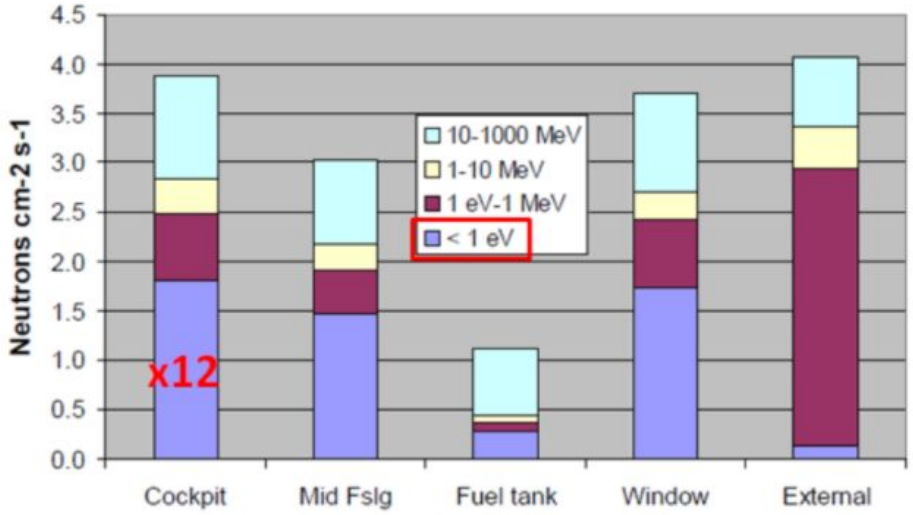


Thermal Neutrons

Margin to consider on soft error rate

- Neutrons < 1 eV
- Produced within aircraft through moderation of high-energy neutrons with fuel, passengers or hydrogeneous materials
- Thermal neutron interaction with Boron-10 may induce SEE





Inside aircraft (12km)	Thermal neutron contribution to SEU rate
90nm SRAM	3%
45nm BRAM	37%
28nm cache	60%

Based on IEC ratio 1.1

C. Dyer and F. Lei, "*Monte Carlo calculations of the influence on aircraft radiation environments of structures and solar particle events*," IEEE TNS 2001.
C. Weulersse *et al*, "*Contribution of thermal neutrons to soft error rate*," IEEE TNS 2018.

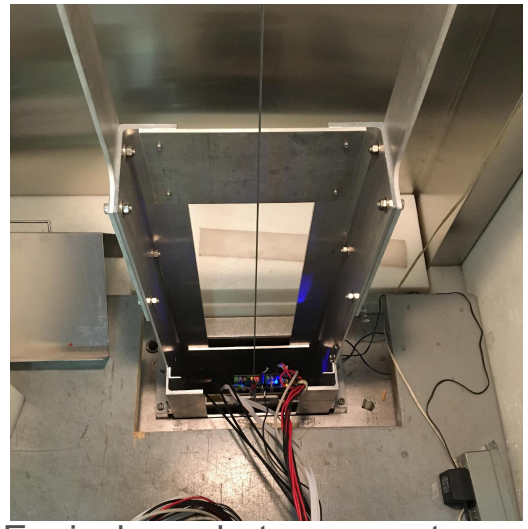
Radiation Testing

Neutron acceleration testing is the most adapted for terrestrial equipment testing

Cross-section Measurement

Real-Time Testing

Accelerated Neutron Testing



Equivalence between neutron and proton sensitivity for E>50 MeV

Laser testing

Validation of mitigation solutions, Latch-up screening, SOA of high voltage devices

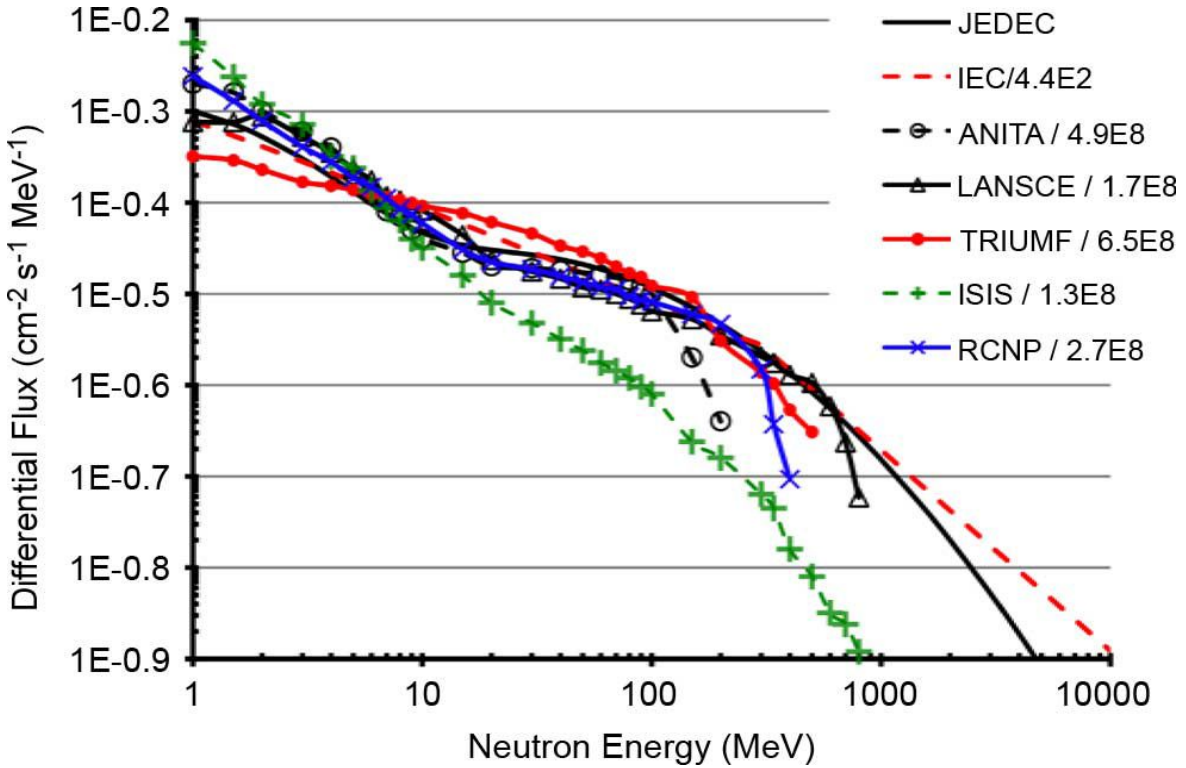
Neutron Testing

Spallation neutron sources are the most adapted for terrestrial equipment testing

- Closely mimic the atmospheric neutron spectrum

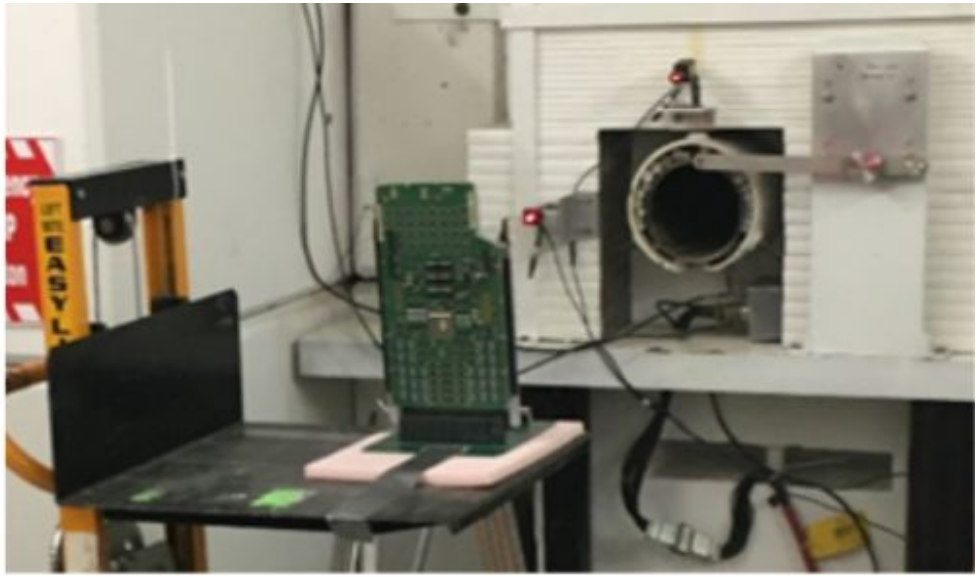
- At ChipIR / ISIS facility (UK),
  - 30 years of A350 mission profile
    - 3-minute testing
  - 1 FIT equivalent fluence
    - 300-hour testing!

- Difference in the spectra,
  may induce some variations on SEE rate



Neutron Testing

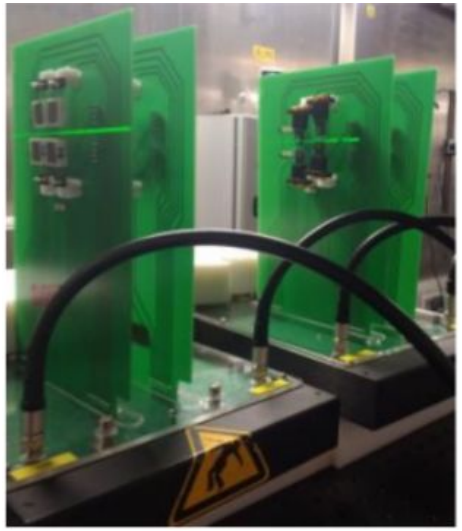
- Radiation tests are performed on complex parts (µP, µC…) from critical equipment
- Testing at TRIUMF at equipment level (flight control computer)

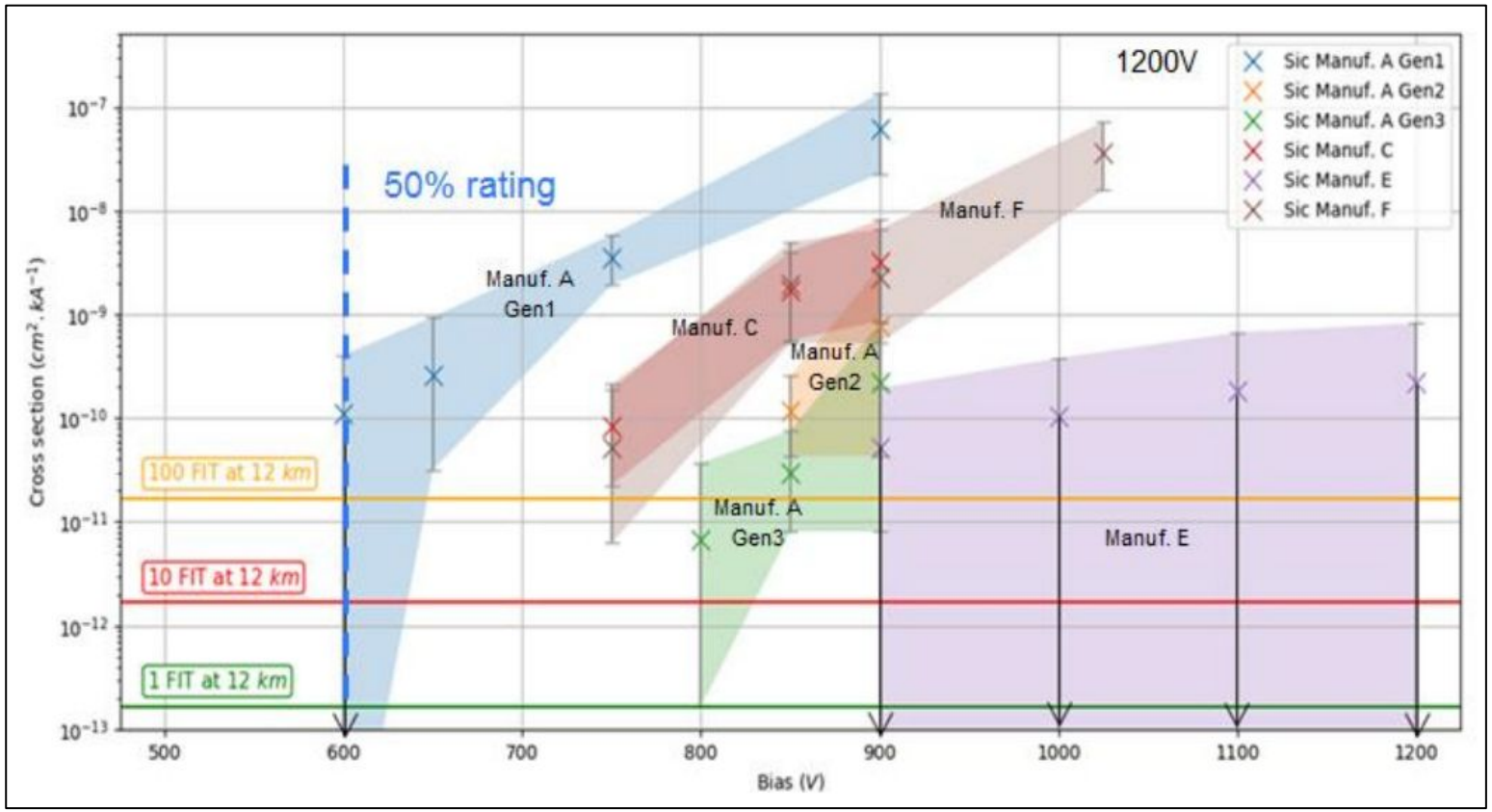


Thermal neutron enhancement PE box at TRIUMF

Neutron Testing

50% derating for power devices





Neutron cross sections given per kA for 1200 V SiC power MOSFETs obtained at ChipIR, ISIS

C. Weulersse et *al*, "*Neutron sensitivity of high voltage SiC devices for avionics applications*," RADECS 2020.

Summary

- The use of electronic components is increased in avionics and chips contain more and more functions (SEFI and SEL are the main challenges)
- Neutrons are the main cause of radiation effects on aircraft equipment (direct ionization of protons and muons effects can be included in the margin currently considered for the neutron flux; this may change if critical charge to induce SEE is continuously decreasing).
- High energy neutron testing using spallation neutron sources
- Testing of complex devices (µP, µC…) and testing at equipment level
- For thermal neutrons, we are currently analysing the risk (especially thermal neutron environment onboard aircraft, partnership with ILL)

Needs of radiation testing for Avionics

- Need to vary neutron flux and spot size
- Interest to have an accurate characterization of thermal neutrons for the spallation neutron sources
- Interest to have a solution to test at high or low temperatures, especially for power devices

Thank you

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