Facilities delivering thermal neutrons and thermal neutron expertise

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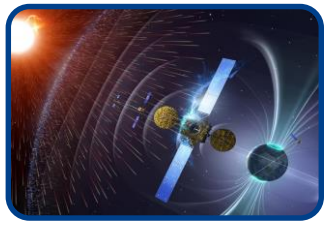
04 May 2022

Thermal neutrons at ground level



Space

- Preliminary radiation assessments of complex devices or out-of-the-shelf (COTS) components in the context of the commercialization of space or “NewSpace”

Automotive

- Evaluation of the radiation sensitivity of power components (electrical vehicles), processors and memories (autonomous and semi-autonomous vehicles)

Medical

- Radiation effects on implants and medical equipment (harsh environments)

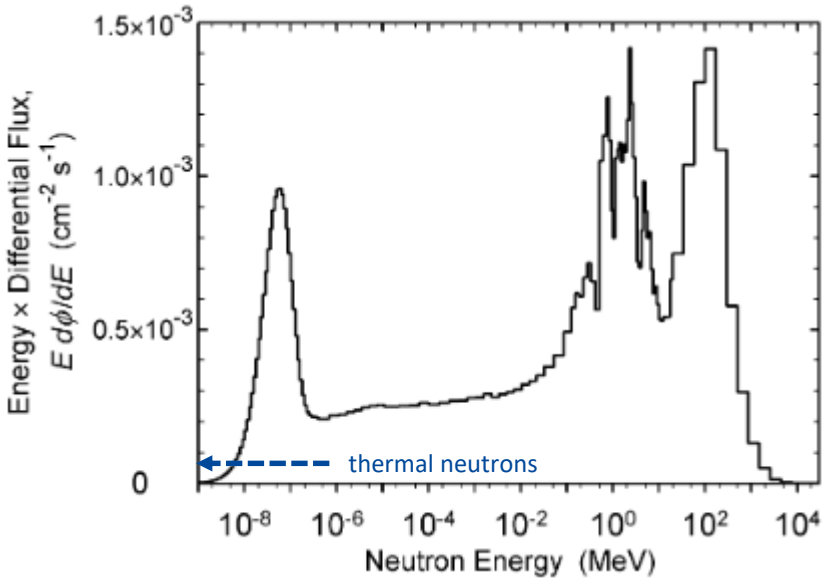
Datacenters and IoT

- Reliability of high-performance memory and processors in the natural radiative environment (high and low energy neutrons)

complex technologies and multiple applications => reliability of electronic components

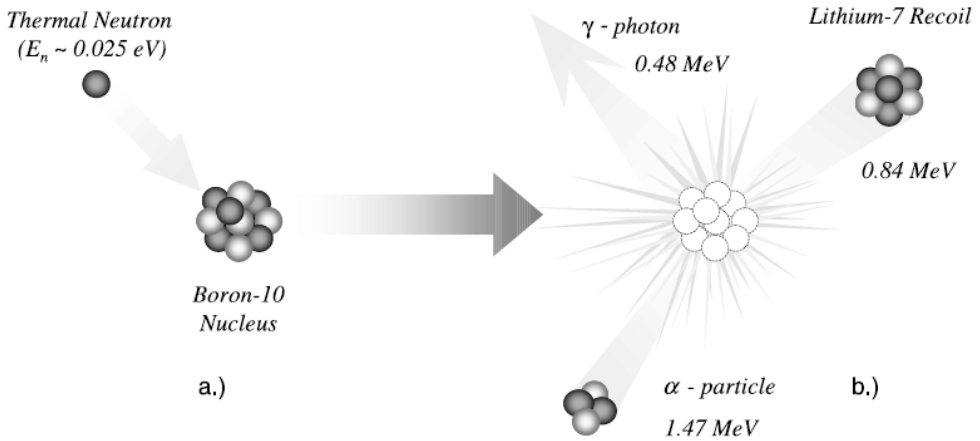
Thermal neutrons at ground level ?

Ground-level neutron spectrum



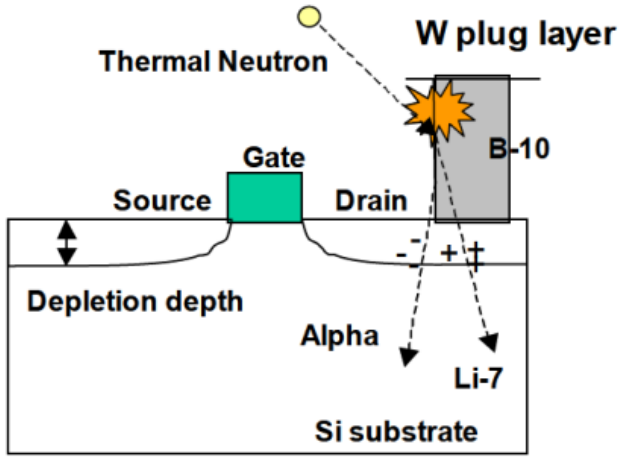
M. S. Gordon *et al.*, "Measurement of the flux and energy spectrum of cosmic-ray induced neutrons on the ground," in *IEEE Transactions on Nuclear Science*, vol. 51, no. 6, pp. 3427-3434, Dec. 2004, doi: 10.1109/TNS.2004.839134.

The case of 10-B : strongly interacting with thermal neutrons



R.C. Baumann et al., "Neutron-induced 10B fission as a major source of soft errors in high density SRAMs " in Microelectronics Reliability, Volume 41, Issue 2, 2001, Pages 211-218, ISSN 0026-2714, https://doi.org/10.1016/S0026-2714(00)00218-3.

Thermal Neutrons induce bit flip in advanced electronics



C. Dyer and F. Lei, "Monte Carlo calculations of the influence on aircraft radiation environments of structures and solar particle events," in *IEEE Transactions on Nuclear Science*, vol. 48, no. 6, pp. 1987-1995, Dec. 2001, doi: 10.1109/23.983161.

Thermal neutrons and fault assessment

Effects of thermal neutron radiation on a hardware-implemented machine learning algorithm

M. Garay Trindade [a,*], F. Benevenuti [b], M. Letiche [c], R. Possamai Bastos [a]

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ARTICLE INFO

Keywords:
Radiation effects
Machine learning algorithms
SEUs
Reliability

ABSTRACT

Hardware-implemented machine
critical applications. This has d
conditions, such as in avionics a
has been target of hardware im

IEEE TRANSACTIONS ON NUCLEA

Assessment of On-Chip Current Se Detection of Thermal-Neutron-Induce

R. Possamai Bastos, *Member, IEEE*, J.-M. Dutertre, *Member, IEEE*, M.
R. A. C. Viera, O. Potin, *Member, IEEE*, M. Letiche, B. Cheymol, and

bstract—This article
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ts, opening prospect
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ndex Terms—Body/bu
detection, high-ene
grated circuits (ICs),
ron, transient faults.

High Energy and Thermal Neutrons Sensitivity of Google Tensor Processing Units

Rubens Luiz Rech Junior*, Sujit Malde†, Carlo Cazzaniga†, Maria Kastriotou†, Manon Letiche‡, Christopher Frost†, and Paolo Rech*§
*Institute of Informatics, UFRGS, Porto Alegre, Brazil
†ISIS Facility, UKRI-STFC, United Kingdom
‡TENIS, Institut Laue-Langevin, France
§DAUIN, Politecnico di Torino, Italy

Thermal Neutron-Induced SEUs in the LHC Accelerator Environment

Matteo Cecchetto, *Student Member, IEEE*, Rubén García Alía, *Member, IEEE*, Frédéric Wrobel, *Member, IEEE*, Maris Tali, *Member, IEEE*, Oliver Stein, Giuseppe Lerner, Kacper Bilko, Luigi Esposito, Cristina Bahamonde Castro, Yacine Kadi, Salvatore Danzeca, *Member, IEEE*, Matteo Brucoli, *Associate Member, IEEE*, Carlo Cazzaniga, Marta Bagatin, *Member, IEEE*,

2020 25th IEEE European Test Symposium (ETS)

Thermal Neutrons: a Possible Threat for Supercomputers and Safety Critical Applications

Daniel Oliveira, Sean Blanchard, Nathan DeBardeleben, Fernando F. dos Santos, Gabriel Piscoya Dávila, Philippe Navaux, Carlo Cazzaniga, Christopher Frost, Robert C. Baumann, Paolo Rech

Neutron-induced effects on a self-refresh DRAM☆

Lucas Matana Luza [a,*], Daniel Söderström [b], Helmut Puchner [c], Rubén García Alía [d], Manon Letiche [e], Carlo Cazzanig

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[b] Department of Physics, University of Jyväskylä, Jyväsk
[c] Infineon Technologies, CA, San Jose, USA
[d] Accelerator Systems Department, CERN, Geneva, Swit
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[g] Univ Lyon, ECL, INSA Lyon, CNRS, UCBL, CPE Lyon,

Effects of Thermal Neutron Irradiation on a Self-Refresh DRAM

Lucas Matana Luza[1], Daniel Söderström[2], Helmut Puchner[3], Rubén García Alía[4], Manon Letiche[5], Alberto Bosio[6] and Luigi Dilillo[1]

ARTICLE INFO

ABSTRACT

The field of radiation effects in electronics research includes unknowns for every new device, node size, and technical development. In this study, static and dynamic test methods were used to define the response of a self-refresh DRAM under neutron irradiation. The neutron-induced effects were investigated and characterised by event cross sections, soft-error rate, and bitmaps evaluations, leading to an identification of permanent and temporary stuck cells, single-bit upsets, and block errors. Block errors were identified in different patterns with dependency in the addressing order, leading to up to two thousand faulty words per event, representing a real threat from a user perspective, especially in critical applications. An analysis of the damaged cells' retention time was performed, showing a difference in the efficiency of the self-refresh mechanism and a read operation. Also, a correlation of the fault mechanism that generates both single-bit upsets and stuck bits is proposed. Post-irradiation high-temperature annealing procedures were applied, showing a recovery behaviour on the damaged cells.

Thermal neutrons at ground level ?

Main interaction responsible for effect on electronics: n+ B-10
Interaction: cascade from the device environment (H-rich material like polymers)

Robert C. Baumann, Eric B. Smith,
Neutron-induced 10B fission as a major source of soft errors in high density SRAMs,
Microelectronics Reliability,
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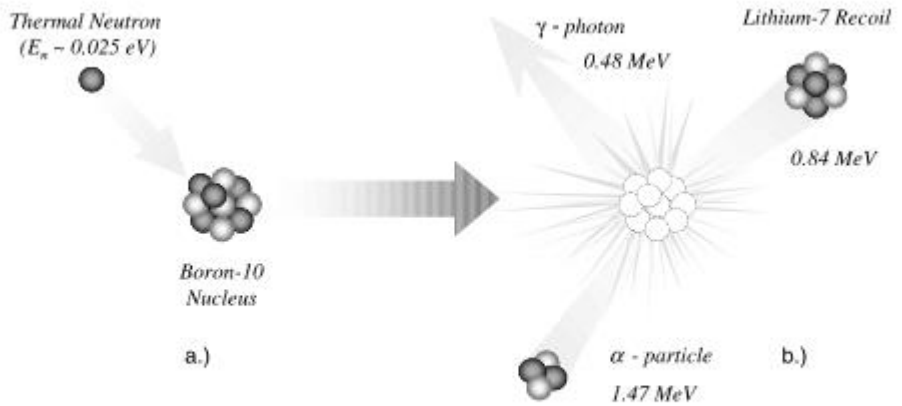


Fig. 2. Schematic of the process of ^{10}B fission. Neutron capture occurs (a) at a relatively high rate due to ^{10}B's high neutron capture cross section. The unstable nucleus fissions (b) producing ionizing recoil fragments and a gamma photon.

Thermal neutrons and fault assessment

- Thermal neutrons
  - Energies lower that 0.5 eV

Oliveira et al., "Thermal Neutrons: a Possible Threat for Supercomputers and Safety Critical Applications," 2020 IEEE European Test Symposium (ETS), 2020, pp. 1-6, doi: 10.1109/ETS48528.2020.9131597.

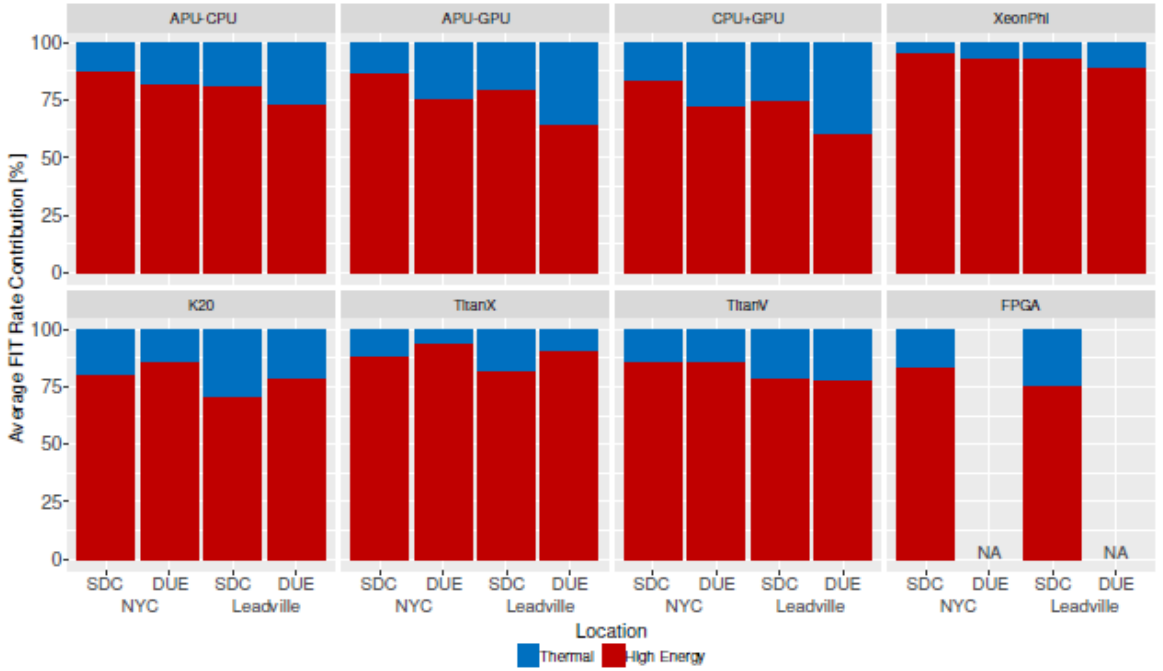


Fig. 5: Percentage of total FIT rate due to high energy and thermal neutrons. All tested parts except Xeon Phi show significant errors due to ^{10}B levels.

- "The flux of thermal neutrons […] can be difficult to predict as it strongly depends on the environmental conditions as well the presence of other materials (primarily hydrogen containing) in device's immediate surroundings (like concrete, water, a fuel tank, etc…) in addition to latitude, longitude and altitudes."
  => last slide

Irradiation stations delivering thermal neutrons (RADNEXT)

- Irradiation stations (generally) equipped with sample stage, collimations, filters
- Thermal neutrons often come along with gamma rays and sometimes with fast neutrons too
- Beam size usually ranges few centimetre squares
- Beam homogeneity varies according to collimation, beam sizes and filters
- Sample environment may be available (in vacuum, oven, cryostat, magnetic field, etc.)

Organisation	Facility (link)	Country	thermal neutron flux [$cm^{-2}.s^{-1}$]	
STFC-ISIS	EMMA	United Kingdom	4.10^5	pulsed
TRIUMF	TNF	Canada	$5.\ 10^5$	pulsed
Institut Laue-Langevin (ILL)	TENIS	France	$2.4\ 10^9$	continuous

Evaluation of components expected to have low sensitivity to thermal neutrons

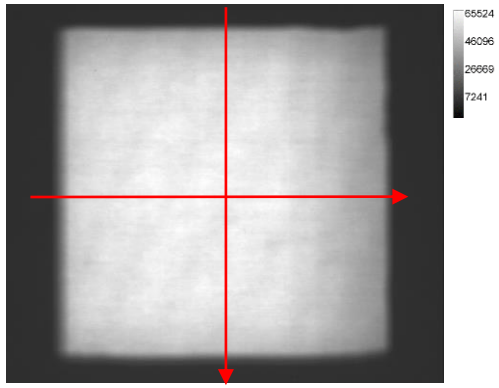
TENIS @t ILL

100 h through RADNEXT

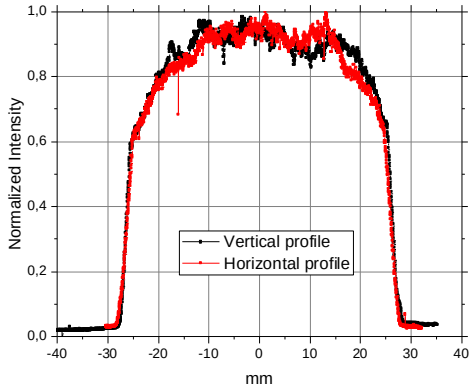
- **T**hermal and **E**pi-thermal **N**eutron **I**rradiation **S**tation **TENIS**

  - Beam with a fission spectrum
    - Flux: 2.4 10^9 $cm^{-2}.s^{-1}$ (25 meV-equivalent neutrons at reactor nominal power of 58 MW)
    - Adjustable beam size from 1x1 mm^2 to 50 x 50 mm^2
    - 2-axes sample stage for positioning
    - About 150 days/year available

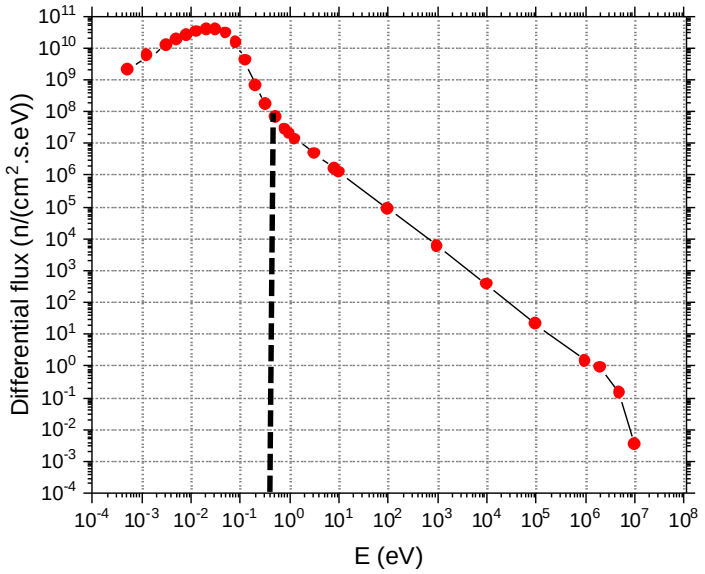
Image of the beam



Profiles of the beam



Neutron beam spectrum (computed)



  - Flux of gamma (computed)
    - Φγ = 7.5x10^8 $cm^{-2}.s^{-1}$
    - Dose Rate = 18 Gy/h (1,8 KRad/h)

⇒ *Upgrade in progress :*

- *Rotation axis (sample stage)*
- *Improved beam dosimetry*
- *Gamma-spectrometer available at the station to check activity of samples/devices*
- *Beam tuning: neutrons up to 1-2 MeV (IROC-Technologies)*

Irradiation with neutrons (and more) @Grenoble

NANOELEC.

Low energy neutrons (TENIS)

Main Applications

- Single-event effects (SEE) testing
- Qualification of HiRel components for ground and aeronautical applications

14MeV energy neutrons (GENESIS)

Main Applications

- Ramdon fault injection on large systems
- Single-event effects (SEE) testing for microelectronics
- Pre-qualification of components
- Debug and preparation for high energy protons testing

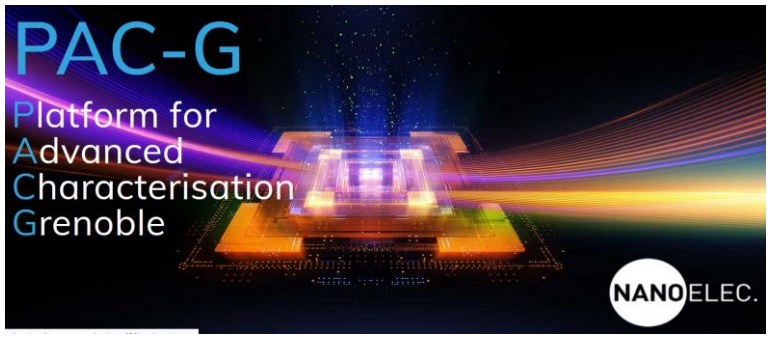
Pulsed synchrotron X-rays focused beam

Main Applications

- Spatially localised fault injection on microchips
- Single-event effects (SEE) testing for microelectronics
- Pre-assessment of the sensitivity of a microchip
- Debug and preparation for heavy ion testing

A **center of competence in irradiation** (ideation stage)

- Increase visibility of facilities (in France first then Europe) and sustain a network of capabilities for the European Industry
- Awaken synergies and foster partnerships in collaborative projects



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leti ceatech · cnrs · ESRF The European Synchrotron · NEUTRONS FOR SOCIETY

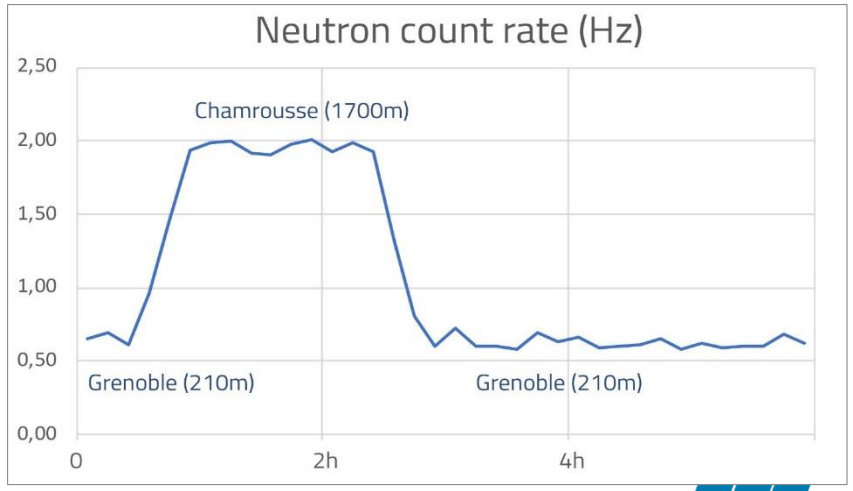
Coming back to operational conditions...

=> Talk by Cécile Weulersse @3.30pm

- Modelling requires entry data: in-situ measurements
  - low flux of thermal neutrons at ground and airline altitudes

- Airbus R&D: estimation of real thermal neutron fluxes inside an aircraft by direct measurements during flights at cruising altitude
  - An ILL neutron detector installed in an aircraft
  - Detector: ^{3}He cylindrical proportional counters.
  - In-flight measurements performed at various location in the aircraft, at an altitude of 12 km - where the neutron flux is about 300 times greater than at sea level.

A drive up the mountains as proof of concept



RADNEXT transnational access call for projects in June:
take the chance to visit us in Grenoble !

https://radnext.web.cern.ch/transnational-access/

Thanks for your attention!

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