S. Duzellier, J.P. David,
C. Inguimbert, T. Nuns,
G. Hubert, L. Artola
(ONERA)

E-mail : sophie.duzellier@onera.fr

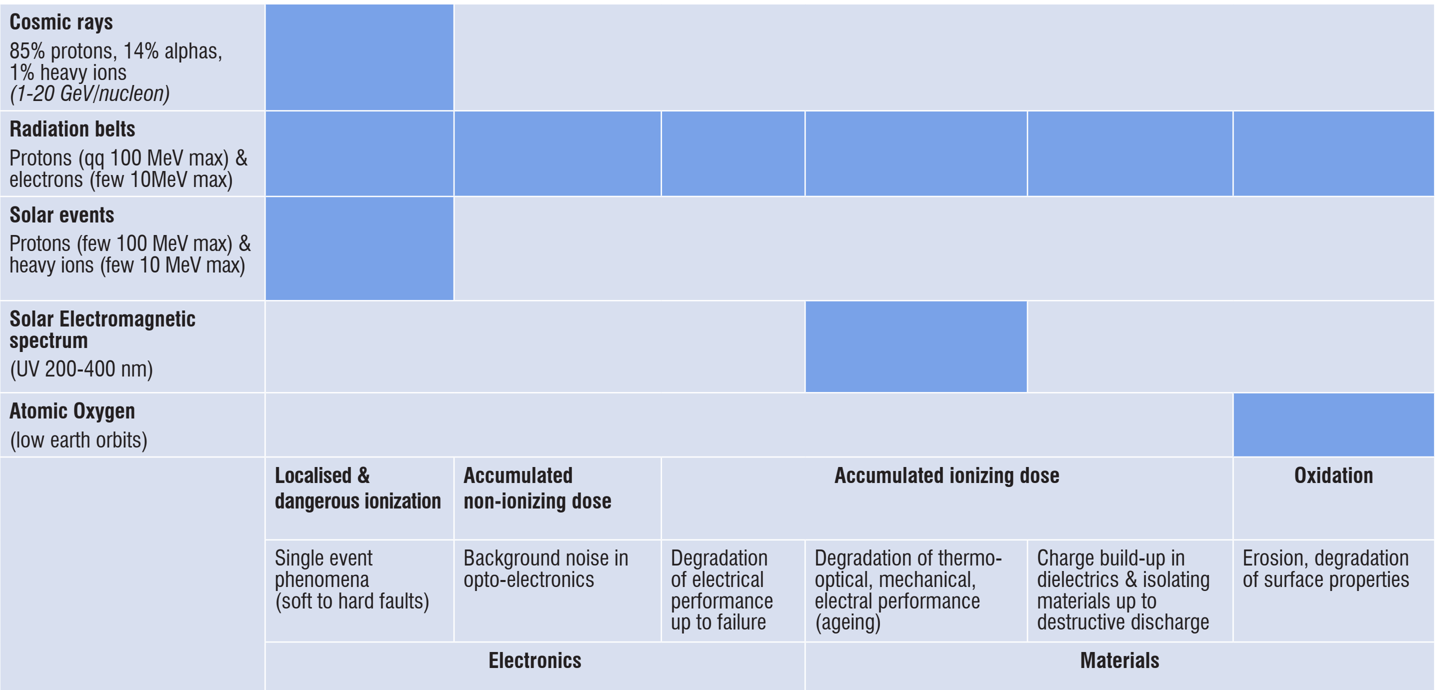
DOI : 10.12762/2016.AL12-12

Radiation Testing of Electronics Systems: How Can Simulation Tools Help in the Definition and Optimization of Test Plans in Labs?

On-board space systems are exposed to harsh environmental conditions including radiations, extreme temperatures and high-vacuum… Each component of this space environment, either separately or in synergy, induces short or long term degradation of electronics or materials, thereby impacting reliability. The wide diversity of observed disruptions, potential anomalies (and therefore of their underlying physical-chemical mechanisms) and the large set of technologies involved require the development of modeling tools to support experimentation, in order to achieve a representative simulation of device response and a reliable prediction of the life, as well as to limit ground testing.

Introduction

On-board space systems are exposed to a harsh environment composed of highly diversified components. At the electronics and materials level, radiations (Figure 1), temperature, vacuum and other conditions, locally induced specific conditions such as contamination, and charging conditions affect the overall performance of sub-systems. They separately cause short term functional disruptions in electronic circuits or a more gradual degradation of materials and, moreover, their synergy adds to the criticality of this problem with increased loss of performance.



	Localised & dangerous ionization	**Accumulated non-ionizing dose**	**Accumulated ionizing dose**			**Oxidation**
Cosmic rays 85% protons, 14% alphas, 1% heavy ions *(1-20 GeV/nucleon)*	■					
Radiation belts Protons (qq 100 MeV max) & electrons (few 10MeV max)	■	■	■	■	■	■
Solar events Protons (few 100 MeV max) & heavy ions (few 10 MeV max)	■					
Solar Electromagnetic spectrum (UV 200-400 nm)				■		
Atomic Oxygen (low earth orbits)						■
	Single event phenomena (soft to hard faults)	Background noise in opto-electronics	Degradation of electrical performance up to failure	Degradation of thermo-optical, mechanical, electrical performance (ageing)	Charge build-up in dielectrics & isolating materials up to destructive discharge	Erosion, degradation of surface properties
	Electronics			**Materials**		

Figure 1 – Space environment components and associated effects on space systems

Consequently, the complexity and wide diversity of the mechanisms at play in observed anomalies and degradations render the study of these phenomena difficult and, moreover, the available ground capabilities for the simulation of these mechanisms are limited and incomplete.

In this game, coupling modeling and experimentation is often mandatory to obtain a realistic and representative description of the device response. The reliability challenges are manifold: event mechanisms or large shift of electrical parameters due to the ionizing dose may lead to functional failure of circuits embedded in critical sub-systems (attitude and orbit control, scientific data acquisition, etc.), and performance loss in thermal control or solar array sub-systems leads to a shortened mission duration.

The physics behind a failure in a circuit or the degradation of passive material is different and therefore the methods for their evaluation and qualification are also. Norms and standards exist with a very generic approach for electronics and more specific to the application for materials. In any cases, testing is complex and costly because many experimental parameters affect the representativeness and thus the validity of the measured data (Table 1).

The wide range of technologies (materials and electronics) systems, and processes involved in any single one of these categories adds to the difficulties in carrying out experimental activities: this wide diversity is also encountered in the observed responses under radiation exposure.

In electronics, lot-to-lot down to part-to-part variation is observed in the total ionizing dose response. The measurement of the single event sensitivity of digital devices entails technological variability that affects the event occurrence threshold (the minimum charge needed to induce event is actually measured as a distribution). Then, depending on the circuit function, the mode of failure may be critical or not (a transient signal can be interpreted as a valid signal, or filtered in the circuit).

Therefore, the ground evaluation of a device for its specific application requires very complex experimental investigation and cannot be deduced from a generic approach. In such a context, numerical tools are very helpful for identifying anomalies or degradation mechanisms and thus 1) support the definition and optimization of a test plan, 2) develop adequate prediction codes or extrapolate test results to complete an available data set, thereby limiting the number of qualification tests.

In the following, several study cases are described to illustrate how modeling and experimentation can combine successfully to investigate radiation effects in electronics, providing advances and discussing the benefits that can be reaped by ensuring the reliability of space systems.

Single Event Modeling with MUSCA SEP3

SEE (Single Event Effect) modeling is complex because many physical mechanisms intervene between the incoming particle and SEE phenomena, each playing an important role in the event occurrence. The ionizing particles of the environment (composed of protons and heavy ions for the space environment and of neutrons, protons and muons for the atmospheric environment) pass through the vehicle structure, shielding and circuit package all the way through to the sensitive structure. Then, primary or secondary ions induced by nuclear reactions generate electron-hole pairs along their paths in the semiconductor, which progress into the media according to transport mechanisms and are collected at the electrodes of the device. Finally, transient currents (SET, Single Event Transient) disturb the circuit operations and lead to the occurrence of SEE.

Experimental parameters critical for the ground simulation of radiation effects			
Single event (functional anomaly)	Degradation of electrical perform		Degradation of thermo-optical performance of surface coatings (ageing of polymer)
	Shift of electronical parameters (ionizing dose)	Background noise in opto-electronics (non-ionising dose)	
> Particle species & energy (deposited local charge density) > Particle flux & fluence (anomaly statistics, testbench detection capability) > Bias Conditions (collected charge quantity) > temperature (internal gain and parasitic signal amplification) > *Topology* *(circuit reponse to parasitic signal, functional anomaly criteria for occurence)*	> Particle species & energy (deposited local charge density) > Dose rate (charge generation charge) > Bias Conditions (electric field, charge transport) > Temperature (charge transport and annealing) > *Oxide quality* *(charges mobility and trapping rate)*	> Particle species & energy (species, size and distribution of defects) > Bias Conditions (charge carriers assist in the rearrangement of defects) > Temperature (re-arrangement/annealing of defects) > *Topology* *(edge effect, dark current distribution, etc.)*	> Particle species & energy (dose profile, degradation mode) > Dose rate (free radicals generation charge) > Test methods (combined/sequential exposure, sequence and timing) > Temperature (scission/xlinking ratio of molecular chains, annealing) > Vacuum (annealing of free radicals, absence of oxidation)

Table 1 – Critical experimental parameters in 4 typical cases. In italics, some technological parameters (device-dependent) directly affecting circuit response

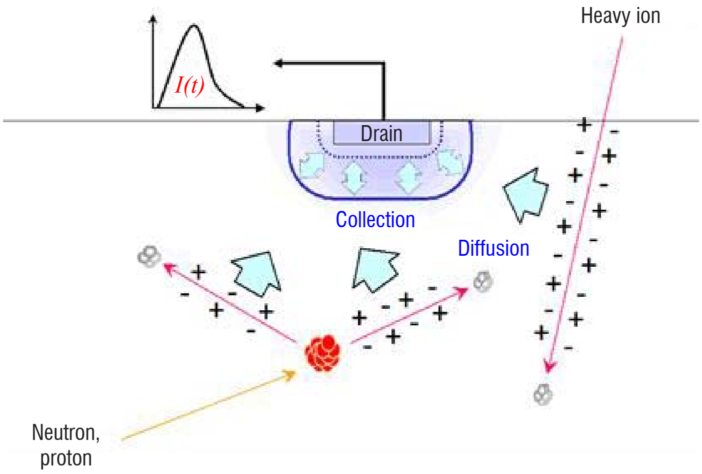


Figure 2 – Principles for charge generation and collection leading to SET occurrence at the transistor drain. This SET is at the origin of the electrical disruption that may trigger an SEE event at the circuit (functional) level

The SEE phenomenon is probabilistic, *i.e.*, it is possible to associate a threshold and probability parameters to describe the phenomena (the sensitivity or cross-section is determined by the ratio of the events count to the received particle flow).

The MUlti-SCAles Single Event Phenomena Predictive Platform (MUSCA SEP3), in development at ONERA since 2007, aims at evaluating the SEE risks within the framework of research and industrial applications. Therefore, MUSCA SEP3 has been designed to be part of the overall device qualification methodology, to allow emerging risks or problems to be anticipated, as expected from the technology roadmap (ITRS -International Technology Roadmap for Semiconductors) or new applications, and to support the analysis of in-flight anomalies. In addition, the chosen approach accounts for structure geometry and design rules and thus helps the investigation of the SET characteristics and sensitivities as a function of a cell design, representing an opportunity to define and validate solutions for SET mitigations or hardening by design process.

SEU (Single Event Upset) estimate is performed by means of MUSCA SEP3, whose detailed framework is presented in previous works [Ref. 1, Ref. 2, Ref. 3]. It is based on a Monte Carlo approach, and consists in sequentially modeling all of the physical and electrical mechanisms, from the global system down to the semiconductor target: (a) the radiation field, (b) the transport mechanisms of radiation particles (protons, neutrons or heavy ions) through the materials comprising the shielding and the Back-End Of Line (BEOL), (c) the generation of electron-hole pairs in the semiconductor via direct or indirect ionization mechanisms, (d) the charge transport and collection mechanisms in the Front-End Of Line (FEOL), (e) the circuit electrical response. The modeling of radiation effects in nanoscale devices implies taking into account a high-level physical description. Thus, realistic primary or secondary ion track structures from databases generated by GEANT4 can be coupled with MUSCA SEP3 to model the 3D structure charge deposition by the incident particle [Ref. 4]. 3D carrier morphology evolves according to mechanisms like drift (electric field), diffusion (carrier concentration gradient), collection and recombination processes. Bipolar amplifications can also be considered. Thus, models describing the transport and collection mechanisms mainly resulted from TCAD simulations, and were calibrated for investigated technological nodes. The particle-induced parasitic currents disturb the circuit response; this will depend on the transient characteristics (duration, amplitude, shape and multiplicity). Transient currents can be injected on each collection node, *i.e.*, the drains of each transistor.

With this tool, it is possible to address numeric circuits (up to a few hundreds of transistors), and destructive effects in power devices. Moreover, the continuous evolution towards a more technological integration brings with it a new set of error mechanisms or problems requiring basic research and scientific investigation to propose alternatives to the obsolete models.

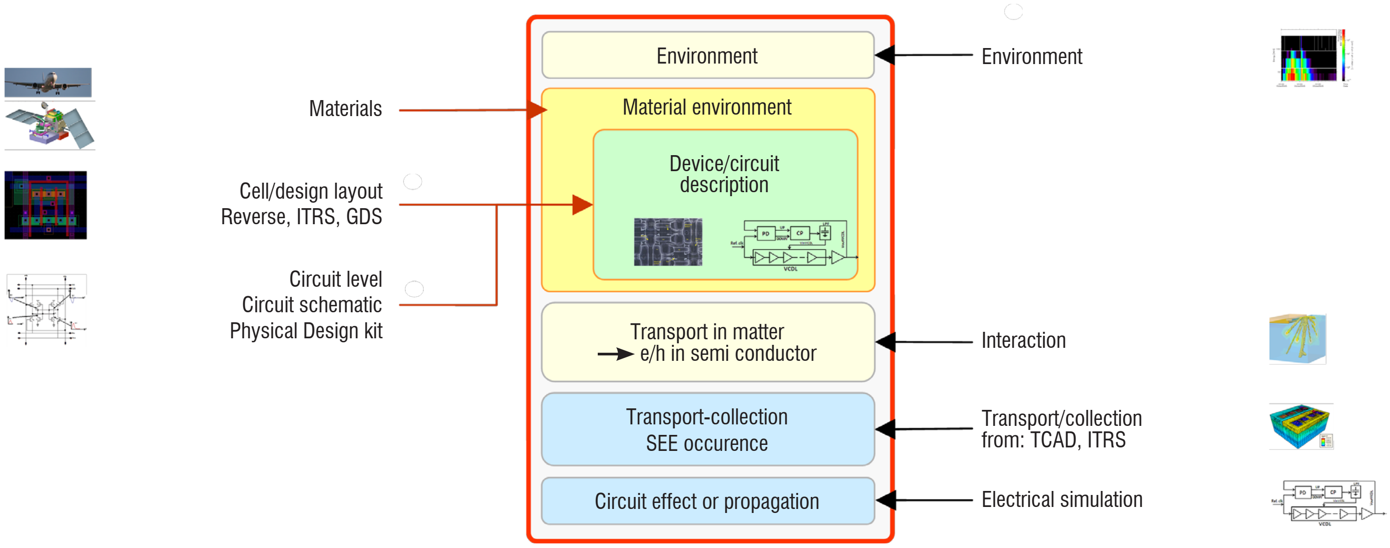


Figure 3 – The MUSCA SEP3 platform integrates the whole physical modeling chain (sequentially) from charge injection down to the event mechanism accounting for the sensitive structure within its global and local environments (hard – material and soft – application)

Data assimilation

Within the framework of a standard qualification, the experimental evaluation of SEE sensitivity for a device requires a complex test plan under many measurement conditions: different particle species and energies (definition of the mode of charge injection), many flux and fluence levels for plotting sensitivity curves, covering the response to most of the expected environmental conditions. This approach is expensive and time-demanding.

The MUSCA SEP3 core approach is based on a technological description of the target structure associated with representative physical parameters, in order to describe the device response to any type of environment (space, atmospheric and terrestrial applications). Thus, the MUSCA SEP3 can be considered as a virtual irradiator. This set of physical parameters can be reduced to a set of the most critical parameters within the framework of an industrial application and project context, without much affecting the validity of the final results, in order to meet the industrial constraints (timescale, cost, available information, etc.). However, as for any modeling approach, experimental data are required to validate the models and obviously the level of reliability and precision of the tool will be defined by the quantity of measurements that can be considered for this "calibration" step.

Figure 4 shows some results of memory sensitivity to protons determined from heavy ion experiments and vice versa (by data assimilation, the first results from this approach can be found in Ref. 1). Indeed, the proton cross-section is used to determine the critical charge by fit process, and then this critical charge value is considered to calculate the heavy ion response. This assimilation process can be applied for any radiation fields.

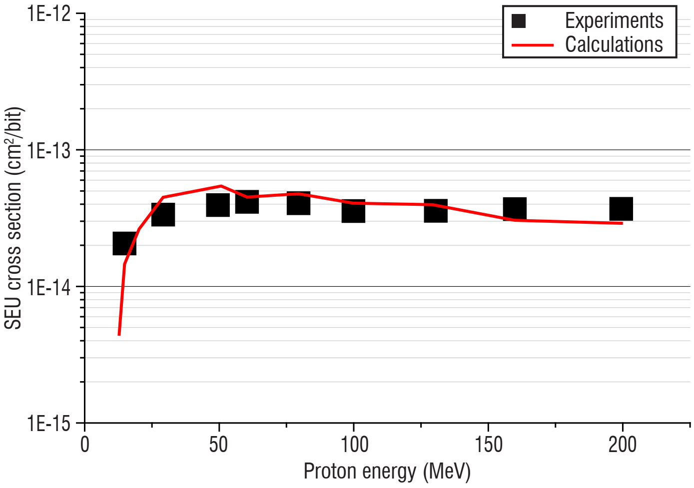
With such use, the MUSCA SEP3 contribution helps to optimize a test plan (selection of a minimum set of beam conditions to obtain a satisfactory radiation response description) and to complete a data set without performing a large number of tests (gain cost and time for a project).

Test plan definition

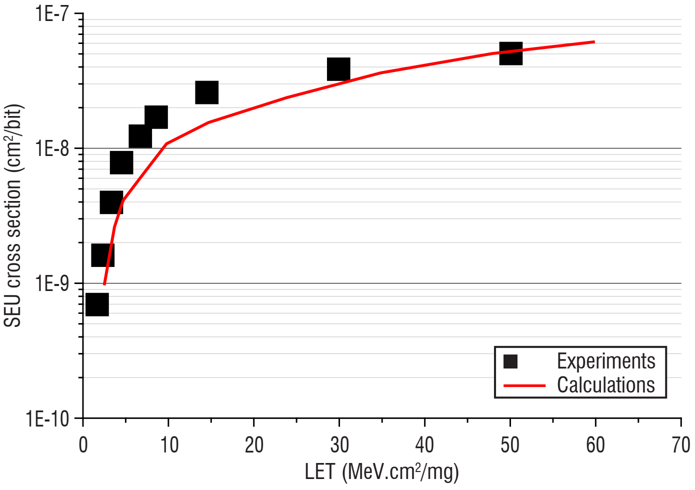
Temperature effect on SET feature induced by ionizing particles, such as heavy ions, have mostly been studied for a high temperature range over the last decades. For infrared technologies, investigations have been dedicated to very low temperatures down to 77K (supported by CNES). This study was focused on the SEU sensitivity of D Flip-Flops used in the readout circuit of a CMOS image sensor developed by Sofradir.

The SEU sensitivity estimate obtained by calculations with MUSCA SEP3 has been compared with success to preliminary experimental data obtained from an irradiation test campaign performed by the CNES in 2014. However, a strong variability of the experimental data was observed although the error bars of the measured events were limited (statistical uncertainties). The interest of the MUSCA SEP3 prediction platform is, in addition to the estimation of SEE cross-sections, to allow for a failure analysis at the design and transistor levels, as shown in Figure 5 for a DFF cell.

It is interesting to note here that the critical features of the SEE sensitive zones associated with the logical states "1" (in red) and "0" (in blue) of the DFF are diversified (area and shape) and scattered (location).

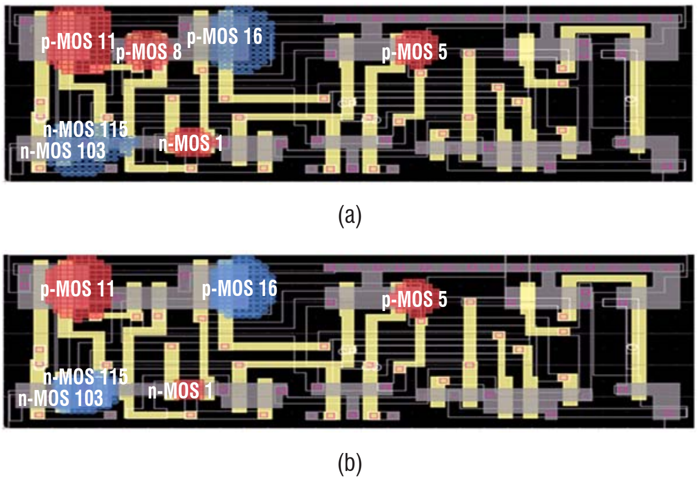


(a) Heavy ions → Protons



(b) Protons → Heavy ions

Figure 4 – Comparison of measured and calculated cross-sections in the case of a RAM memory. (a) Heavy ion-to-proton calculation compared to proton experimental data, (b) Proton-to-heavy ion calculation compared to heavy ion experimental data.

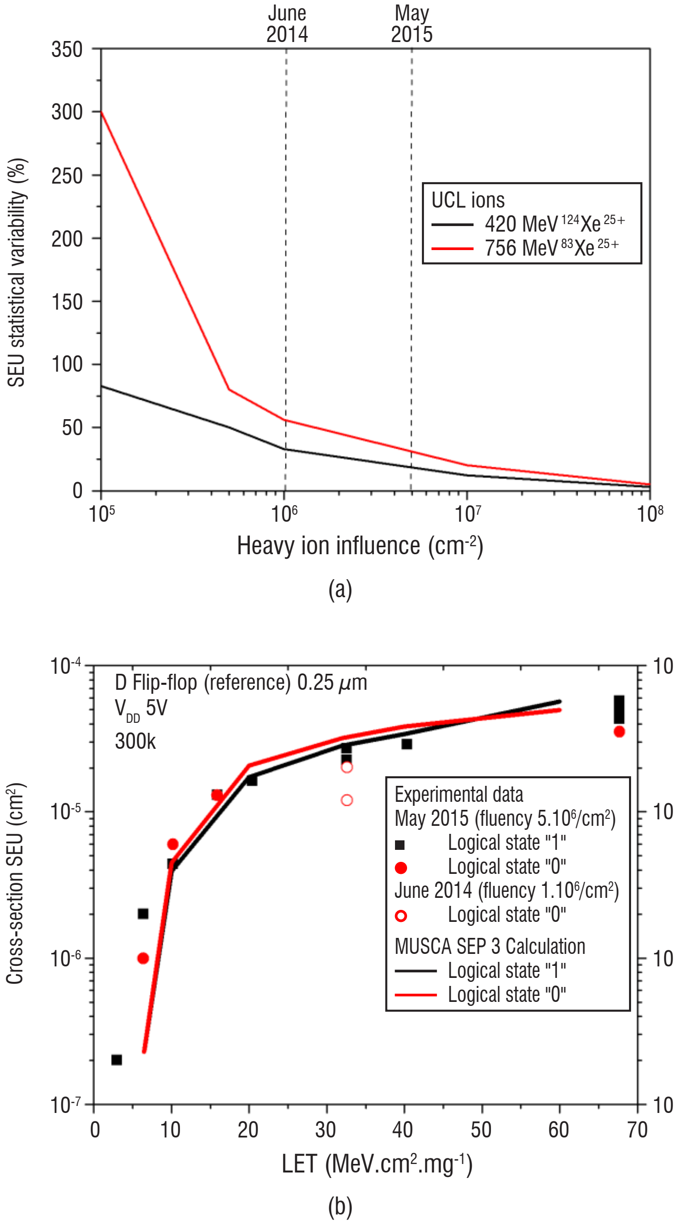


(a)

(b)

Figure 5 – SEU sensitivity mapping of the DFF cell reference design, as a function of the stored data, a) "0" (blue areas) and b) "1" (red areas) at 300K. The locations, shapes and areas of the critical zones determined by multi-collection and circuit effects affect the global measured SEU cross-section.

SEE phenomena are probabilistic by nature; any disparity in the topological origins of the events can induce strong variability of the measured SEU cross-sections, if the number of measured events is not statistically significant relative to the DFF cell area and the number of critical zones. Indeed, only 20 errors were measured during the first irradiation campaign in June 2014, while over 160 events have been estimated by MUSCA SEP3 for a relevant mapping of SEU events (Figure 5). Thus, in 2015 the experimental setup of the second irradiation campaign was defined using the MUSCA SEP3 calculations as inputs, in order to achieve the best trade-off for the relevant particle fluence to be used (which was actually increased by a factor of 5). Figure 6 shows the impact of fluence on the measured SEU variability (a) and compares the measurements and calculations for both irradiation campaigns (b) [Ref. 5].



(a)

(b)

Figure 6 – (a) SEU Statistic variability as a function of fluence for 420 MeV Xe and 756 MeV Kr ions, calculated by MUSCA SEP3 for the reference design of the DFF. (b) Comparison of the experimental data obtained from both irradiation campaigns (2014 and 2015) with the SEU cross-sections calculated by MUSCA SEP3 as a function of the logic state of the DFF.

Thus, the interest of such a SEE prediction platform has been shown: first for the estimation of the SEE sensitivity, second for failure analysis (impact of the design), and third for the definition of the experimental setup of irradiation campaigns, constituting a major asset to reduce the cost defined by the space industry roadmap.

Modeling of ionizing dose phenomena with the AC-DC code

The AC-DC code (Analytical Computing of Dose -induced Charges) was developed at ONERA-DESP with the aim of developing a physical tool to finely describe the TiD (Total Ionizing Dose) mechanisms in the circuits. This degradation effect is related to the trapping of charges in the insulating zones (often SiO_2) of transistors and/or isolation of the active areas of the circuits. Although the mechanisms of generation, recombination, transport, and charge trapping in insulators and interfaces are well known [Ref. 6, Ref. 7], due to the number of parameters and sensitivity it is difficult to implement models capable of predicting the response of a circuit at the functional level.

This "physical modeling" approach is undeveloped in the community, but was chosen as the back track for experimental investigations in the department. The AC-DC code has been developed with the aim of answering questions arising from the circuit evaluation methods, as well as regarding the influence of critical experimental parameters (temperature, dose rate, bias, etc. [Ref. 8]). It describes in a SiO_2 layer the charge generation and initial recombination, the free electrons and the hole diffusion and transport, the deep and shallow trapping/de-trapping processes and the [H+] ions generation and transport. At the SiO_2/Si interface, the interface state generation and the holes trapping on these interface states are modeled [Ref. 9]. Finally, the interface trapped holes profile is calculated, taking into account thermal and tunnel-assisted annealing processes [Ref. 10]. The main physical processes are electrical field-dependent; a coupled solving of Poisson and drift–diffusion equations has been implemented in a 1D MOS structure. All of the well-known dependencies on temperature are explicit for all of the physical processes, in order to evaluate the effect of temperature on electrical degradation.

The AC-DC code was first used to study the ELDRS (Enhanced Low Dose Rate Sensitivity) mechanism observed in bipolar technology essentially. When ELDRS occurs, an electrostatic shielding mechanism (Figure 7) limits the degradation at a high dose rate and therefore becomes critical at low rates since the degradation in a spatial application is stronger than under ground evaluation conditions.

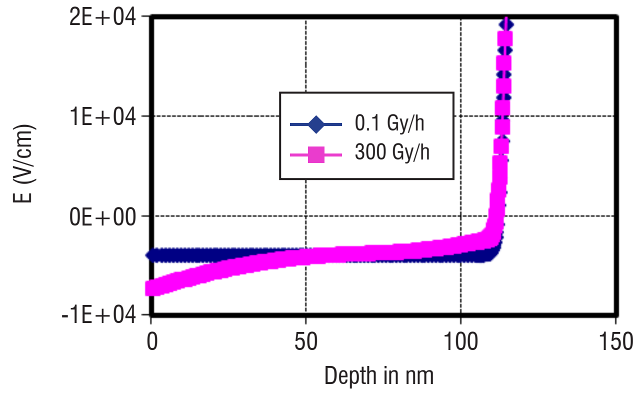


Figure 7 – Electric field profiles in the silica volume of an irradiated MOS for 2 different dose rates. These differences are the cause of the phenomenon ELDRS.

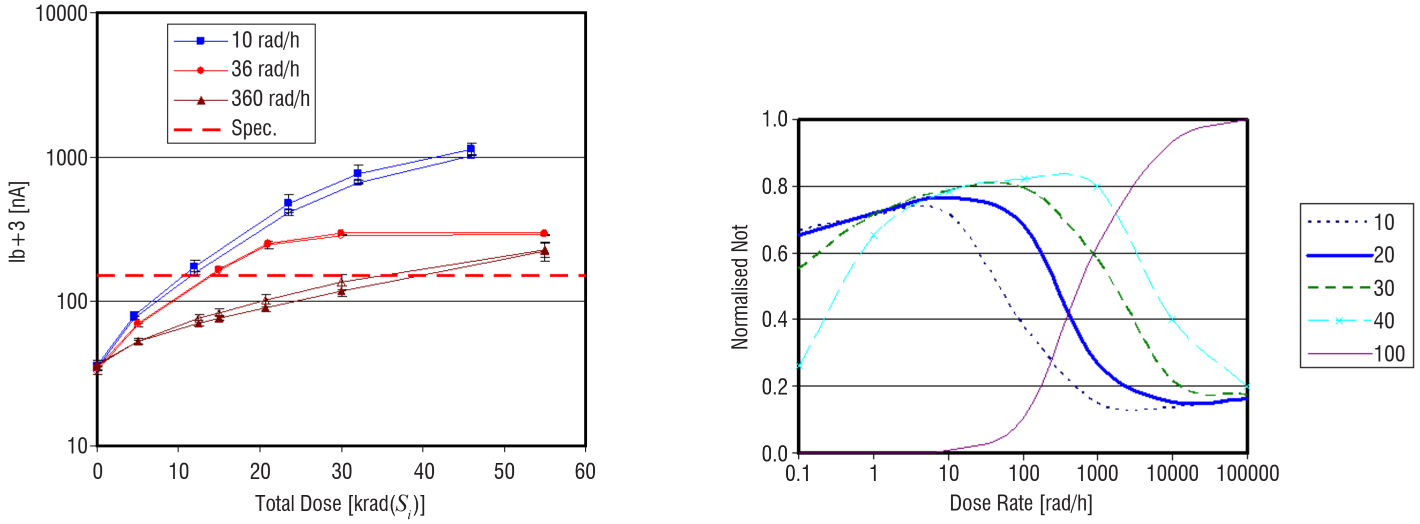


Figure 8 – Test results on a LM111 operational amplifier. (Left) influence of the dose rate on the positive bias current (experiment under biased and un-biased conditions), (Right) trapped charge density (normalized) in the oxide as a function of the dose rate for different irradiation temperatures (AC-DC calculations).

In 2012, tests on a representative set of components were conducted for ESA as the basis for the definition of recommendations, as part of the establishment of the new Test Standard ECSS22900 (dose rates: 36-360rad/h, Figure 8 left).

AC-DC modeling has shown that accelerated configuration could be proposed. When a temperature of 40°C is applied during irradiation, the experimental standard dose rate provides a conservative estimate of the TiD resistance of devices relative to the space dose rate; indeed, the quantity of trapped charges induced at ground testing remains a worst case (Figure 8 right). Obviously, this approach requires a "calibration phase", since many physical parameters are technology-dependent (quality of the oxide). However, such a tool is helpful for proposing an optimized test configuration.

Another example is that of IR sensors operating at temperatures near 80 K (study classified as confidential). The TiD response at such temperatures is not well known and requires modeling as support for analysis (impact of charge trapping and transport). The experiment developed to answer these questions is based on the evolution of the amount of charge during a rise in temperature after irradiation at 80 K on appropriate test vehicles (MOS transistors) and various topologies (design influence). For this type of topic, where experimentation is quite heavy (irradiation of components in cryostats, use of liquid nitrogen) and few results are available in the literature, modeling the physics with AC-DC is a valuable tool to select the critical experimental parameters and to help in the interpretation of results. In particular, it enables the evaluation of the theoretical response of a MOS structures irradiated at 80 K during a temperature ramp (Figure 9).

In the figures below, the calculated degradation is represented by the two characteristic quantities, volume (Qot) and interface (Qit) charge concentrations, and for three dose rates. The 80K degradation that is observed immediately after irradiation is not the worst-case situation (as opposed to 150 K), both from the point of view of the volume or interface charges. The use of experimental results obtained at 80 K will have to consider this behavior.

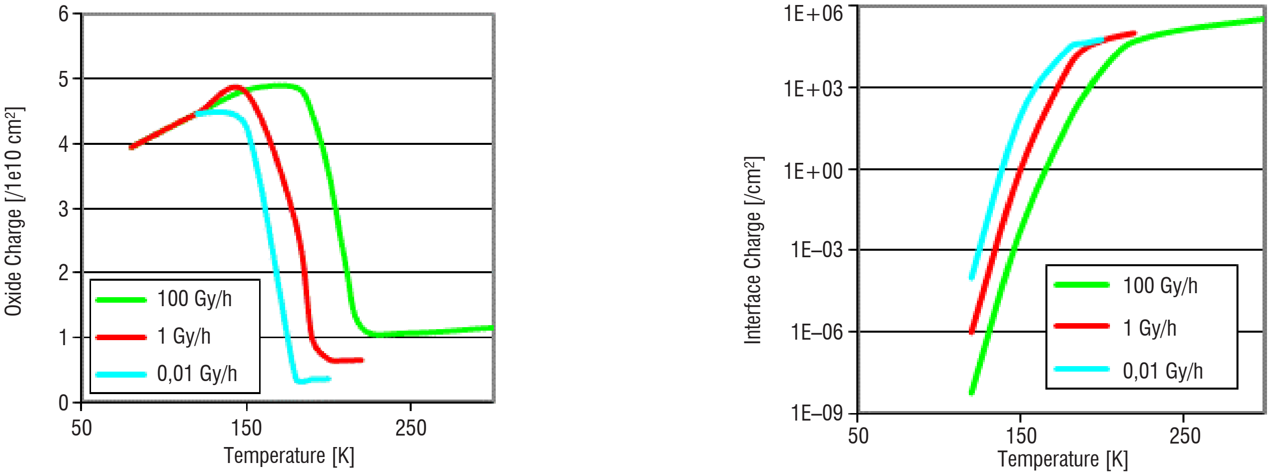


Figure 9 – Calculation with AC-DC changes in the amount of volume (left) and interface (right) charges depending on irradiation temperature and for three dose rates.

Displacement defects and the effective NIEL concept

The displacement damage and ionizing dose often combine to affect the performance of image sensors and, more generally, optoelectronics (Figure 10). The atoms displaced by proton or electron irradiation are at the origin of degradation mechanisms involving a non-ionizing dose. These defects can be electrically-active, and affect the charge carrier physics (generation, recombination, trapping, diffusion, etc.), which in turn degrades the electrical performance of circuits (for instance, an increase in the background dark current noise).

Generally, mean degradations vary linearly with NIEL (Non-Ionizing Energy Loss) when applying the NIEL scaling law, which considers that damage is proportional to the product of NIEL by the particle fluence. But deviations are observed, especially with electrons and also in cases of III-V semiconductor devices.

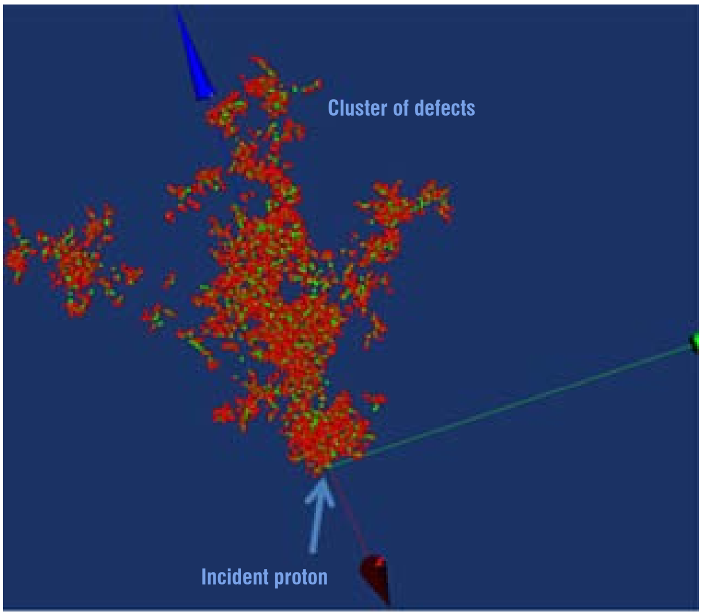


Figure 10 – Calculation with AC-DC changes in the amount of volume (left) and interface (right) charges depending on irradiation temperature and for three dose rates.

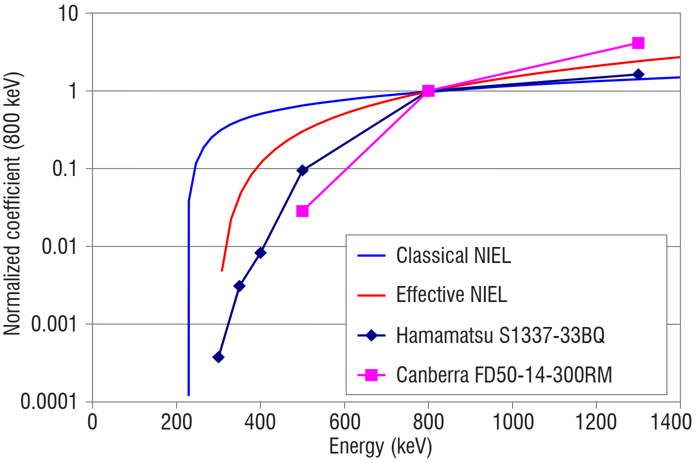


Figure 11 – Calculations based on effective or classical NIEL concepts compared with measurements.

At DESP, the existing experimental facilities (particle accelerators, characterization tools as DLTS equipment, test bench, etc.) and the numerical modeling capabilities (radiation-matter interaction tool) allowed for developing over years a deep background knowledge on physical mechanisms and thereby adequate and representative degradation models.
For instance, an effective NIEL parameter has been proposed as an improvement of NIEL calculations for predicting mean degradations [Ref. 11, Ref. 12]. In Figure 11, the deviation between calculations with classical NIEL (blue line) and experimental observations (symbols) can be observed. These deviations may come from experimental uncertainties, but more from the rough estimate of the NIEL values. Based on molecular dynamics data showing how the formation of amorphous zones (localized melting of the target matter) can modify the quantity of radiation-induced defects, the concept of effective NIEL was developed and successfully compared with existing data (red line).

These data illustrate the benefit of modeling here to provide a better description of the device response (life prediction) and to help in the selection of appropriate beam parameters for final testing.

Conclusions and perspectives

Over the last decades, the concern for radiation effects has extended to the fields of avionics, automotive, large computers and networking, etc., and to an ever wider range of technologies (CMOS, FDSOI and FinFET devices, as well as power components, SiC technology, etc.) and deeper integration. With the growing need for on-board computing, criticality increases and new mechanisms emerge (direct ionization from protons, neutrons-and muons, lately electron-induced anomalies, and now synergy between ageing and the radiation –reliability concern, etc.).

Nowadays, space missions are more diversified, leading to the definition of new environmental conditions (use of electrical orbit raising EOR, scientific missions with extreme conditions, mega-constellations, etc.). The "materials" topic is also concerned, for instance, with the EOR orbits inducing a higher electrons flux and higher doses (enhanced ageing and charging effects).

Thus, coupling modeling and experimentation begins inevitably with the anticipation of emerging phenomena in a constantly evolving context. However, access to the technology is now vital and development times are often too long for project timeframes. A realistic and pragmatic approach is therefore mandatory for future generations of tools (modularity, application-oriented, validity domain, etc) ■

References

[1] G. HUBERT, S. DUZELLIER, C. INGUIMBERT, C. BOATELLA-POLO, F. BEZERRA, and R. ECOFFET - *Operational ser Calculations on the Sac-C Orbit Using the Multi-Scales Single Event Phenomena Predictive Platform (MUSCA SEP3)*. IEEE Trans. Nucl. Sci., vol. 56, no. 6, pp. 3032-3042, Dec. 2009.

[2] G. HUBERT and L. ARTOLA - *Single-Event Transient Modeling in a 65-nm Bulk CMOS Technology Based-on Multi-Physical Approach and Electrical Simulations*. IEEE Trans. Nucl. Sci., Vol. 60, No. 6, pp. 4421-4429, Dec. 2013.

[3] G. HUBERT, S. BOURDARIE, S. DUZELLIER, R. ECOFFET - *Impact of the Solar Flares on the SER dynamics on Micro and Nanometric Technologies in the Geostationary Orbit*. IEEE Trans. Nucl. Sci., Vol. 57, No. 6, pp. 3127-3134, Dec. 2010.

[4] M. RAINE (CEA-DAM), G. HUBERT, P. PAILLET (CEA-DAM), M. GAILLARDIN (CEA-DAM), A. BOURNEL (IEF-CNRS) - *Implementing Realistic Heavy Ion Tracks in a See Prediction Tool: Comparison Between Different Approaches*. IEEE Transactions on Nuclear Science Vol. 59, No. 4, pp. 950-957.

[5] L. ARTOLA, G. HUBERT, O. GILARD, S. DUCRET, F. PERRIER, M. BOUTILLIER, P. GARCIA, G. VIGNON, B. BARADAT, N. RICARD - *Single Event Upset Sensitivity of D-Flip Flop of Infrared Image Sensors for Low Temperature Applications Down to 77 K*. IEEE Trans. Nucl. Sci., Vol. 62, No. 6, pp. 2979-2987, dec. 2015.

[6] J.-L. LERAY - *Total Dose Effects: Modeling for Present and Futur*. IEEE Trans. Nucl. Sci., NS-46, p. 1574, Dec. 1999.

[7] R.J. GRAVES, C.R. CIRBA, R.D. SCHRIMPF, R.J. MILANOWSKI, A. MICHEZ, D.M. FLEETWOOD, S.C. WITZAK and F. SAIGNE - *Modeling Low-Dose-Rate Effects in Irradiated Bipolar-Base Oxide*.

[8] R. DURAND, J.-P. DAVID, A. GAUFFIER and E. LORFEVRE - *Modeling Temperature Effects of Thick Oxide 60Co Induced Degradation Under Low Electric Field. Hardness Assurance Implications*. 9th European Conference on Radiation and Its Effects on Components and Systems, 2007.

[9] S. N. RASHKEEV, D. M. FLEETWOOD, FELLOW, IEEE, R. D. SCHRIMPF, FELLOW, IEEE, and S. T. PANTELIDES - *Effects of Hydrogen Motion on Interface Trap Formation and Annealing*. IEEE Trans. Nucl. Sci., Vol. 51, No. 6, Dec. 2004.

[10] P. J. MCWHORTER, S.L. MILLER and W.M. MILLER - *Modeling the Anneal of Radiation Induced Trapped Holes in a Varying Thermal Environment*. IEEE Trans. Nucl. Sci., VOL. 37, P. 1682-1689.

[11] C. INGUIMBERT, S. MESSENGER - *Equivalent Displacement Damage Dose For On-Orbit Space Applications*. IEEE Trans. Nucl. Sci., Vol. 59, No. 6, pp. 3117-3125, Dec. 2012.

[12] C. INGUIMBERT, P. ARNOLDA, T. NUNS, G. ROLLAND - "*Effective Niel*" *in Silicon: Calculation Using Molecular Dynamics Simulation Results*, IEEE Trans. Nucl. Sci., Vol. 57, No. 4, pp. 1915-1923, Aug. 2010.

Acronyms

AC-DC	(Analytical Computing of Dose-induced Charges (code))
BEOL	(Back-End Of Line)
CMOS, FDSOI and FinFET devices	
DFF	(D Flip-Flop cell)
ELDRS	(Enhanced Low-Dose Rate Sensitivity)
EOR	(Electric Orbit Raising)
FEOL	(Front-End Of Line)
ITRS	(International Technology Roadmap for Semiconductors)
MOS	(Metal-Oxide-Semiconductor (structure))
MUSCA SEP3	(MUlti-SCAles Single Event Phenomena Predictive Platform)
NIEL	(Non-Ionizing Energy Loss)
SEE	(Single Event Effect)
SET	(Single Event Transient)
SEU	(Single Event Upset)
TCAD	(Technology Computer-Aided Design (tool))
TiD	(Total Ionizing Dose)
TniD	(Total Non-Ionizing Dose)

Sophie Duzellier, Graduated in 1986 from the INSA (*Institut National des Sciences Appliquées*) Engineering school, and received a Ph.D. degree in microelectronics from Toulouse Univ. in 1989. She joined ONERA in 1989 as a research engineer in the Space Environment department. Her first activities addressed radiation effects on electronic devices through ground simulation and experimental work (testing methods and prediction tools). Head of the ECM group at DESP since 2005, she still carries out research activities on the topic of space materials, dealing with radiation ageing (thermal coatings, optics, etc.), and develops on-board experiments (PI of MEDET on-board ISS 2009-2010).

Guillaume Hubert, Graduated with a M.Sc. degree in theoretical physics from the Univ. of Pierre & Marie Curie (Paris VI) in 1998, and received a Ph.D. degree in electrical engineering from Montpellier Univ. in 2001. Then, he worked for five years at the European Aeronautic Defense and Space Company (EADS) on the effects of radiation on electronics. Since 2007, he is a researcher engineer at ONERA (Space Environment Department). His research activities are in the field of multi-physics / multi-scale SEE modeling for space, terrestrial and avionic environments and radiation environment characterization. He is also member of ONERA's scientific council of and the Scientific Management Board of the LSBB (Low Noise Underground Laboratory) of Rustrel.

Laurent Artola, PhD, senior research engineer at ONERA-DESP since 2012. He graduated with a M.Sc. degree from the University of Montpellier in 2007, specializing in the reliability of electronic devices subjected to radiation (in space and avionic environments). After a short experience at NXP Semiconductor IMEC (Belgium), he started his PhD program in Toulouse, supported by ONERA and the CNES (the French space agency) in the prediction of Single Event Effects (SEE) in electronic devices for space applications (PhD in 2011). He is now in charge of electrical and physical modeling of semiconductors for the prediction of radiation-induced Single Event Effects in VLSI.

Jean-Pierre David, Graduated in 1980 from the INSA (*Institut National des Sciences Appliquées*) Engineering school in solid state physics, he was hired at ONERA in 1982. His early work mainly concerned the characterization of III-V materials, and then, in the 1990s, he particularly studied ionizing dose effects and hardening assurance issues on electronic circuits. He is now the Deputy Director of the Space Environment Department, but is still in charge of studies on the topic of atomic displacements in photonics and opto-electronics (solar cells).

Thierry Nuns, Graduated from the SupElec (*Ecole Supérieure d'Electricité*) Engineering school in 1993, he joined ONERA in 1995 as a research engineer in the Space Environment department and defended his PhD in 2002 on radiation effects in commercial CCDs (ionizing and non-ionizing dose effects). In the 90s, he first led the development of software/hardware for the radiation testing of devices and flight experiments in collaboration with the CNES. He is now in charge of optoelectronics activities at the ECM group (degradation models due to ionizing and non-ionizing doses) and is developing radiation monitors based on imagers.

Christophe Inguimbert, Graduated in 1995 from Paul Sabatier University in Solid State Physics, then PhD degrees at ISAE in space electronics in 1998. After his Ph.D, he joined the space environment department of the ONERA (ECM group), where he has taken over the radiation transport-in-matter activities. He is in charge of developing the GEANT4-based codes to address the topic of radiation-induced degradation in electronics and materials (atomic displacements in optoelectronic devices, particle-semiconductor interactions leading to Single Event Effects, secondary electrons emission in materials, etc.).