Calculation of the effects of the cosmic-ray induced neutrons at different altitudes on highly integrated microeletonics

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Introduction

Great effort is required to understand the accumulate dose of neutrons as function of altitude in the South Atlantic Anomaly (SAA)

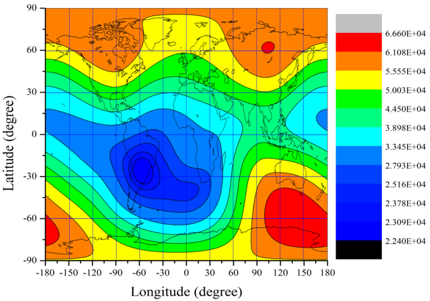
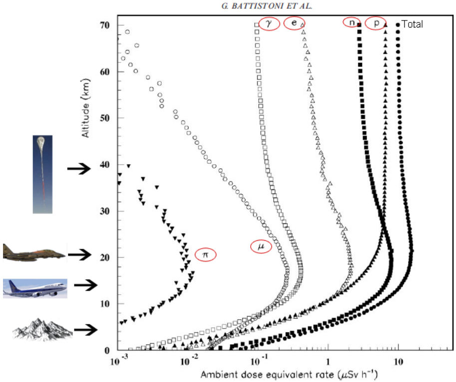


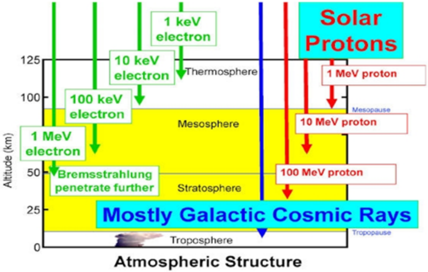
Figure: Earth's magnetic field map at 12 km altitude.

Neutrons are an important particle in dose levels received by aircraft crews and sensitive equipment;

Introduction

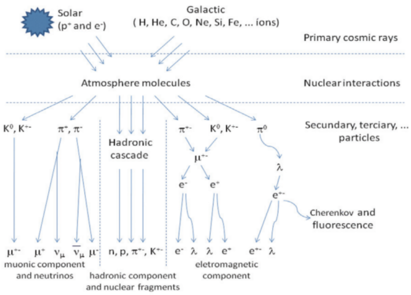


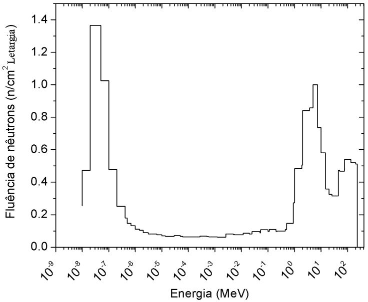
(a) Calculated ambient dose equivalent rate produced by cosmic rays along the shower development in the atmosphere.



Introduction

- The interaction of primary cosmic rays with atmospheric atoms produces neutrons with high energy;
- Secondary neutrons produced with high energy are moderated by the atmosphere;
- The result is a wide neutron spectrum of energy.

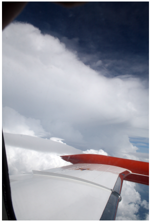




(b) Neutron spectrum measured at 2400m, RJ-Brazil. (Federico, C.A. Rad. Measurements, 2010)

Introduction

- The Institute for Advanced Studies is doing dosimetric studies of the Brazilian airspace.

- Multi-institutional collaboration.

Introduction

ATSB Transport Safety Report

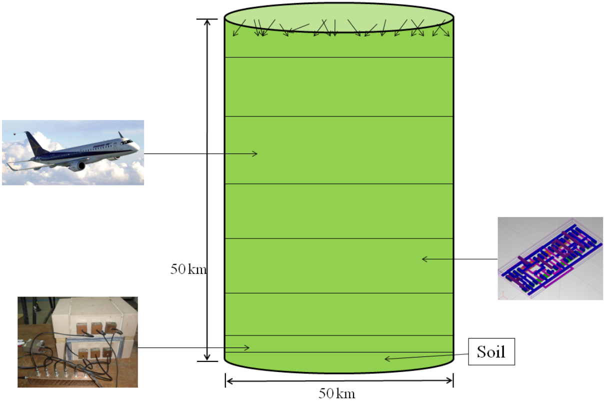
- October 7th 2008: The Airbus A330 VH-QPA, Qantas Flight 72 en route Singapur-Perth, FL370 (11277m) had two consecutive sudden altitude drops (-0.8 g).
- Autumn 2008, 45º latitude, solar minimum and cosmic ray maximum. Neutron flux 1000 neutrons/cm^2-hour on October 7th 2008, FL40000 (12192 m).
- Investigation demonstrated erroneous data peaks in the nº 1 ADIRU (Air Data Reference Unit) that forced absurd autopilot manoeuvres.
- Possible cause: neutron induced SEUs in the nº 1 ADIRU CPU RAM.

Introduction

- Fast neutron effects on microelectronics is a growing field due to concerns related to atmospheric neutron effects on highly integrated microelectronics;
- Measuring the absorbed energy per event in the micro-structures of an integrated circuit is dificult; therefore a Monte Carlo simulation can be useful.

Atmospheric modeling

There is interest in modeling the atmosphere in the South Atlantic Magnetic Anomaly with MCNPX and GEANT4 in order to obtain the neutron spectra as a function of altitude and develop further applications.



Objective

The purpose of this work is to approximate the CRINS using the Monte Carlo (MC) computational code MCNPX and the GEANT4 code system and to present an application to simulate the spectrum obtained on a CMOS flip-flop

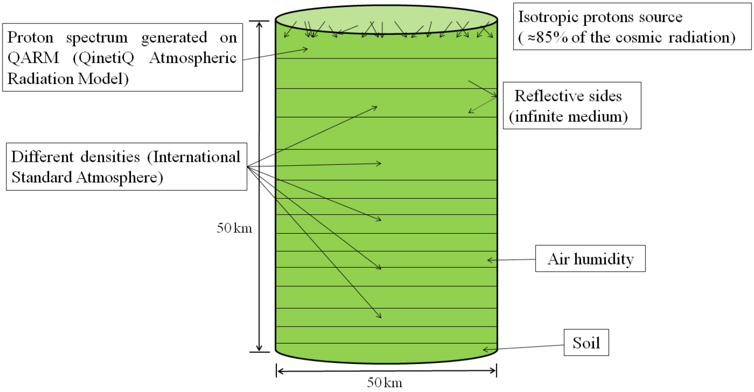
Methodology

Computational procedure

- Modeling of the atmosphere using MCNPX and GEANT4 codes;
- Application of the primary cosmic radiation;
- Neutron spectrum as a function of altitude;
- Comparison of the energy dependence of the neutron spectrum with the EXPACS and QARM programs and experimental data;
- Application of GEANT4 to neutrons incident on the flip-flop transistors.

Atmosphere modeling

Atmosphere modeling of cosmic ray propagation.



M. L. Salby, R. A. Pielke, R. Dmowska. Fundamentals of Atmospheric Physics, vol. 61 (International Geophysics), 1996;

Nuclear data and MCNPX parameterization for high energy neutron interactions

- The ENDF/VI nuclear data library was used for all materials.
- Scattering matrices S(α,β) were used to correct the water hydrogen cross sections;
- Nuclear data libraries were used for energies under 20 MeV. Physical models were used above this energy.

Nuclear data and MCNPX parameterization for high energy neutron interactions

Parameterization

- Neutron and proton elastic scattering;
- Preequilibrium model after intranuclear cascade;
- Bertini for nucleons;
- Coulomb barrier for incident charged particles;
- The subtracted nuclear recoil energy was not used to get excitation energy;
- Experimental branching ratios were used.

GEANT4

Parameterization - Atmospheric model

- Hadronic interactions were simulated with a physics list based on the builders called QGSP-BIC-HP and QGSP-BERT-HP.
- *Standard-EM* package;
- High precision (HP) model for neutrons with kinetic energy below 20 MeV;

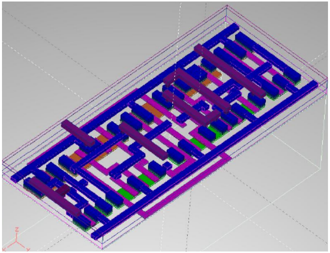
Parameterization - Irradiation application (CMOS flip-flop)

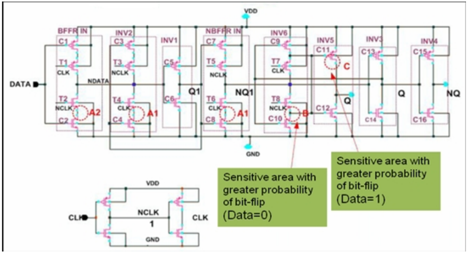
- Hadronic interactions were simulated with a physics list based on the builder called QGSP-BIC-HP.
- Livermore Lowenergy EM package (eletrons and photons interactions with matter down to 250 eV). Cross sections are calculated by means of the evaluated data libraries EPDL (photons), EEDL (electrons) and EADL (atomic relaxations);
- *Standard-EM* package for other particles;
- High precision (HP) model for neutrons with kinetic energy below 20 MeV;

GEANT4 application

Irradiation application (CMOS flip-flop)

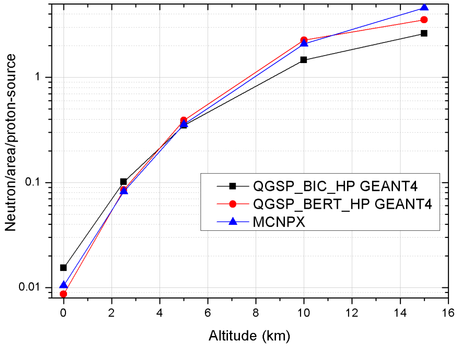
- The flip-flop target has been implemented as a CAD model using the FASTRAD tool;
- It was imported to GEANT4 by means of the GDML interface;
- Spectra of neutrons were used to irradiate the flip-flop transistors;
- Determination of the energy deposition per unit volume in the channel, drain, source and gate oxide of all transistors present in the flip-flop structure.





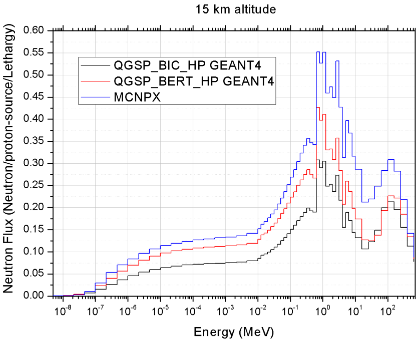
Cosmic-ray induced neutron

Integral flux comparison - MCNPX, GEANT4 (QGSP-BERT-HP GEANT4, QGSP-BIC-HP GEANT4)

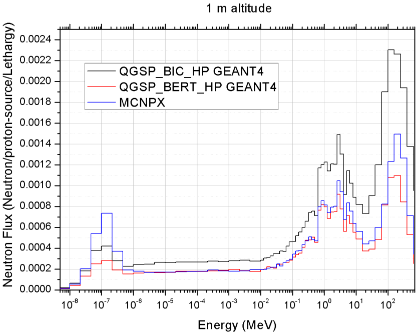


Integral flux comparison between MCNPX and GEANT4. Using the Bertini model on GEANT4, it presents a resonable conformity with MCNPX. There is a difference comparing to the Binary Cascade.

GEANT4 and MCNPX comparison



(c) Neutron spectrum at 15 km altitude.



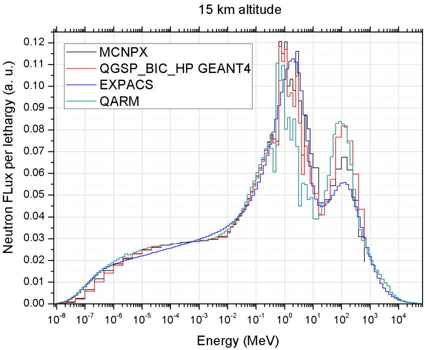
(d) Neutron spectrum at 1 m altitude.

The MCNPX presents a higher production of thermal neutrons that approaches the experimental result. At ground level, that is a higher production of neutrons in the spallation reactions using the BIC.

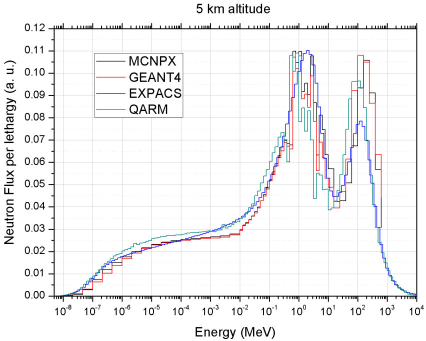
Lethargy interval is $lnE_{i+1} - lnE_i$

Cosmic-ray induced neutron spectrum

Energy dependence of neutron spectrum.



(e) Neutron spectrum at 15 km altitude.

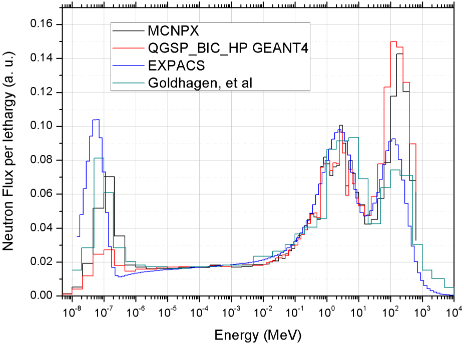


(f) Neutron spectrum at 5 km altitude.

T. Sato, EXPACS User's Manual, Japan Atomic Energy Agency.
Lei, F., et al; Nuclear Science, IEEE Transactions on, 2004.

Cosmic-ray induced neutron spectrum

Energy dependence of neutron spectrum.



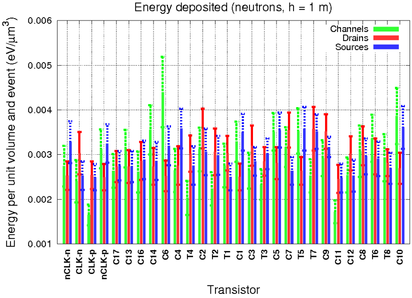
(g) Neutron spectrum at 1 m altitude.

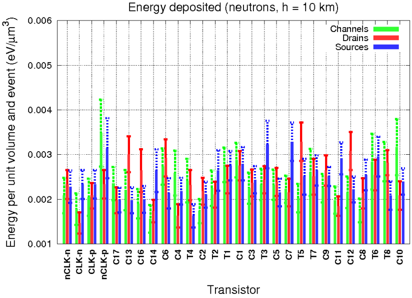
The energy dependece in the thermal region obtained by MCNPX presents a resonable agreement with the experimental data.

Goldhagen, P., et al. Nucl. Instr. Meth. Phys. Res. A, 2002.

Energy deposited

Energy Deposited per unit volume and event in the flip-flop elements at 1 m and 10 km altitude.





The histograms show values for channels, drains and sources.

Future works

Cosmic-ray induced neutron spectrum

- Study the edge effects (computational efficiency).
- Evaluate the appropriate physics list.
- Consider others particles at the top of the atmosphere.
- Consider the Earth's magnetic field;
- Analise the neutron angular distribution as a function of altitude.

Angular distribution of neutrons in the atmosphere

Journal of Radioanalytical and Nuclear Chemistry, Vol. 249, No. 1 (2001) 145–151

RADIONUCLIDES IN THE ENVIRONMENT

A Monte Carlo model of sea-level neutron background: Directionality, spectra, and intensity

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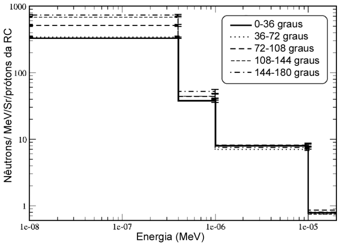
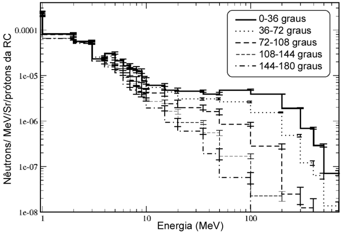


(h) Low energies



(i) High energies

Acknowledgments

- Organizing committee

C A P E S

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