NSREC OTTAWA 2024

July 22-26, 2024

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IEEE NPSS Nuclear & Plasma Sciences Society

As of July 8, 2024

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Technical / Exhibit

- On-site Registration - Rideau Canal Atrium
- A/V Preview Room - Room 211
- Side Meeting #1 - Room 202
- Side Meeting #2 - Room 209
- Side Meeting #3 - Room 212

Monday

Short Course Sessions - Ottawa Salon
Short Course Exam - Ottawa Salon

Tuesday

Technical Sessions - Ottawa Salon
Exhibits - Canada Hall 2 & 3

Wednesday

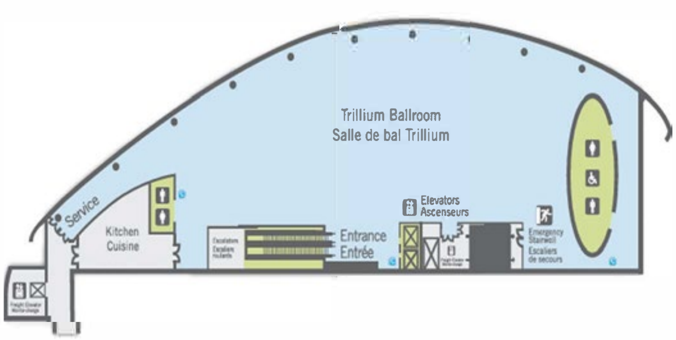
Technical Sessions - Ottawa Salon
Exhibits - Canada Hall 2 & 3
Poster Session - Canada Hall 1 (1:15pm - 4:00pm)

Thursday

Technical Sessions - Ottawa Salon
Open Meeting - Ottawa Salon
Radiation Effects Data Workshop - Canada Hall 1 (1:15pm 4:00pm)

Friday

Technical Sessions - Ottawa Salon



Dining / Social

Sunday

Welcome Reception - Trillium Ballroom

Monday

Continental Breakfast - Trillium Ballroom
Morning & Afternoon Breaks - Rideau Canal Atrium
Short Course Luncheon - Trillium Ballroom

Tuesday

Continental Breakfast, Breaks and Lunch - Canada Hall 2 & 3
Exhibit Reception - Canada Hall 2 & 3

Wednesday

Continental Breakfast, Morning Break, Lunch-Canada Hall 2 & 3
Young Professional Lunch - Westin TwentyTwo - 22nd Floor
Afternoon Break - Canada Hall 1

Thursday

Continental Breakfast - Trillium Ballroom
Morning Break - Rideau Canal Atrium
Women in Engineering (WIE) Lunch - Westin TwentyTwo - 22nd Floor
Westin Afternoon Break - Canada Hall 1

Friday

Continental Breakfast - Trillium Ballroom
Morning Break - Rideau Canal Atrium

Schedule

Time	Monday July 22	Tuesday July 23	Wednesday July 24	Thursday July 25	Friday July 26
7:00	[7:00] Breakfast - Trillium Ballroom	[7:00] Breakfast - Canada Hall 2 & 3	[7:00] Breakfast - Canada Hall 2 & 3	[7:00] Breakfast - Trillium Ballroom	[7:00] Breakfast - Trillium Ballroom
7:30					
8:00	[8:00] **Short Course Introduction** Prof. Vincent Goiffon - Ottawa Salon			[8:00] **Invited Talk – Reliability, Availability, and Serviceability (RAS) Challenges for Spaceborne Computing** Jyotika Athavale, Ottawa Salon	[8:00] **Invited Talk – Mādahòkì Farm – Indigenous Experiences** Workshop: Introduction to Indigenous Culture, Ottawa Salon
8:10	[8:10] **Part I – Basic Mechanisms and Displacement Damage Effects in Electronics** Dr. Elizabeth Auden				
8:15		[8:15] **Opening remarks - Awards Presentation -** Ottawa Salon	[8:15] **Invited Talk – Canada's Role in Space Exploration: Past, Present, and Future** Cassandra Marion, Ottawa Salon		
8:30					
9:00		[9:05] **Technical Session Opening Remarks** [9:10] **Session A - Space and Terrestrial Environments**	[9:15] **Session E - Radiation Effects in Devices and Integrated Circuits**	[9:00] **Session F - Basic Mechanisms of Radiation Effects**	[9:00] **Session H – Hardening by Design**
9:30	[9:40] Break – Rideau Canal Atrium				[9:50] **Session I – Single-Event Effects: Devices and Integrated Circuits**
10:00	[10:10] **Part II – Total Ionizing Dose Effects in SI Mosfets up to Ultrahigh Doses** Dr. Federico Faccio	[10:00] Break – Canada Hall 2 & 3	[10:05] Break – Canada Hall 2 & 3	[10:05] Break – Rideau Canal Atrium	
10:30		[10:30] **Session B - Hardness Assurance: Piece Parts to Systems and Testing Approaches**	[10:35] **Session E -** *(continued)*	[10:35] **Session G - Single-Event Effects: Mechanisms and Modeling**	[10:25] Break – Rideau Canal Atrium
11:00					[10:55] **Session I -** *(continued)*
11:30	[11:40] Short Course Luncheon – Trillium Ballroom	[11:50] Lunch - Canada Hall 2 & 3	[11:20] **Poster Intro -** Ottawa Salon [11:25] Lunch / Exhibitor Raffle – Canada Hall 2 & 3 — and — [11:30-1:00] IEEE Young Professionals Lunch – Westin TwentyTwo - 22nd Floor *Ticket Required to Attend*	[11:40] **Data Workshop Intro -** Ottawa Salon [11:45-1:15] Women in Engineering Lunch – Westin TwentyTwo - 22nd Floor *Ticket Required to Attend* — and — [11:45] Lunch - On Your Own	
12:00					[12:10] Conference Closing
12:30					
1:00	[1:00] **Part III – Single-Event Effects in Devices and ICS: Phenomena and Testing Methods** Dr. Ani Khachatrian	[1:00] **Session C - Dosimetry and Facilities**	[1:15-4:00] **Poster Session -** Canada Hall 1	[1:15-4:00] **Radiation Effects Data Workshop** Canada Hall 1	
1:30					
2:00		[1:50] **Session D – Photonic Devices and Integrated Circuits**			
2:30	[2:30] Break – Rideau Canal Atrium	[2:25] Break – Canada Hall 2 & 3			
3:00	[3:00] **Part IV – Radiation Effects on Photonics: Image Sensors and Optical Fibers** Prof. Sylvain Girard and Dr. Cedric Virmontois	[2:55] **Session D -** *(continued)*			
3:30					
4:00		[4:10] End of Tuesday Sessions	[4:00] End of Wednesday Sessions	[4:00] End of Thursday Sessions	
4:30	[4:50] Wrap-up		[4:30] Load buses for Conf. Social [4:45] Buses leave (15 min ride)	[4:45 to 6:30] **Radiation Effects Committee Annual Open Meeting** – Ottawa Salon	
5:00	[5:00] Exam (for students requesting CEU credit only)		[5:00 to 10:30] Conference Social – **Canadian History Museum**		
5:30	[5:20] End of Short Course	[5:30 to 7:30] Industrial Exhibits Reception – Canada Hall 2 & 3			
6:00					
6:30					
7:00					

Chairman's Invitation

On behalf of the Institute of Electrical and Electronics Engineers (IEEE), its Nuclear and Plasma Sciences Society (NPSS), the Radiation Effects Steering Group (RESG) and the 2024 Nuclear and Space Radiation Effects Conference (NSREC) committee and volunteers, it is my sincere pleasure to invite you to attend the 61st NSREC to be held July 22-26, 2024. The conference will be held in Canada's capital, Ottawa, Ontario, at the Shaw Centre.

The conference begins Monday, July 22nd, with a one-day Short Course titled *"Radiation Effects on Electronic and Photonic Technologies: from Basic Concepts to Advanced Mechanisms"*. It is organized by **Vincent Goiffon** of ISAE SUPAERO. The day covers the main three radiation effects in electronics with a special fourth section on photonics. This short course provides the basic knowledge necessary to understand how radiation affects electronics, which will provide a wonderful introduction to the topic for new attendees and a brush-up on knowledge for more experienced attendees. The Short Course notebook will provide an in-depth write up of the discussion.

The Technical Program will be held from Tuesday, July 23rd to Friday, July 26th. **William Robinson**, Georgia Tech Research Institute, is the Technical Program Chair. William and his technical committee will oversee the development an outstanding contributed papers organized into nine sessions of oral presentations and a poster session. William is working with **Daisuke Kobayashi**, JAXA, who is overseeing the poster session. In addition, the technical committee has developed the Radiation Effects Data Workshop with the Data Workshop Chair, **Li Chen**, University of Saskatchewan. Workshop posters will present radiation effects data on electronics or test facilities. Finally, the technical program includes three invited speakers that present on topics of general interest to the NSREC community.

The Industrial Exhibit, organized by **Nadia Rezzak**, Microchip, opens Tuesday morning. Our exhibitors will display their latest developments, including electronics, engineering services, facilities, modeling, and equipment. Attendees will be able to visit the booths during scheduled breaks, and lunch on Tuesday and Wednesday. A special Industrial Exhibits Reception will be held on Tuesday night that attendees and their guests can attend. The exhibits will conclude at noon Wednesday with the ever-popular exhibitor raffle.

Ottawa is a lovely small city filled with wonderful official and unofficial museums, including The Unofficial Museum of Fueling up and The Unofficial Museum of Saying Football Instead of Soccer! Local Arrangements Chair, **Anthony Sanders**, NASA GSFC, has organized an outstanding social program for attendees and guests. The conference social, which is held on Wednesday evening, will be held at the outstanding Canadian History Museum with cocktails, sit-down dinner, and a tour of the museum. This venue is a must see for attendees with its beautiful architecture reminiscent of canoe paddles and its river-front view of Parliament. There are also two companion tours, including a trip to the Canadian Parliament and the Canadian War Museum.

On behalf of my Conference Committee, which also includes Finance Chair **Ethan Cannon** (The Boeing Corporation); Publicity Chairs **Teresa Farris** (Archon-LLC) and **Michael Campola** (NASA GSFC); Awards Chair **Sylvain Girard** (Université de Saint-Etienne); Webmaster **Greg Allen** (NASA/JPL); A/V **Carl Szabo** (NASA) and **Martha O'Bryan** (NASA); and Meeting Planner **John Teehan** (IEEE MCE), I invite you to join us in Ottawa for an outstanding conference!

We look forward to seeing you in person this July!

"It is my distinct honor to invite you to attend NSREC 2024 in Canada's capital city, Ottawa, Ontario! My Conference Committee and I are excited to host all of you in this wonderful small city. We hope that you enjoy this outstanding conference and make time to enjoy all the social opportunities. Ottawa is the educational and cultural heart of Canada with many universities and cultural institutions, including the National Arts Centre and the National Gallery of Canada. The NSREC website and brochure provide information on different local offerings Ottawa has, so that you and your family can make your plans. On behalf of the many people who make NSREC possible, I welcome you to NSREC 2024. Canada Ho!"

Heather Quinn
NSREC 2024 General Chair
Air Force Research Laboratory

Visit us on the web at:
www.nsrec.com

Short Course Program

RADIATION EFFECTS ON ELECTRONIC AND PHOTONIC TECHNOLOGIES: FROM BASIC CONCEPTS TO ADVANCED MECHANISMS

OTTAWA, ONTARIO, CANADA

OTTAWA SALON
JULY 22, 2024

7:00 AM	**BREAKFAST** **(Trillium Ballroom)**
8:00 AM	**SHORT COURSE INTRODUCTION** Prof. Vincent Goiffon, *ISAE-SUPAERO, Université de Toulouse*
8:10 AM	**PART I – BASIC MECHANISMS AND DISPLACEMENT DAMAGE EFFECTS IN ELECTRONICS** Dr. Elizabeth Auden, *Los Alamos National Laboratory*
9:40 AM	**BREAK (Rideau Canal Atrium)**
10:10 AM	**PART II – TOTAL IONIZING DOSE EFFECTS IN SI MOSFETS UP TO ULTRAHIGH DOSES** Dr. Federico Faccio, *CERN*
11:40 AM	**SHORT COURSE LUNCHEON** **(Trillium Ballroom)**
1:00 PM	**PART III – SINGLE-EVENT EFFECTS IN DEVICES AND ICS: PHENOMENA AND TESTING METHODS** Dr. Ani Khachatrian, *US Naval Research Laboratory*
2:30 PM	**BREAK (Rideau Canal Atrium)**
3:00 PM	**PART IV – RADIATION EFFECTS ON PHOTONICS: IMAGE SENSORS AND OPTICAL FIBERS** Prof. Sylvain Girard and Dr. Cedric Virmontois, *University of Saint-Etienne and CNES, respectively*
4:50 PM	**WRAP-UP**
5:00 PM	**EXAM (only for students requesting CEU credit)**
5:20 PM	**END OF SHORT COURSE**

The NSREC 2024 Short Course Notebook will be available for download at www.NSREC.com for all registered Short Course Attendees one week before NSREC conference.

Short Course

COURSE DESCRIPTION

A short course, *"Radiation Effects on Electronic and Photonic Technologies: from Basic Concepts to Advanced Mechanisms"*, will be presented at the 2024 IEEE Nuclear and Space Radiation Effects Conference. The ongoing need to expose sensors and systems to more and more demanding radiation environments combined with the fast evolution of technologies lead to complex radiation effects in modern electronics and photonics. To enable their use in harsh radiation environments such as space, nuclear power plants, medical imaging/scientific instruments, or particle physics facilities, it is critical for users, designers, manufacturers, and researchers to get an up-to-date overview of the underlying physics and failure mechanisms.

The short course is organized into four sections, all featuring introductory material and advanced topics. The first section addresses the basic mechanisms of radiation effects in electronics, with emphasis on displacement damage on various devices and technologies. The second part focuses on total ionizing dose induced degradation in MOS transistors, discussing the evolution of these effects with the advancement of CMOS manufacturing technologies. The third section describes single-event effects in electronics, and includes discussions about the testing approaches used to reproduce in the laboratory the failure mechanisms observed in the application. The final course presents effects on photonic material, devices and integrated circuits focusing on optical materials, optical fibers, image sensors and detector pixel arrays. More detailed descriptions of each lecture are provided below. The topics covered should benefit people new to the field as well as experienced engineers and scientists, by providing up-to-date material and insights.

The short course is intended for radiation effects engineers, component specialists, system designers, and other technical and management personnel involved in developing reliable systems designed to operate in radiation environments. It provides a unique opportunity for IEEE NSREC attendees to benefit from the expertise of excellent instructors, along with a critical review of state-of-the-art knowledge in the field. Electronic copies of detailed course notes will be provided to each participant.

CONTINUING EDUCATION UNITS (CEUs)

Continuing Education Units (CEUs) will be available. For the interested attendees, an exam will be given at the end of the short course. The course is valued at 0.6 CEUs, and is endorsed by the IEEE and by the International Association for Continuing Education and Training (IACET).

SHORT COURSE CHAIRMAN

Vincent Goiffon, Ph.D.
ISAE-SUPAERO
Short Course Chair

Vincent Goiffon received his Ph.D. in EE from ISAE-SUPAERO, University of Toulouse, France, in 2008. The same year he joined the ISAE-SUPAERO Image Sensor Research group as Associate Professor and has been a Full Professor of EE at the Institute since 2018. In September 2021, he took over the responsibility of the Research Group.

He has contributed to advancing the understanding of radiation effects on solid-state image sensors, notably by identifying original degradation mechanisms in pinned photodiode pixels and clarifying the role of interface and bulk defects in the mysterious dark current random telegraph signal phenomenon.

Besides his contributions to various space R&D projects, Vincent has been leading the development of radiation-hardened CMOS image sensors (CIS) and cameras for nuclear fusion experiments (e.g., ITER and CEA Laser MegaJoule) and nuclear power plant safety.

Vincent Goiffon has authored one book chapter and more than 110 publications, including awards received at IEEE NSREC, RADECS, and IISW conferences. He has been an associate editor of the IEEE Transactions on Nuclear Science since 2017 and has served the community as a reviewer and session chair.

Dr. Elizabeth Auden is an electrical engineer in the Radiation Effects and Reliability capability at Los Alamos National Laboratory (LANL). She received an M. S. in electrical engineering from Tulane University in 2000 and a Ph.D. in electrical engineering from Vanderbilt University in 2013. Elizabeth's professional background includes radiation effects and reliability in electronics, DC electrical metrology, and software engineering. Her radiation effects research focuses on single-event effects and displacement damage in semiconductor and superconductor components.

PART I – BASIC MECHANISMS AND DISPLACEMENT DAMAGE EFFECTS IN ELECTRONICS

Dr. Elizabeth Auden
Los Alamos National Laboratory

Electronics operating in space-based applications are subject to radiation effects from galactic cosmic rays, solar energetic particles, and trapped particles in planetary orbits. Radiative particles can cause single-event effects (SEEs) as well as accumulated damage from total ionizing dose (TID) and displacement damage (DD), leading to data corruption, off-normal electrical conditions, performance degradation, and failure. During the first half of this short course, **Dr. Elizabeth Auden** from *Los Alamos National Laboratory* will provide an overview of space radiation environments; concepts such as particle / matter interactions, stopping power, and dose; radiation effects including TID, DD, and SEEs; and common units necessary for the study of radiation effects such as dose, displacement damage dose (DDD), linear energy transfer (LET), and non-ionizing energy loss (NIEL). The second half of the short course will focus on displacement damage. Topics will include basic physical mechanisms, electrical degradation observed in different device types, and recent displacement damage research in devices with emerging materials and feature sizes.

A top-level outline of the presentation is as follows:

- Introduction to radiation effects in materials
    - Space radiation environments
    - Particle / matter interactions and ionization
    - Depletion regions and pn-junctions
- Units for investigating radiation effects
    - Stopping power and linear energy transfer (LET)
    - Absorbed dose
    - Non-ionizing energy loss (NIEL)
    - Displacement damage dose (DDD)
- Basic mechanisms for displacement damage
    - Displacement damage generation: Frenkel pairs and defect clusters
    - Stable defect creation and annealing
    - Carrier mobility
    - Shockley-Reed-Hall recombination and generation
    - Messenger-Spratt equation
    - Measurements and modeling tools for material damage
- Electrical effects of displacement damage in different electronic components
    - Displacement damage-induced degradation in electrical metrics: leakage current, resistance, gain, charge collection efficient
    - Displacement damage-induced degradation in components: diodes, transistors, solar cells, pixels and other photonic devices, and more complex circuits
    - Measurements and modeling tools for electrical effects of damage
    - Displacement damage in non-silicon devices
- Recent displacement damage results in emerging devices and materials

Dr. Federico Faccio received the M.S. degree in physics from the University of Turin (IT) in 1991 and the PhD degree from INPG (FR) in 1997. He joined CERN, the European laboratory for particle physics, in 1991 where he is now the leader of the Microelectronics section in the electronics group. In the past 30 years, his technical work focused on the study of radiation effects in CMOS technologies used for the design of ASICs exposed to the ultra-high TID levels and hadron fluxes at the CERN LHC and HL-LHC colliders. In this context, he also contributed to the design of radiation-hard ASICs like ADCs, optical receivers and data recovery circuits, linear regulators and DCDC converters. He has authored and co-authored more than 100 technical papers, receiving awards at the NSREC, RADECS and ECCE conferences. He has served the radiation effects community as session and short course chairman at RADECs, and more recently he became associate editor of IEEE TNS.

Dr. Guilio Borghello
CERN

Dr. Stefano Bonaldo
DEI, Universtiy of Padova

PART II – TOTAL IONIZING DOSE EFFECTS IN SI MOSFETS UP TO ULTRA-HIGH DOSES

Dr. Federico Faccio
CERN

Silicon MOSFETs have been sensitive to Total Ionizing Dose (TID) since the early days of radiation studies on electronic devices, and that is still the case after more than 40 years and 20 generations (nodes) of CMOS technologies. Silicon dioxide (SiO2), the insulator that has been a blessing for the semiconductor industry because of its compatibility with Si, has instead been a curse for the application of CMOS circuits in radiation environments. Defects in SiO2 and at its interface with the Si channel of MOS transistors have determined the TID response of CMOS circuits built in micrometer bulk planar technologies of the 1980s as well as in today's nanometer-scale FinFETs.

In this course, prepared in collaboration with **Dr. Giulio Borghello** *(CERN)*, and **Dr. Stefano Bonaldo** *(DEI, University of Padova)*, **Dr. Federico Faccio** *(CERN)* will illustrate the basic mechanisms of TID in SiO2: charge yield, charge and hydrogen transport, charge trapping and de-trapping, interface state activation and annealing. The course will show how very similar mechanisms have differently affected the performance of MOSFETs in time. While in older technologies the gate oxide was the weak point and determined failure at krad TID levels, with the down-scaling of CMOS in the 100 nm range and below, the radiation response became dominated by auxiliary oxides like Shallow Trench Isolation (STI) or spacers.

The last part of the course will thus focus on the consequences of ionization in these insulators: the leakage currents that often represent the prevalent limitation to radiation tolerance in recent technologies, the dose-rate effects observable at high TID levels, and the transistor size dependencies including RINCE, RISCE (Radiation-Induced Narrow or Short Channel Effects) and halo implant effects. The manufacturing of these auxiliary oxides is less controlled and less uniform across nodes and fabrication plants than for the thermally grown gate oxide, leading to a wide variability in radiation response. This will be illustrated by a comparison between manufacturers, plants of the same manufacturer and manufacturing lots. In conclusion the course will show how, with or even without costly dedicated design techniques, TID tolerance to ultra- high levels (>100Mrad) is not a dream anymore.

A top-level outline of the presentation is as follows:

- Introduction
  - Environments with ultra-high TID levels
  - MOS transistors and CMOS technologies
  - TID-induced failures in CMOS ICs: all originate in the oxides
- Basic mechanisms behind TID effects in the oxides
  - Ionization and charge yield for different radiation sources
  - Charge transport in the oxide
  - Charge trapping: traps in the oxide, border traps, interface traps
  - Time evolution of the defects: switching and annealing
  - Influence of bias, temperature and dose rate
- The oxides in CMOS technologies and associated TID effects
  - Gate oxide
    - Threshold voltage, transconductance, carrier mobility
    - Proportionality between oxide thickness and TID effects
    - Low-frequency noise in MOS transistors
  - STI oxide
    - Leakage currents: drain-source and inter-device
    - Radiation-Induced Narrow Channel Effects (RINCE)
    - Influence of the Halo implants on the STI effects
    - Hardness-By-Design techniques (HBD) to eliminate the STI effects
  - Spacers
    - Radiation-Induced Short Channel Effects (RISCE)
  - Buried oxide in SOI technologies
  - True Enhanced Low-Dose Rate Sensitivity (ELDRs) in CMOS
- Trends in the TID sensitivity of CMOS technologies over time (technology nodes)
  - From old planar technologies to FinFETs
  - Variability in the radiation response: Fab-to-Fab, lot-to-lot
- Summary and conclusion

PART III – SINGLE-EVENT EFFECTS IN DEVICES AND ICS: PHENOMENA AND TESTING METHODS

Dr. Ani Khachatrian
US Naval Research Laboratory

Dr. Ani Khachatrian is a Research Scientist at the Optoelectronics & Radiation Effects Branch of the US Naval Research Laboratory. She received her Ph.D. in Chemical Physics from the University of Illinois at Chicago. Dr. Khachatrian completed her Postdoctoral Research Fellowship at the Johns Hopkins University Department of Chemistry and American Society of Engineering Education Fellowship at the Electronic Science and Technology Division of the US Naval Research Laboratory. Dr. Khachatrian's current research interests include development and implementation of linear and nonlinear optical methods to simulate single-event effects in micro- and nano-electronic devices and integrated circuits; application of pulsed-lasers to study single-event effects in wide bandgap material systems.

Dr. Ani Khachatrian from the *US Naval Research Laboratory* will present an overview of single- event effects phenomena in devices and integrated circuits. In harsh radiation environment, in addition to total ionizing dose, displacement damage dose, microelectronic devices are susceptible to single-event effects. SEE is a phenomenon that occurs when single energetic particle such as alpha particle, heavy ion, proton, neutron or other highly energetic particle, strikes sensitive area of a microelectronic device. There are three steps that can lead to a single-event effect: charge generation via both direct and indirect interactions of an energetic particle with matter; charge collection and the associated modification of the electrical potential at a sensitive node; and the response of the circuit to the collected charge. Single-event effects can be either non-destructive or destructive and can disrupt the normal operation of a device leading to potential failure events. Non-destructive single-event effects can manifest as single-event upsets, single-event transient, multi-bit upsets, and upsets hard error. Single-event latchup, single-event burnout and single event gate rapture are the examples of destructive events. With continued technology scaling, microelectronic devices growing more complex and emergence of novel semiconductor materials, the understanding of the mechanisms leading to single-event effects becomes increasingly important.

The presentation will discuss mechanisms responsible for single-event effects formation in devices and integrated circuits; types of single-event effects in analog, digital, logic circuits, memory cells and modern microelectronic devices and different test methods of single-event effects in modern technologies, their benefits and limitations.

A top-level outline of the presentation is as follows:

- Introduction
  - Radiation Effects in Devices and ICs
  - Definition of single event effects (SEE) phenomena
  - Environments that can cause SEE
- Three Steps in SEE Formation
  - Charge generation
  - Charge collection mechanisms
  - Circuit response to SEE
- SEE effects in devices and integrated circuits
  - SETs in linear analog circuits
  - SEUs in digital circuits
  - SETs in power devices
  - SEE in memory cells
  - SEE in logic circuits
- Testing methods
  - Heavy Ion (HI) testing – advantages and limitations
  - HI testing vs pulsed laser SEE method
- Conclusion

PART IV – RADIATION EFFECTS ON PHOTONICS: IMAGE SENSORS AND OPTICAL FIBERS

Prof. Sylvain Girard
University of Saint-Etienne
Dr. Cedric Virmontois
CNES

Photonics is an important topic due to its wide-ranging applications and transformative impact on various fields, from communications, data transfer, imaging and sensing. Today, high performance photonic solutions developed for terrestrial applications are more and more implemented in radiation-rich environments. It is then crucial to study the radiation effects on these technologies in order to be able to assess their vulnerabilities and if needed to apply hardening techniques before integrating them under irradiation.

In this lecture **Prof. Sylvain Girard** from *University of Saint-Etienne* and **Dr. Cedric Virmontois** from **CNES** will describe radiation effects on two of the main photonic technologies: image sensors and optical fibers.

The first part will address radiation effects on silica-based optical fibers and bulk glasses. The advantages and limitations for the implementation of these technologies in various harsh environments will be discussed as well as the different targeted applications from communications to sensors. The parameters governing their macroscopic radiation responses through the generation of radiation induced point defects will be reviewed as well as the existing strategies to design radiation hardened optical fibers and fiber sensors.

The second part will address image sensors and detectors. A particular emphasis will be made on visible and infrared technologies used in space. After a description of the device principles, the lecture will focus on the performances degraded by radiation. Dark signal, noises, charge transfer inefficiency, quantum efficiency and blinking pixels will be introduced as well as how these parameters evolve under irradiation.

A top-level outline of the presentation is as follows:

Part A – Radiation Effects on Silica-Based Optical Fibers and Bulk Glasses
- Introduction to fiber-based technologies and their applications under irradiation
  - Optical fiber operation principles & manufacturing processes
  - Optical fibers for telecommunications and sensing
- Optical Fibers in Radiation-Rich Environments
  - A short historical perspective
  - Main applications domains and environments of interest
- Radiation Effects on Optical Fibers & Bulk Glasses
  - Radiation-glass interactions
  - At microscopic scale: physics of point defects
  - At macroscopic scale: RIA, RIE, RIRIC
  - Intrinsic and Extrinsic Parameters influencing the RIA levels and kinetics
- Radiation Hardening Strategies
  - For optical fibers
  - For optical fiber sensors
- Fiber Radiation Sensors and Dosimeters
- Current and Future Challenges

Part B – Radiation Effects on Detectors and image sensors
- Presentation of Detectors and Image Sensors Technologies
- Basic Mechanisms of Radiation Effects on Detectors
  - Ionizing effects
  - Displacement Damage Effects
- Radiation effects on detector technologies
  - Bolometer and calorimeter
  - Silicon-based image sensor
  - IR sensors

Prof. Sylvain Girard obtained his PhD in Photonics in 2003 from Université Jean Monnet (UJM), France. He joined the CEA in 2004 to investigate the vulnerability and radiation hardening of optical components for the Laser Mégajoule and became a CEA Senior Expert in 2011. In 2012, Sylvain joined the UJM as Full Professor. He is today leading the MOPERE research group of Lab. Hubert Curien and is one of the founders of the LabH6 joint research lab between UJM, CNRS and the industrial Exail. His main research axis deals with the radiation effects on photonic technologies, in particular fiber-based technologies. He serves the radiation effects community in several positions, in particular as Member-at-Large on the IEEE NPSS Radiation Effects Steering Group and as one of the Associate Editors of IEEE Transactions on Nuclear Science. He has authored or co-authored more than 280 peer-reviewed papers. Sylvain received the 2013 IEEE NPSS Early Achievement Award, the 2014 IEEE/SEE Léon-Nicolas Brillouin Award from and the 2021 Research Prize from the iXcore, iXblue, iXlife Foundation. In 2023, he has been nominated as a Senior Member of the Academic Institute of France, IUF.

Dr. Cedric Virmontois received the Ph.D. degree in Microelectronic from the Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO), Toulouse, France, in 2012. Cedric presently works for the Centre National d'Études Spatiales (CNES) in Toulouse, France, in the Technology & Digital Directorate. He started as Detection Chain specialist from 2012 to 2018, his work involves the development of imagers for future space imaging missions, electro-optical characterizations, analysis and testing of detectors. He extends his researches to several solid state image senssors dedicated to visible and infrared imaging using ground and in-flight data in order to find generic ways to predict and mitigate space radiation effects. Cedric has also contributed to the understanding and modeling of dark-current Random Telegraph Signals (RTS) in image sensor. Since 2021 he is the head of the Opto-Electronic detection department.

Technical Program

TECHNICAL INFORMATION

"On behalf of the Technical Program Committee, I invite you to attend the 2024 NSREC Technical Program in Canada's capital city of Ottawa. This international gathering of representatives from industry, academia, and government will enhance our understanding of the latest developments in nuclear and space radiation effects on materials, microelectronics, and systems. We welcome the attendance from students to seasoned professionals to engage in robust technical debates across a broad set of topics in the research field. I am grateful for the service of our poster chair, data workshop chair, and our session chairs who will assemble an outstanding program. I look forward to working with all the authors, reviewers, invited speakers, and chairpersons who will contribute to the 2024 NSREC Technical Program."

William H. Robinson,
Georgia Tech Research Institute
Technical Program Chair

The NSREC Technical Program consists of contributed oral and poster papers, a data workshop, and invited talks. The oral presentations will be 12 minutes in duration with an additional three minutes for questions. The technical sessions and their chairpersons are:

- **Basic Mechanisms of Radiation Effects**
  Chair: David Hughart, Sandia National Laboratories
- **Dosimetry and Facilities**
  Chair: Federico Ravotti, CERN
- **Hardening by Design**
  Chair: Dakai Chen, Zero-G Radiation Assurance
- **Hardness Assurance Technologies, Modeling, and Testing**
  Chair: Camille Bélanger-Champagne, TRIUMF
- **Photonic Devices and Integrated Circuits**
  Chair: Serena Rizzolo, Airbus Defence and Space
- **Radiation Effects in Devices and Integrated Circuits**
  Chair: Adrian Ildefonso, Naval Research Laboratory
- **Single-Event Effects: Devices and Integrated Circuits**
  Chair: Daniel Limbrick, North Carolina A&T State University
- **Single-Event Effects: Mechanisms and Modeling**
  Chair: Florent Miller, Nuclétudes
- **Space and Terrestrial Environments**
  Chair: Justin Likar, Johns Hopkins University Applied Physics Laboratory
- **Poster Session**
  Chair: Daisuke Kobayashi, JAXA
- **Radiation Effects Data Workshop**
  Chair: Li Chen, University of Saskatchewan

POSTER SESSION

Those papers that can be presented more effectively in a visual format with group discussion will be displayed in the Poster Session. Posters can be viewed during the week, and authors will be available during the Poster Session (Wednesday, July 24th. 1:15 PM - 4:00 PM). The Poster Session is chaired by **Daisuke Kobayashi** from *JAXA*.

RADIATION EFFECTS DATA WORKSHOP

Workshop papers provide piece part radiation response data and radiation test facilities technical information. Workshop papers can be viewed during the week, and authors will be available during the Workshop Session (Thursday, July 25th. 1:15 PM - 4:00 PM). The Data Workshop is chaired by **Li Chen** from the *University of Saskatchewan.*

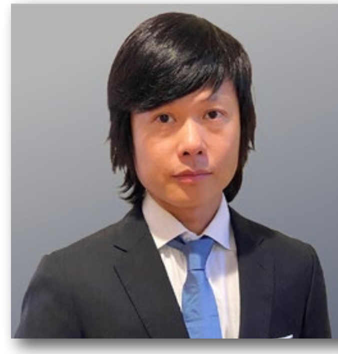
LATE-NEWS PAPERS

A limited number of late-news papers will be accepted and included in the Poster Session and the Radiation Effects Data Workshop. The submission window for these newsworthy papers is open from April 12, 2024 through May 10, 2024. Detailed instructions for submitting late-news summary will be available on the NSREC website at ***www.nsrec.com.***

Session Chairs

David Hughart
Sandia National Laboratories
Basic Mechanisms of Radiation Effects

Federico Ravotti
CERN
Dosimetry and Facilities



Dakai Chen
Zero-G Radiation Assurance
Hardening by Design

Camille Bélanger-Champagne
TRIUMF
Hardness Assurance Technologies, Modeling, and Testing

Serena Rizzolo
Airbus Defence and Space
Photonic Devices and Integrated Circuits

Adrian Ildefonso
Naval Research Laboratory
Radiation Effects in Devices and Integrated Circuits

Daniel Limbrick
North Carolina A&T State Universityr
Single-Event Effects: Devices and Integrated Circuits

Florent Miller
Nuclétudes
Single-Event Effects: Mechanisms and Modeling

Justin Likar
Johns Hopkins University Applied Physics Laboratory
Space and Terrestrial Environments

Technical Program Tuesday

OTTAWA SALON

8:15 AM **OPENING REMARKS**
Heather Quinn, Air Force Research Laboratory, General Chair

8:20 AM **AWARDS PRESENTATION**
Robert Reed, Vanderbilt University, Radiation Effects Steering Group, Executive Chair

9:05 AM **TECHNICAL SESSION OPENING REMARKS**
William H. Robinson, Georgia Tech Research Institute, Technical Program Chair

SESSION A **SPACE AND TERRESTRIAL ENVIRONMENTS**
9:10 AM SESSION INTRODUCTION
Chair: Justin Likar (JHU APL)

A-1 **A Review of Single-Event Upset Rate Calculation Methods**
9:15 AM
D. Hansen[1], T. Manich[1], I. Zavatkay[2]
1. L3Harris, San Diego, CA (USA)
2. L3Harris, Rochester, NY (USA)

This paper reviews rate calculation methods in the open literature and compares them to published on-orbit data.

A-2 **Design of a Miniaturized Scintillation Detector for Energetic Electron**
9:30 AM **Precipitation Measurements on the RADICALS Mission**
A. Telikicherla[1], B. Yu[1], K. Gan[1], J. M. Gan[1], T. Kaur Sraw[1], H. Tiedje[1], R. Fedosejeves[1], L. Ozeke[1], I. R. Mann[1]
1. University of Alberta, Canada

We present the design of a novel Silicon Photomultiplier based scintillation detector for making in-situ energetic electron precipitation measurements in space. The detector is planned to be flown on-board the RADICALS low Earth orbiting satellite.

A-3 **Evaluating Proton Dose Modeling in Shielded Systems with On-Orbit**
9:45 AM **LED Degradation**
N.E. Nickles[1], B. Fodness[1], T. McCracken[1]
1. Ball Aerospace, Boulder, CO

On-orbit LED output degradation is used to compare displacement damage calculation techniques, trapped proton models, and increasing levels of shielding fidelity to make conclusions on margins inherent in dose modeling for light to heavily-shielded systems.

10:00 AM – 10:30 AM BREAK
CANADA HALL 2 & 3

SESSION B 10:30 AM

HARDNESS ASSURANCE: PIECE PARTS TO SYSTEMS AND TESTING APPROACHES

SESSION INTRODUCTION

Chair: Camille Bélanger-Champagne (TRIUMF)

B-1 10:35 AM

The HEARTS EU Project and Its Initial Results on Fragmented High-Energy Heavy Ion Single-Event Effects Testing

R. Garcia Alia[1], A. Waets[1], A. Coronetti[1], K. Bilko[1], M. Derlieux[1], N. Emriskova[1], L. Esposito[1], M. Fraser[1], E. Johnson[1], K. Klimek[1], D. Prelipcean[1], M. Sacristan Barbero[1], S. Danzeca[1], F. Ravotti[1], S. Gilardoni[1], F. Cerutti[1], M. Durante[2], C. Schuy[2], T. Wagner[2], U. Weber[2], M. Bagatin[3], S. Gerardin[3], S. Francola[4], R. Mancini[4], M. Rostewitz[5]

1. *CERN, Switzerland*
2. *GSI, Germany*
3. *University of Padova, Italy*
4. *Thales Alenia Space, Italy*
5. *TESAT, Germany*

We perform SEE tests with well-characterized fragmented high-energy heavy-ion beams and compare the results with those expected from conventional, mono-LET measurements, showing a satisfactory agreement between the two, and paving the way to RHA exploitation.

B-2 10:50 AM

A Rapid, Pulsed Laser Testing Approach for Single-Event Latchup Screening in Microelectronics

L. Andrus[1], J. Warner[2], W. Rice[2], A. Le[2], C. Saltonstall[1]

1. *Sandia National Laboratories, USA*
2. *Northrop Grumman, USA*

A laser testing system for rapid screening of single-event latchup in microelectronics with real-time visualization of SEL sensitive nodes via photo-emission is presented.

B-3 11:05 AM

Dose Measurements and Effects in DRAMs During PCB Inspections Using X rays

M. Chun[1], G. Bak[2], N. Pieper[3], Y. Xiong[3], S. Jeon[4], R. Fung[4], S. Wen[4], B. Bhuva[3], S. Baeg[1]

1. *Hanyang University, Korea, Republic of*
2. *Radiate Inc., Korea, Republic of*
3. *Vanderbilt University, USA*
4. *Cisco Systems Inc., USA*

Under the PCB inspection environment, TID levels were measured for various combinations of filters, PCB, and packages to demonstrate significant variances in TID effects by X rays. Retention-time degradations were compared for 1y-nm DRAM components.

B-4 11:20 AM

A Parallelized Neutron Radiation Testing Technique to Understand Failures Within a Complex SoC

N. Harris[1], W. Smith[1], M. Wirthlin[1], J. Goeders[1]

1. *Brigham Young University, USA*

This work presents a methodology for testing multiple components of a system-on-chip (SoC) device, focusing on simultaneous testing of multiple components. Results are included for two neutron beam tests.

B-5
11:35 AM

Design and Characterization of a Radiation Tolerant Wireless Physical Layer for Control Applications in Particle Accelerators

A. Scialdone[1], R. Ferraro[1], J. Boch[2], F. Saigné[2], L. Dilillo[2], S. Danzeca[1], A. Masi[1]

1. *CERN, Switzerland*
2. *Université de Montpellier, France*

The article explores the design and the evaluation of a wireless physical layer (PHY) capable of withstanding radiations, specifically tailored for equipment control in harsh radiation environments, such as those found in particle accelerators.

POSTER PAPERS
PB-1

Single-Event Degradation and Failure of a Multi-Die, SiC MOSFET Module for Deep Space Applications

J. Kozak[1], C. Pham[1], J. Likar[1], S. Katz[1], J. Oarethu[1], J. Neville[1]

1. *Johns Hopkins University Applied Physics Laboratory, USA*

Multi-chip, SiC MOSFET modules were subjected to Heavy Ion stressors under varying gate and drain voltages as well as temperature conditions. Tests were conducted at multiple beam facilities.

PB-2

A Comparative Analysis of Radiation Tolerance in Charge-Trap and Floating-Gate 3D NAND Memory Technologies

M. Kumar[1], M. Buddhanoy[1], B. Ray[1]

1. *Colorado State University, USA*

Floating-gate 3D NAND technology is found to be more sensitive to total-ionizing-dose effects than charge-trap counterparts under identical irradiation conditions. The surrounding dielectric region of floating-gate cell may explain its higher sensitivity.

PB-3

Context-Dependent Outlier Detection Technique for Analysis of Single-Event Frequency Transients in LC Oscillators

W. Rombouts[1], P. Karsmakers[1], G. Adom-Bamfi[1], S. Biereigel[2], J. Prinzie[1]

1. *KU Leuven, Belgium*
2. *CERN, Switzerland*

Channeltron detector non-idealities introduce anomalies in measured data of LC oscillators. We propose a context-dependent anomaly removal methodology using machine learning techniques. Results demonstrate improved data consistency, ensuring reliable analysis in radiation sensitivity studies.

PB-4

Statistical Analysis of Historical SEL Test Data to Provide A Priori Risk Estimates for Use of Unhardened CMOS Parts

R. Ladbury[1], G. Allen[2], F. Irom[2], R. Gaza[3], S. Vartanian[2], J. Barth[1], R. Hodson[4]

1. *NASA Goddard Space Flight Center, USA*
2. *NASA Jet Propulsion Laboratory, USA*
3. *NASA Johnson Space Center, USA*
4. *NASA Langley Research Center, USA*

We develop guidelines for a priori assessment of risk due to potentially SEL susceptible parts by exploratory analysis of large datasets of SEE test data for unhardened CMOS parts.

PB-5 **Evaluating System-Level Radiation Hardness with Minimum Order Distributions**

C. Champagne[1], B. Sierawski[1]
1. Vanderbilt University, USA

A probabilistic framework for system-level TID and displacement damage hardness assurance is developed using order statistics. Piece part failure distributions inform system-level failure distributions for series configurations, achieving confidence-bounded failure probabilities in variable space environments.

PB-6 **Analysis of System Radiation Effects Using Markov Chains**

D. Hansen[1], T. Manich[1], I. Zavatkay[1]
1. L3Harris, USA

This paper describes methods for using Markov chains to perform single-event upset analysis for satellite systems. The discussion includes methods to calculate the hitting time for failure states in the system.

PB-7L **Solid State Drive Radiation Tolerance with Active Testing**

E. Wilcox[1], A. Wood[1], G. Allen[2], M. Carts[1], M. Casey[1]
1. NASA, USA
2. Jet Propulsion Laboratory, USA

Single-event effects (SEE) and total ionizing dose (TID) data are presented for several off-the-shelf automotive-grade and industrial-grade solid-state drives, and the effects of different active test configurations are explored.

PB-8L **Correlative Heavy Ion and Pulsed Laser Latchup Results and Initial Radiation Hardness Assurance Implications**

J. Likar[1], C. Pham[1], J. Oarethu[1], S. Zajac[1], N. Ahmed[1], S. Katz[1], B. Dean[2]
1. JHU APL, USA
2. Vanderbilt University, USA

Correlative heavy ion and pulsed laser (PL) Single Event Latchup results are presented for a series of devices developed on sub-micron CMOS processes. Implications for PL latchup screening for non-radiation hardened devices are discussed.

11:50 AM – 1:00 PM
CANADA HALL 2 & 3
LUNCH

SESSION C **DOSIMETRY AND FACILITIES**
1:00 PM SESSION INTRODUCTION
Chair: Federico Ravotti (CERN)

C-1 **Electron Beam Dosimetry for Space Solar Cell Radiation Qualifications**
1:05 PM

S. Messenger[1], S. Witczak[1], J. Warner[1]
1. Northrop Grumman Corporation (NGC), USA

The implications of common dosimetry methods used in electron beam irradiations for solar cell space qualifications are investigated. Monte Carlo simulations show that ionizing dosimetry can lead to an underestimation of the desired electron fluence.

C-2
1:20 PM

Characterization of Fully Fragmented High-Energy Heavy Ion Beams for SEE Testing Through Measurements and Simulations

A. Waets[1], R. Garcia Alia[1], N. Emriskova[1], L. Salvatore Esposito[1], K. Bilko[2]

1. *European Organization for Nuclear Research (CERN), Switzerland*
2. *Université Jean Monnet, France*

We performed dosimetry of fully fragmented, very-high-energy heavy ion beams for SEE testing using solid state detector measurements and detailed Monte Carlo FLUKA simulations focusing on the interaction between beam and device-under-test.

C-3
1:35 PM

Sensitivity Enhancement of Tapered Cerium-Doped Optical Fibers for Dosimetry Applications

F. Fricano[1], R. Vallifuoco[2], D. Lambert[3], A. Morana[1], P. Paillet[3], H. El Hamzaoui[4], B. Capoen[4], M. Bouazaoui[4], E. Marin[1], E. Catalano[2], A. Minardo[2], Y. Ouerdane[1], A. Boukenter[1], S. Girard[1]

1. *Laboratoire Hubert Curien, Université de Saint Etienne, France*
2. *Università della Campania, Italy*
3. *CEA, France*
4. *Université de Lille, France*

We compared radiation-induced luminescence in cerium-doped optical fiber and its tapered versions, having different sensitive volumes. It is proved the radiation sensitivity increases when decreasing core size, advancing microscale fiber-based dosimetry.

POSTER PAPERS
PC-1

14 MeV and Atmospheric Neutron Monitoring Through Optical Fiber Dosimeters

M. Roche[1], D. Lambert[2], L. Weninger[1], A. Morana[1], N. Kerboub[3], C. Bélanger-Champagne[4], H. Cornelia[4], M. Trinczek[4], E. Marin[1], A. Boukenter[1], Y. Ouerdane[1], P. Paillet[2], J. Mekki[3], T. Robin[5], S. Girard[1]

1. *Laboratoire Hubert Curien, Université de Saint Etienne, France*
2. *CEA, France*
3. *CNES, France*
4. *TRIUMF, Canada*
5. *EXAIL, France*

Radiation-induced attenuation-based dosimetry exploiting phosphosilicate optical fiber has been established as a reliable and precise dosimetry technique. We evaluate here its potential to monitor 14-MeV and atmospheric neutrons by combining radiation tests with Geant4 simulations.

PC-2

Using Quasi-Monoenergetic Neutrons From a 30-MeV Proton Beam for Single-Event Effects Studies

Y. Chiang[1], H-M. Lee[2], K-Y. Chu[2], Y-H. Teng[2]

1. *Taiwan Semiconductor Manufacturing Company, Ltd., Taiwan*
2. *National Atomic Research Institute, Taiwan*

A new facility that generates quasi-monoenergetic neutrons from a 30-MeV proton beam hitting Be target is presented for evaluating SE response to terrestrial neutrons. Results show agreement with LANSCE facility for a 16 nm process.

PC-3 **Scan-Based Radiation Testing Using SRAM Dosimeters for Device and Beam Characterization**

S. Khan[1], D. Eom[1], J. Kim[1], S. Chung[1], J. Kih[1], S. Woo[1], C. Cho[1], K. Kim[1], S. Wender[2]

1. *QRT Inc., Republic of Korea*
2. *Los Alamos National Laboratory (LANL), USA*

We performed single-event effects (SEE) tests by scanning a SRAM-based dosimeter in discrete steps along horizontal and vertical directions in the beamline for beam and device characterization to measure beam profile and intrinsic sensitivity.

PC-4L **Calibrating P-I-N Diodes for Displacement Damage Monitoring in a Space Radiation Environment**

A. Rosenfeld[1], D. Bennett[1], V. Pan[1], J. Vohradsky[1], T. Tran[1], D. Bolst[1], M. Petesecca[1], M. Lerch[1], K. Aoki[2], T. Nakaji[2], H. Mizuno[2], T. Inaniwa[2], D. Wagenaar[3], B. Bergmann[4], H. Cintas[4], P. Smolyankiy[4], I. Anokhin[5]

1. *University of Wollongong, Australia*
2. *QST Hospital, Japan*
3. *University Medical Center Groningen, Netherlands*
4. *Czech Technical University, Czech Republic*
5. *Institute for Nuclear Research, Ukraine*

The NIEL sensors based on p-i-n diodes with long base of different topology and n-Si resistivity were fabricated, and their response to heavy ions typical for GCR, electrons, and fast neutrons was investigated.

SESSION D **PHOTONIC DEVICES AND INTEGRATED CIRCUITS**
1:50 PM SESSION INTRODUCTION
Chair: Serena Rizzolo (Airbus Defence and Space S.A.S.)

D-1 **Temperature Dependence of the Radiation Response of Ultra-Low Loss**
1:55 PM **Optical Fibers: Role of Self-Trapped Holes**

M. Roche[1], C. Campanella[1], A. Morana[1], V. De Michele[1], E. Marin[1], A. Boukenter[1], Y. Ouerdane[1], J. Mekki[2], S. Girard[1]

1. *Université Jean Monnet de Saint-Etienne, Laboratoire Hubert Curien, France*
2. *CNES, France*

We investigated the temperature (-60 °C, 20 °C 100 °C) dependence of the X-ray radiation induced attenuation, in the visible to infrared spectral domain, of an ultra-low loss pure silica core single mode optical fiber.

D-2 **Total-Ionizing-Dose Effects in Integrated Silicon Photonics Mach-Zehnder**
2:10 PM **Modulators Using Localized X-Ray Pulses**

M. Hosseinzadeh[1], J. Teng[1], B. Ringel[1], P. Francis[1], J. Heimerl[1], G. Tzintzarov[2], A. Little[2], J. Bonsall[2], S. Lalumondiere[2], D. Monahan[2], J. Cressler[1]

1. *Georgia Institute of Technology, USA*
2. *The Aerospace Corporation, USA*

Silicon-photonic MZMs were exposed to a microbeam X-ray source, revealing three distinct TID effects in the phase shifter. Derivations and potential physical mechanisms underlying these effects are discussed.

2:25 PM – 2:55 PM CANADA HALL 2 & 3 — BREAK

D-3 2:55 PM

Displacement Damage and Ionization Effects on Waveguide-Integrated Germanium-Silicon PIN Photodiodes

K. Arnold[1], H. Dattilo[1], E. Zhang[2], M. McCurdy[1], S. Musibau[3], M. Berciano[4], A. Tsiara[4], D. Linten[4], K. Croes[4], J. Van Campenhout[4], R. Schrimpf[1], D. Fleetwood[1], R. Reed[1], S. Weiss[1]

1. *Vanderbilt University, USA*
2. *University of Central Florida, USA*
3. *Katholieke Universiteit Leuven*
4. *imec, Belgium*

Effects of configuration on germanium-silicon photodiode performance under 1.8-MeV proton and 10-keV X-ray irradiation are studied. Modest operating dark current increases up to 35 nA result from nonradiative defect center generation and ionization-induced traps.

D-4 3:10 PM

Proton Radiation Effects on Low Flux P-on-N Short Wavelength Infrared HgCdTe Focal Plane Array

T. Friess[1,2,3,4], T. Pichon[5], T. Le Goff[1], M. Baumann[5], L. Provost[5], C. Koumeir[6], A. Rouvie[4], O. Boulade[5], A. Le Roch[2], V. Goiffon[2], S. Rizzolo[3], O. Gravrand[1]

1. *CEA Leti, France*
2. *ISAE-SUPAERO, France*
3. *Airbus Defence and Space S.A.S., France*
4. *CNES, France*
5. *CEA IRFU, France*
6. *Arronax Nantes, France*

Dark current estimates have been made on a very low flux short wave infra-red (SWIR) HgCdTe detector for astronomical purposes. Degradations were observed pixel to pixel following proton irradiation.

D-5 3:25 PM

Radiation Effects in Quanta Image Sensors

J. Krynski[1], A. Neyret[1], V. Bernard[2], V. Lalucaa[2], A. Materne[2], A. Le Roch[1], C. Virmontois[2], V. Goiffon[1]

1. *ISAE-SUPAERO, France*
2. *CNES, France*

We study the impact of radiation on a quanta image sensor. We find dark current increases linearly with proton fluence and we extend an empirical model of predicting dark current increase to this new technology.

D-6
3:40 PM

Displacement Damage Effects on Hole Collection P-Type Deep-Trench Pinned Photo-MOS Pixels

A. Antonsanti[1], V. Malherbe[2], A. Le Roch[1], L. Ryder[3], P. Roche[2], A. Tournier[2], C. Virmontois[4], J. Lauenstein[3], V. Goiffon[1]

1. *ISAE-SUPAERO, France*
2. *STMicroelectronics, France*
3. *NASA GSFC, USA*
4. *CNES, France*

This work studies displacement damage effects in P-type, hole collecting photogates, developed by STMicroelectronics after proton irradiation. The focus is made on radiation induced dark current and dark current random telegraph signal.

D-7
3:55 PM

Displacement Damage Effects on a CDTI based CCD-on-CMOS: Dark Current and Charge Transfer Inefficiency

A. Salih Alj[1,2,3], A. Antonsanti[1], A. Le Roch[1], P. Touron[3], F. Roy[3], A. Tournier[3], S. Demiguel[4], C. Virmontois[2], V. Lalucaa[2], J. Michelot[5], P. Magnan[1], V. Goiffon[1]

1. *ISAE-SUPAERO*
2. *CNES, France*
3. *STMicroelectronics, France*
4. *Thales Alenia Space, France*
5. *Pyxalis, France*

Displacement damage effects induced by proton and neutron irradiation are explored in a capacitive deep trench CCD-on-CMOS image sensor. Dark current and charge transfer inefficiency are studied to reveal the generation and capture-release trap signatures.

POSTER PAPERS
PD-1

Radiation Assessment of a 56 Gbps Electro-Absorption Modulator Driver for Optical Intra-Satellite Links

K. De Bruyn[1], A. Karmakar[1], M. Vanhoecke[2], L. Bogaert[3], G. Roelkens[3], A. Naughton[4], D. Mackey[4], J. Prinzie[5], P. Leroux[5], J. Bauwelinck[1]

1. *Ghent University - imec, Belgium*
2. *NVIDIA Ghent, Belgium*
3. *Ghent University, Belgium*
4. *mbryonics, Ireland*
5. *KU Leuven, Belgium*

A 130 nm SiGe BiCMOS radiation hardened by process 56 Gbps electro-absorption modulator driver chip is proposed for optical intra-satellite links. The total ionizing dose and single-event effects responses are presented.

PD-2 **Radiation Hardness of Silicon Avalanche Photodiodes Used in Space Applications**

P. Berard[1], J.-F. Germain[1], M. Couture[1], F. Belfio[2], N. Kerff[2], N. Sasseville-Langelier[2], A. Touville[2], E. Tremblay[2], M. Chicoine[3], L. Martinu[2], F. Schiettekatte[3]

1. *Excelitas Canada Inc., Canada*
2. *École Polytechnique de Montréal, Canada*
3. *Université de Montréal, Canada*

Silicon avalanche photodiodes of different structures, sizes, and thicknesses were exposed to protons of various energies and fluences. Impact on parameters, with emphasis on bulk noise, are presented and discussed.

PD-3L **Total Ionizing Dose Hardness of a Silicon Photonic Optical Receiver with Polarization Controller**

E. Chansky[1], M. Hu[2], A. Wissing[1], X. Du[1], T. Heim[2], M. Garcia-Sciveres[2], C. Schow[1]

1. *University of California Santa Barbara, USA*
2. *Lawrence Berkeley National Laboratory, USA*

A Silicon photonic optical receiver with polarization controller was irradiated to 7.5 Mrad with a Krypton source. On chip polarization splitter, photodiodes, and thermal phase shifters are shown to be hardened for optical communication use.

4:10 PM END OF TUESDAY SESSIONS

5:30 – 7:30 PM
SHAW CENTER
CANADA HALL 2 & 3
EXHIBITOR RECEPTION

Technical Program Wednesday

OTTAWA SALON
INVITED TALK
8:15 AM - 9:15 AM

Canada's Role in Space Exploration: Past, Present, and Future

Cassandra Marion, Ph.D.
Geologist – Planetary Scientist, Science Advisor; Canada Aviation and Space Museum

Cassandra is a life-long explorer and learner. She completed her BSc in Earth Sciences at the University of Ottawa, MSc in Geology at Memorial University, NL and a PhD in Geology and Planetary Science and Exploration at Western University's Earth and Planetary Institute. Her studies focus on meteorite impact craters, and lunar and Martian analogue environments in the Canadian Arctic and sub-Arctic. After 13 northern expeditions, she has developed considerable expertise leading and managing field expeditions and had the privilege of assisting in the expedition and geology training of 3 astronauts including Canadians Jeremy Hansen and Joshua Kutryk. Cassandra has also participated and led a series of simulated robotic and human missions designed to learn, train and prepare for real missions to the Moon and Mars. She has more than a decade of experience in education and public outreach, developing and delivering science programming which led to her current role as Science Advisor for the Canada Aviation and Space Museum in Ottawa, where she acts as a science communicator dedicated to sharing her passion and knowledge of Earth and planetary science with communities near and far.

OTTAWA SALON
SESSION E
9:15 AM

RADIATION EFFECTS IN DEVICES AND INTEGRATED CIRCUITS
SESSION INTRODUCTION
Chair: Adrian Ildefonso (U.S. Naval Research Laboratory)

E-1
9:20 AM

Total-Dose Induced Threshold Voltage Shift Dependence on Tier Pitch in 3D NAND Flash Memories

M. Bagatin[1], S. Beltrami[2], A. Paccagnella[1], S. Gerardin[1]
1. *University of Padova, Italy*
2. *Micron Technology-Process R&D, Italy*

The impact of tier pitch scaling on the total ionizing dose sensitivity of the cell array is investigated in 3D NAND Flash memories using charge-trap technology. Results show a mild dependence on tier pitch.

E-2
9:35 AM

In-situ Analog Computing Under Ionizing Radiation With SONOS Charge Trap Memory

M. Siath[1], T. Xiao[2], M. Spear[1], D. Wilson[1], C. Bennett[2], B. Feinberg[2], D. Hughart[2], J. Neuendank[1], W. Brown[3], H. Barnaby[1], V. Agrawal[4], H. Puchner[4], S. Agarwal[2], M. Marinella[1]
1. *Arizona State University, USA*
2. *Sandia National Laboratories, USA*
3. *Ellutions, LLC, USA*
4. *Infineon Technologies, USA*

We experimentally performed analog in-memory computing on a SONOS charge-trap memory array that was simultaneously exposed to ionizing radiation and measured the accuracy of image classification as a function of total ionizing dose.

E-3 9:50 AM

Ionizing Radiation-Induced Data Imprinting Effects in SRAM Arrays

U. Surendranathan[1], A. Milenkovic[1], B. Ray[2]

1. The University of Alabama in Huntsville, USA

2. Colorado State University, USA

We evaluate commercial SRAMs for data imprinting under ionizing radiation, finding near-perfect imprinting at 50 krad(Si) and reverse imprinting in some samples. Newer SRAMs with smaller transistors are less susceptible, and imprinting diminishes with annealing.

10:05 AM – 10:35 AM
CANADA HALL 2 & 3

BREAK

E-4 10:35 AM

Displacement Damage and Total Ionizing Dose Induced by Proton Irradiations in SiC Vertical Power MOSFETs at Ultra-High Doses

C. Martinella[1], S. Bonaldo[2], M. Bagatin[2], S. Gerardin[2], N. Für[1], V. Gassenmeier[1], A. Paccagnella[2], U. Grossner[1]

1. APS Laboratory - ETH Zurich, Switzerland

2. University of Padova, Italy

The radiation effects in SiC power MOSFETs induced by 3-MeV protons at high fluence are evaluated. Significant parametric shifts are observed due to DD and TID depending on the bias condition and technology generation.

E-5 10:50 AM

TID-Induced Flicker and Lorentzian Noise Degradation in 110 nm CMOS Transistors

L. Ratti[1], L. Gaioni[2], S. Giroletti[1], M. Manghisoni[2], V. Re[2], G. Traversi[2], C. Vacchi[1]

1. University of Pavia, Italy

2. University of Bergamo, Italy

Effects of 10-keV X rays on the noise performance of 110-nm CMOS transistors are investigated. Particular attention is paid to 1/f and Lorentzian noise, whose degradation mechanism is linked to hole build-up in the STI.

E-6 11:05 AM

Impact of Total-Ionizing Dose on Injection-Locked Voltage-Controlled Oscillators

D. Sam[1], J. Teng[1], J. Heimerl[1], D. Nergui[1], M. Frounchi[1], Y. Mensah[1], Z. Brumbach[1], B. Ringel[1], M. Hosseinzadeh[1], J. Shin[1], A. Sarrafinazhad[2], E. Zhang[3], C. Bryant[4], H. Dattilo[4], D. Fleetwood[4], J. D. Cressler[1]

1. Georgia Institute of Technology, USA

2. Arizona State University, USA

3. University of Central Florida, USA

4. Vanderbilt University, USA

TID effects on the locking range and phase noise of 130-nm CMOS injection-locked VCOs were explored using an X-ray irradiation source. Surprisingly, the locking range extended, and the phase noise improved, with increasing TID.

POSTER PAPERS

PE-1

Impact of 12nm FinFET Technology Variations on TID Effects: A Comparative Study of GF 12LP and 12LP+ at the Transistor Level

A. Vidana[1], N. A. Dodds[1], N. Nowlin[1], P. Oldiges[1], K. Sapkota[1], T. Wallace[1], J. Kauppila[2], L. Massengill[2], H. Barnaby[3]

1. *Sandia National Laboratories, USA*
2. *Reliable MicroSystems, LLC, USA*
3. *Arizona State University, USA*

We compare the measured TID responses of GlobalFoundries 12LP and 12LP+ 12nm FinFET technologies. Differences in their TID response are attributed to certain expected differences between the physical parameters of these two processes.

PE-2

Modeling of Doped Fully Depleted Behavior Induced by Total Ionizing Dose in Voltage Reference Circuits from a 65 nm Partially Depleted SOI Technology

J. Lomonaco[1], N. Rostand[1], S. Martinie[2], G. Charbonnier[1], C. Marcandella[1], T. Bedecarrats[2], A. Bournel[3]

1. *CEA DAM DIF, France*
2. *CEA-LETI, France*
3. *Université Paris-Saclay, France*

The degradation induced by ionizing dose is characterized in partially depleted SOI voltage reference circuits: a fully depleted-like behavior is evidenced. The front and back interface coupling is confirmed through characterization and TCAD simulations.

PE-3

Comparison of Total Ionizing Dose Effects Between Double and Conventional SOI Devices

S. Chen[1], J. Li[1], F. Liu[1], B. Li[1], Y. Wang[1], H. Zhu[1], Y. Huang[1], D. Li[1], F. Wang[1], Y. Zhang[1], J. Wang[1], B. Sun[1], Y. Zhang[1], W. Lu[1], J. Wan[2], Y. Xu[3], B. Li[1], T. Ye[1]

1. *Chinese Academy of Sciences, China*
2. *Fudan University, China*
3. *Nanjing University of Posts and Telecommunications, China*

The total ionizing dose (TID) responses are experimentally compared between double silicon-on-insulator (DSOI) and SOI devices. Higher threshold voltage shift is observed in DSOI, which is attributed to defects generated in the second buried oxide.

PE-4

Heavy Ion-Induced Microdose Effects on the Reliability of Planar and FinFET-Based SRAM Physical Unclonable Functions

J. Shao[1], Y. Wang[1], R. Song[1], S. Li[1], Y. Guo[1], Y. Chi[1], B. Liang[1], J. Chen[1]

1. *National University of Defense Technology, China*

Planar bulk, FD-SOI and FinFET-based SRAM PUFs are irradiated by heavy ions. 3%-10% of SRAM bits change from their original power-on states. Experimental results demonstrate that ion-induced microdose effects degrade the PUF's reliability.

PE-5 **Total Ionizing Dose Effects in Oxide Based ECRAM**

R. Faruque[1], C. Bennett[2], S. Oh[3], B. Zutter[3], M. Siath[1], J. Neuendank[1], M. Spear[1], T. P. Xiao[2], D. Hughart[2], S. Agarwal[3], H. Barnaby[1], Y. Li[4], A. Talin[3], M. Marinella[1]

1. *Arizona State University, USA*
2. *Sandia National Laboratories, NM, USA*
3. *Sandia National Laboratories, CA, USA*
4. *University of Michigan, USA*

Total ionizing dose (TID) effect on oxide based ECRAMs (VOx and TaOx) is characterized experimentally using a Co-60 source. VOx ECRAM exhibited moderate resistance decrease with increased dose, whereas TaOx ECRAM resistance did not change significantly.

PE-6 **Investigation of DC/RF Performances Degradations on 200 nm Gate Length GaN-on-Si RF MIS-HEMTs Under Gamma Radiation**

A. Johari[1,2], C. Su[1], M. Tsai[1], D. Chao[3], A. Gupta[2], R. Singh[2], T. Wu[1]

1. *National Yang Ming Chiao Tung University, Taiwan*
2. *Indian Institute of Technology Delhi, India*
3. *National Tsing Hua University, Taiwan*

This study investigates the impact of 25 kGy gamma radiation on fabricated 200 nm gate length GaN-on-Si RF MIS-HEMT for space applications. The experimental findings confirm excellent electrical stability with radiation hardness in GaN-on-Si MIS-HEMT.

PE-7L **Temperature Dependence of Heavy Ion Induced Leakage Current in SiC Power MOSFETs**

K. Niskanen[1], A. Javanainen[1], H. Kettunen[1], C. Martinella[2], A. Sengupta[3], P. Harris[3], A. Witulski[3]

1. *University of Jyväskylä, Finland*
2. *APS Laboratory - ETH Zurich, Switzerland*
3. *Vanderbilt University, USA*

Temperature dependence of the heavy-ion induced leakage current in SiC power MOSFETs was studied. The devices exhibit an order of magnitude lower drain leakage current at elevated temperatures compared to the values measured at a room temperature.

POSTER SESSION 11:20 AM	INTRODUCTION  *Chair: Daisuke Kobayashi (ISAS/JAXA)*
11:30 AM TO 1:00 PM WESTIN TWENTYTWO 22ND FLOOR	**IEEE YOUNG PROFESSIONAL LUNCHEON** *(Ticket Required to Attend)*
11:25 AM TO 1:15 PM CANADA HALL 2 & 3	LUNCH
POSTER SESSION 1:15 PM TO 4:00 PM	CANADA HALL 1
4:00 PM	END OF WEDNESDAY SESSIONS
5:00 PM TO 10:30 PM (Buses load at 4:30 PM)	**CONFERENCE SOCIAL** **CANADIAN HISTORY MUSEUM**

OTTAWA SALON
INVITED TALK
8:00 - 9:00 AM

Reliability, Availability, and Serviceability (RAS) Challenges for Spaceborne Computing

Jyotika Athavale, 2024 IEEE Computer Society President
Director, Silicon Lifecycle Management and Reliability, Availability, and Serviceability (RAS) Architecture; Synopsys

Jyotika is a Director, Engineering Architecture at Synopsys, leading quality, reliability and safety research, pathfinding and architectures for data centers and automotive applications. She also serves as the 2024 President of the IEEE Computer Society, overseeing overall IEEE-CS programs, operations and service to the global computing community.

Jyotika leads and influences several international standardization initiatives in the area of RAS/safety in IEEE, ISO, SAE, JEDEC and OCP. She led the development of the IEEE 2851-2023 standard on Functional Safety Data Format for Interoperability, and now chairs the IEEE P2851.1 standardization initiative on Functional Safety interoperability with reliability. For her leadership in international safety standardization, Jyotika was awarded the 2023 IEEE SA Standards Medallion. And for her leadership in service, she was awarded the IEEE Computer Society Golden Core Award in 2022.

Jyotika has authored patents and many technical publications in various international conferences and journals. She has also pioneered & chaired international workshops and conferences in the field of dependable technologies.

OTTAWA SALON
SESSION F
9:00 AM

BASIC MECHANISMS OF RADIATION EFFECTS
SESSION INTRODUCTION
Chair: David Hughart (Sandia National Laboratories)

F-1
9:05 AM

Electron Holography Characterization of Total Ionizing Dose Effects in Oxide-Nitride Stack

C. Chang[1], H. Barnaby[1], M. McCartney[1], D. Smith[1], K. Holbert[1]
1. Arizona State University, USA

Analysis of irradiated metal-nitride-oxide semiconductor is performed using electrical characterization and electron holography. The presence of holes and electrons in the nitride and oxide film can be identified by electron holography and TCAD simulations.

F-2
9:20 AM

Enhancement of Hf0.5Zr0.5O2 Ferroelectric Properties by Proton Irradiation

D. Zhang[1], P. Lu[1], H. Ma[1], B. Wang[2], C. Yang[1], X. Li[1], K. Wang[1], J. Gao[1], B. Li[1]
1. Institute of Microelectronics, Chinese Academy of Sciences; Key Laboratory of Science and Technology on Silicon Devices, Chinese Academy of Sciences, China
2. Laboratory of Integrated Circuits and Microsystems, China

A hafnium-zirconium oxide (Hf0.5Zr0.5O2, HZO) ferroelectric properties' enhancement technology by proton irradiation was demonstrated. The 5-MeV proton-irradiation-induced monoclinic-to-tetragonal phase transfer can effectively reduce HZO non-volatile memory's coercivity field by 19.0% (from 1.61 to 1.30 MV/cm).

F-3 9:35 AM

TCAD-Optimization Coupling Enabled TID Modeling and Calibration of Commercial SiC Power MOSFET

X. Gao[1], J. Ray[1], E. Rhoades[1], J. Young[1], B. Rummel[1], L. Musson[1], T. Buchheit[1]
1. Sandia National Laboratories, USA

We propose a TCAD-optimization coupling approach that allows to determine major device parameters in COTS devices. The coupling together with surrogate model and Bayesian calibration enables accurate TID modeling and calibration of commercial SiC MOSFET.

F-4 9:50 AM

Investigating the Effects of Individual Neutron-Induced Defects in Bipolar Junction Transistors

S. Banerjee[1], X. Gao[1], J. Young[1], L. Ho[2], L. Musson[1], H. Barnaby[2], T. Buchheit[1]
1. Sandia National Laboratories, USA
2. Arizona State University, USA

Neutron induced displacement damage in BJTs is modeled with TCAD using DLTS informed trap properties. Individual effects of those defects are studied by calibrating the model against experimental measurements performed at various neutron fluences.

POSTER PAPERS

PF-1

Evaluating the Contribution of Terrestrial Radiation Sources to a Quantum Device Error Rate

G. Casagranda[1], F. Vella[1], P. Rech[1]
1. University of Trento, Italy

Through GEANT4 simulations we compare the effect of neutrons, alphas, muons, and gammas in a quantum device. We combine non-equilibrium generation probability with natural flux to identify the most harmful radiation source for qubits.

PF-2

Implications of an ARC-DPA 1-MeV Equivalent Neutron Fluence Metric for GaAs

N. Asper[1]
1. Sandia National Laboratories, USA

An ARC-DPA function was fitted to the GaAs data used in the development of the ASTM E722 1-MeV equivalent neutron fluence standard. The new functional form suggests that the current standard significantly underestimates displacement damage.

PF-3

A Defect-Aware Device Model Realized: A Case Study in GaAs

L. Diaz[1], H. Hjalmarson[1], J. Lutz[1], P. Schultz[1]
1. Sandia National Laboratories, USA

Fermi level shifting and defect-defect reactions in irradiated Si-doped GaAs are explored within a novel defect-aware device model. The approach uses atomistically computed defect properties as input parameters within the device model.

PF-4 **Analysis of Impact of Gate Bias and Oxide Thickness on Base Current in Post-Rad Gate LPNP BJTs**

L. Ho[1], A. Benedetto[1], X. Gao[2], J. Young[2], S. Banerjee[2], L. Musson[2], H. Barnaby[1], T. Buchheit[2], M. Campola[3]

1. *Arizona State University, USA*
2. *Sandia National Laboratories, USA*
3. *NASA GSFC, USA*

Space flight data on GLPNP BJTs with different gate oxide thicknesses are analyzed. Results suggest mechanisms for different base current responses are not explained by the expected dependence of radiation-induced defect buildup on thickness.

PF-5 **High Temperature and Total Ionization Dose Synergetic Effect of Top-Gate CNT FET**

C. Yang[1], P. Lu[1], D. Zhang[1], H. Ma[1], X. Li[1], K. Wang[1], J. Bu[1], Z. Han[1], B. Li[1]

1. *Institute of Microelectronics, Chinese Academy of Sciences; Key Laboratory of Science and Technology on Silicon Devices, Chinese Academy of Sciences, China*

High temperature and total ionization dose synergetic effect of top-gate CNT FET has been studied experimentally. Worst operating state is determined by comparative experiments, and high-temperature and TID irradiation is conducted and analyzed.

10:05 AM – 10:35 AM
RIDEAU CANAL ATRIUM

BREAK

OTTAWA SALON
SESSION G **SINGLE-EVENT EFFECTS: MECHANISMS AND MODELING**
10:35 AM SESSION INTRODUCTION

Chair: Florent Miller (Nucletudes)

G-1 **Single-Event Responses of Dual- and Triple-Well Designs at the 5-nm Bulk FinFET Technology Node**
10:40 AM

J. Kronenberg[1], N. Pieper[1], Y. Xiong[1], C. Nunez Sanchez[1], D. Ball[1], B. Bhuva[1]

1. *Vanderbilt University, USA*

The addition of a triple-well significantly changes charge collection in advanced FinFET technologies. Results from heavy-ion and alpha exposures show increased SEU vulnerability for triple-well designs over dual-well designs at the 5-nm FinFET nodes.

G-2 **Impacts of Elevated Temperatures on Laser-Equivalent LET Calculations**
10:55 PM

J. Hales[1], A. Ildefonso[1], A. Khachatrian[1], G. Allen[2], D. McMorrow[1]

1. *US Naval Research Laboratory, USA*
2. *NASA Jet Propulsion Laboratory, USA*

Elevated temperature can impact the accuracy of laser-equivalent LET calculations due to the temperature dependence of optical absorption. This study aims to account for this dependence by analyzing collected charge in a simple test vehicle.

G-3
11:10 AM

The Effect of Heavy Ion Strikes on Charge Trap Memory Arrays with Analog State Programmability

T. Xiao[1], C. Bennett[1], W. Donald[2], J. Joffrion[1], D. Udoni[1], A. Talin[1], V. Agrawal[3], H. Puchner[3], M. Marinella[2], S. Agarwal[1], D. Hughart[1]
1. Sandia National Laboratories, USA
2. Arizona State University, USA
3. Infineon Technologies, USA

Heavy-ion single-event effects were characterized in 40nm SONOS computational charge-trap memory programmed to 32 analog states. The state dependence and spatial profile of the effects were resolved. Struck devices showed no degradation in long-term retention.

G-4
11:25 PM

Effectiveness of NIEL as a Predictor of Single-Particle Displacement Damage Effects

J. Trippe[1], B. Sierawski[1], H. Dattilo[1], R. Reed[1]
1. Vanderbilt University, USA

NIEL's usefulness as a figure of merit for single particle displacement damage effects is investigated. Nuclear physics codes predict discrepancies correlating NIEL to predicted damage distributions. Implications for testing and rate predictions are explored.

POSTER PAPERS

PG-1

Impact of FEOL and BEOL Parameters on SEEs in 7nm, 5nm, and 3nm Bulk FinFET Technologies

C. Nunez Sanchez[1], Y. Xiong[1], N. Pieper[1], J. Kronenberg[1], D. Ball[1], B. Bhuva[1]
1. Vanderbilt University, USA

SEU cross-sections show a strong dependence on technology node (7/5nm FinFET) and Vt variant. Analysis indicates that the FinFET geometry does not affect charge collection; the circuit-level parameters are responsible for the SEU differences.

PG-2

Best-Fit Techniques to Estimate SBU/MCU Cross Sections from Radiation-Ground Tests in Memories

F. Franco[1], J. Fabero[1], H. Mecha[1], M. Rezaei[1], J. Clemente[1]
1. Universidad Complutense de Madrid, Spain

In a radiation-ground test on a memory device with a sufficient amount of rounds of reading and bitflips per round, two best-fit approaches are proposed to estimate its SBU/MCU cross sections.

PG-3

Analysis of Gate-Source Damage Induced by Heavy Ion at High Drain Bias in SiC power MOSFET

L. Qiu[1], Y. Bai[1], J. Ding[2], X. Liu[1]
1. Institute of Microelectronics of the Chinese Academy of Sciences, China
2. The State Key Laboratory of Advance Power Semiconductor Device, Zhuzhou CRRC Times Semiconductor Company Ltd., China

A failure induced by heavy-ion impact at high drain bias uncovered a leakage path existing between the gate and source in SiC power MOSFETs, which was correlated with damages to the polysilicon gate and oxide.

PG-4 **Proton Energy Dependence of SiC Power MOSFET Single-Event Burnout Sensitivity**

K. Niskanen[1], A. Javanainen[1], H. Kettunen[1], C. Martinella[2], W. Hajdas[3]

1. University of Jyväskylä, Finland
2. APS Laboratory - ETH Zurich, Switzerland
3. Paul Scherrer Institute, Switzerland

The proton energy dependence on single-event burnout (SEB) sensitivity of silicon carbide power MOSFETs is studied. The results show that the SEB is dependent on the primary proton energy and drain voltage during irradiation.

PG-5 **Experimental Evidence of the Role of the Parasitic Bipolar Transistor in Neutron-Induced Single-Event Burnout in Si and SiC Power MOSFETs**

F. Principato[1], C. Cazzaniga[2], C. Frost[3], M. Kastriotou[2], F. Pintacuda[4]

1. Dipartimento Fisica e Chimica-Palermo University, Italy
2. STFC, United Kingdom
3. ISIS Neutron and Muon Facility, United Kingdom
4. STMicroelectronics, Italy

Accelerated single-event burnout (SEB) tests with atmospheric neutrons were performed for power MOSFETs and for modified structures of these devices to study the impact of the parasitic bipolar transistor of the MOSFET.

PG-6L **Pre-Strike Analytical Model for SiC Power Device SEB from 1200V to 4500V**

S. Kosier[1], A. Sengupta[1], S. Ball[1], J. Hutson[2], A. Sternberg[1], S. Islam[1], A. Witulski[1], R. Schrimpf[1], K. Galloway[1], M. Alles[1], J. Osheroff[3]

1. Vanderbilt University, USA
2. Lipscomb University, USA
3. NASA GSFC, USA

An analytical model for predicting Single-Event Burnout (SEB) in SiC power devices from pre-strike conditions is presented. The model is validated by experimental data ranging from 1200V to 4500V.

RADIATION EFFECTS DATA WORKSHOP

11:40 PM INTRODUCTION

Chair: Li Chen (University of Saskatchewan)

11:45 AM TO 1:15 PM
WESTIN TWENTYTWO
22ND FLOOR

WOMEN IN ENGINEERING LUNCH
(Ticket Required to Attend)

11:45 PM TO 1:15 PM

LUNCH
ON YOUR OWN!

RADIATION EFFECTS DATA WORKSHOP
1:15 PM - 4:00 PM

CANADA HALL 1

DW-1 **Compendium of NASA Goddard Space Flight Center's Recent Radiation Effects Test Results**

M. Obryan[1], S. Roffe[2], E. Wilcox[2], M. Campola[2], J. Osheroff[2], M. Casey[2], M. Joplin[2], T. Carstens[2], J. Barth[2], L. Ryder[2], K. Ryder[2], J. Lauenstein[2], W. Adia[2], P. Majewicz[2]
1. SSAI Inc., USA
2. NASA Goddard Space Flight Center, USA

We present results and analysis investigating the radiation effects on a variety of candidate spacecraft electronics including heavy ion and proton induced SEE, proton-induced displacement damage dose (DDD), and total ionizing dose (TID).

DW-2 **Total Ionizing Dose Testing of a Current Sense Amplifier for Space Applications**

D. Gomez Toro[1], H. Kuhm[1], H. Gunasekar[1], M. Eilenberger[1], N. Aksteiner[1]
1. German Aerospace Center (DLR), Germany

The work presented in this paper shows the results of the total ionizing dose (TID) test on current sense amplifiers of the series INA 240A4-Q1. Biased and unbiased samples were characterized up to 200 krad.

DW-3 **Compendium of Single-Event Effects Test Results for Candidate Electronics at NASA Johnson Space Center from 2023**

E. Agarwal[1], J. Pritts[1], K. Nguyen[1], R. Rinderknecht[1], S. Martinez[1], R. Gaza[1], C. Bailey[1], B. Reddell[1]
1. NASA Johnson Space Center, USA

We present test results and analysis produced by NASA JSC in 2023 for candidate electronics. Test environments include heavy ions or protons, depending on intended use case regarding mission, environment, application, and lifetime.

DW-4 **A Space Qualified High Accuracy Linear-in-dB RMS Detector with High Dynamic Range**

C. Xiao[1]
1. Analog Devices Inc, USA

A high accuracy linear-in-dB RMS detector with high dynamic range and frequency up to 40 GHz was designed. The radiation tests were performed to show the radiation tolerance, including TID, heavy ion SEE, and LDR tests.

DW-5 IRRAD/CHARM, a CERN Irradiation Facility for Accelerator and Experiments Radiation Hardness Qualification

P. Pelissou[1], D. Bozzato[1], S. Danzeca[1], S. Fiore[1], R. Froeschl[1], B. Gkotse[1], J. Lendaro[1], G. Pezzulo[1], F. Ravotti[1]

1. *CERN, Switzerland*

Radiation hardness qualification of ever-changing detectors, electronics components, and materials is an everyday challenge. The IRRAD/CHARM facility at CERN has a key role in performing irradiation tests for diverse applications and increasing number of users.

DW-6 Assessing the Suitability of a 28nm European FPGA for CERN LHC Environments: An In-Depth Radiation Qualification Study

L. Koers[1,2], R. Jung[1,2], A. Scialdone[3], R. Ferraro[1], M. Karagounis[2], S. Danzeca[1], A. Masi[1]

1. *CERN, Switzerland*
2. *University of Applied Sciences and Arts Dortmund, Germany*
3. *University of Montpellier, France*

This study presents the radiation qualification of the GateMate FPGA from Cologne Chip. The tests addressed the sensitivity of the different individual elements and evaluated the overall sensitivity of the FPGA using benchmark circuits.

DW-7 TID and ELDRS Evaluation of SiGe HBTs Integrated in a 45-nm PDSOI BiCMOS Process

D. Nergui[1], Z. Brumbach[1], J. Teng[1], J. Shin[1], D. Sam[1], G. Tzintzarov[2], J. Taggart[2], A. Wright[2], A. Bushmaker[2], P. Harris[3], M. McCurdy[3], R. Reed[3], J. Cressler[1]

1. *Georgia Institute of Technology, USA*
2. *The Aerospace Corporation, USA*
3. *Vanderbilt University, USA*

TID response and ELDRS of newly-developed SiGe HBT integrated in a 45-nm PDSOI BiCMOS process are evaluated. The devices showed good TID tolerance when irradiated at both low and high dose rates.

DW-8 Radiation Hardened MOSFET Fabricated at LA Semiconductor

A. Benedetto[1], P. Benedetto[2]

1. *Alphacore, USA*
2. *LA Semiconductor LLC, USA*

VPT Components developed n-channel radiation-hardened MOSFETs at LA Semiconductor. These RAD7130 (100V Size 3 die) MOSFETs are radiation hardened to 100 krad(Si) and SEE immune to Xe (15 MeV/n beam) at full rated drain potential.

DW-9 Radiation Evaluation of the TPS7H6003-SP 200V Half-Bridge GaN Gate Driver

T. Lew[1], E. Johnson[1], A. Mareinlarena[1], J. Nuttall[1]

1. *Texas Instruments, USA*

Single-events effect (SEE) characterization and total ionizing dose (TID) results for the TPS7H6003-SP GaN FET gate driver are summarized, showing very robust SEE performance up to LETEFF=75 MeV-cm2/mg and excellent TID behavior.

DW-10 Radiation Evaluation of the TPS7H2140-SEP Radiation-Tolerant 32 V, 160 mΩ Quad-Channel eFuse

A. Marinelarena[1], J. Cruz-Colon[1], T. Lew[1]
1. Texas Instruments, USA

Single-events effect (SEE) characterization and total ionizing dose (TID) results for TPS7H2140-SEP 32 V, 160 mΩ Quad-Channel eFuse is summarized, showing very robust SEE performance up to LETEFF = MeV-cm2/mg.

DW-11 Heavy Ion Radiation Effects Facility Developments at Michigan State University

A. Yeck[1], S. Cogan[1], E. Daykin[1], D. McNanney[1], B. Phan[1], S. Lidia[1]
1. Facility for Rare Isotope Beams, USA

A review of the technical developments at Michigan State University's heavy ion radiation effects facility.

DW-12 Guide to the 2023 IEEE Radiation Effects Data Workshop Record

D. Hiemstra[1]
1. MDA, Canada

The 2023 Workshop Record has been reviewed and a table prepared to facilitate the search for radiation response data by part number, type, or effect.

DW-13 Functional Failure and Parametric Degradation of Commercial-off-the-Shelf Electronics Irradiated With High Energy Protons

D. Hiemstra[1], B. Torres-Kulik[1], M. Mahmud[1], F. Desulme[1]
1. MDA, Canada

Commercial-off-the-shelf electronic components were subjected to 105 MeV proton irradiation to characterize their susceptibility to total ionizing dose and displacement damage dose.

DW-14 Irradiation Campaign on TinyVers: A System-on-Chip for Ultra-Low Power NN Inference

N. Jonckers[1,2], R. Van Dyck[2], G. Dekkers[2], B. Boons[2], J. Prinzie[1], Y. Cao[2]
1. KU Leuven University, Belgium
2. Magics Technologies, Belgium

This work presents the SEE and TID irradiation campaign that was conducted on TinyVers, a System-on-Chip designed to target ultra-low power neural network inference for applications running at the extreme edge.

DW-15 Heavy Ion Characterization of GaN HEMT Hybrids Under RF Loading

J. Likar[1], J. Dennison[1], J. Osheroff[2], C. Pham[1], S. Reynolds[1], D. Matlin[1], K. Nunely[1], M. Harris[1]
1. Applied Physics Laboratory, The Johns Hopkings University, USA
2. NASA Goddard Space Flight Center, USA

A pair of Qorvo (Triquint) based GaN HEMT hybrids were subjected to heavy ion single-event effects testing under application specific bias and RF loading.

DW-16 **Results of Single-Event Effect Testing at the New HEARTS@CERN High-Energy Heavy Ion Facility at CERN**

A. Coronetti[1,2], M. Sacristan Barbero[1,2], R. Garcia Alia[1], A. Waets[1], N. Emriskova[1], K. Bilko[1], E. Johnson[1]

1. *CERN, Switzerland*
2. *University of Montpellier, France*

We present results for SEU, SEL and SEB testing of several electronic devices under high-energy heavy ion irradiation at the new HEARTS@CERN facility at CERN.

DW-17 **Single-Event Effects and Total Ionizing Dose Characterization of MNEMOSYNE STT MRAM Prototype with 1.8V SPI Interface**

S. Gerardin[1], M. Bagatin[1], P. Wang[2], P. Kohler[2], A. Bosser[2], L. Gouyet[3], G. Vignon[3], P. Zuber[4], G. Thys[4]

1. *University of Padova, Italy*
2. *3D PLUS, France*
3. *TRAD, France*
4. *IMEC, Belgium*

Single-event effects and total ionizing dose results of the final prototype of the memory ASIC for space applications developed in the framework of the EU H2020 MNEMOSYNE project are presented.

DW-18 **Heavy-Ion SET and SEL Response of a Wide-Band Operational Amplifier Fabricated in the SkyWater S90LN 90 nm Process**

J. Carpenter[1], D. Loveless[1], R. Young[2], J. Kim[1], H. Barnaby[3], J. Neuendank[3], M. Nour[4], P. Manos[4], M. Chambers[4], J. Pew[1]

1. *Indiana University, USA*
2. *University of Tennessee at Chattanooga, USA*
3. *Arizona State University, USA*
4. *SkyWater Technology, USA*

Heavy-ion single-event latchup and transient data are presented for a wide-band operational amplifier fabricated in the SkyWater S90LN process. The SET cross-sections are limited to 3×10^{-6} cm^2; the design is immune to SEL up to 82 MeV-cm^2/mg

DW-19 **Understanding Commercial Power MOSFET Survivability in a Heavy-Ion Environment Using High Throughput Screening**

O. Ahmad[1], D. Castelli[1], C. Kong[1], H. Diggins[1], K. Diggins[1], Z. J. Diggins[1]

1. *Cyclo Technologies Inc., USA*

We present an approach using large scale testing campaigns to select commercial-off-the-shelf components for space applications. We tested three samples each of 533 power MOSFET part numbers, analyzing their single-event performance.

DW-20 **Total Dose and Single-Event Effects Testing of the ISL73006SLH and ISL73007SEH Point-of-Load Regulators**

M. Campanella[1], W. Newman[1], N. Van Vonno[1], B. Rabel[1], L. Pearce[1], E. Thomson[1], C. Thomson[1]

1. Renesas Electronics America, USA

We report the single-event effects and total ionizing dose test results for the ISL73006SLH and ISL73007SEH radiation hardened 1 A and 3 A point-of-load regulators.

DW-21 **Combined Total Dose and Displacement Damage Testing of the ISL71831SEH 32-Channel Analog Multiplexer**

N. Van Vonno[1], W. Newman[1], L. Pearce[1], E. Thomso[1], M. Campanella[1]

1. Renesas, USA

We report the results of combined total ionizing dose and displacement damage testing performed by Renesas Electronics America on the ISL71831SEH, a radiation tolerant 32 channel analog multiplexer fabricated in an SOI process.

DW-22 **2024 Compendium of Radiation-Induced Effects for Candidate Particle Accelerator**

R. Ferraro[1], G. Foucard[1], A. Scialdone[1], A. Zimmaro[1], G. Andreetta[1], D. Krzysztof Rucinski[1], L. Koers[1], S. Danzeca[1], A. Masi[1]

1. CERN, Switzerland

The sensitivity of a variety of components for particle accelerator electronics has been analyzed against single-event effects, total ionizing dose, and displacement damage. The tested parts include analog, linear, digital, and mixed devices.

DW-23 **Single-Event Effects Characterization of the Frontgrade Technologies UT24CP1008 CertusProTM-NX-RT FPGA for Space Applications**

G. Hoglund[1], M. Von Thun[1], E. Fehrman[1], B. Baranski[1], R. Dumitru[1], A. Turnbull[1]

1. Frontgrade, USA

Single-event effects (SEE) radiation characterization was performed on the Frontgrade Technologies UT24CP1008 CertusPro™-NX-RT FPGA. The device was shown to be suitable for space applications.

DW-24 **Evaluation of Radiation Effects Performance in GF 12-nm FinFET Node**

C. Elash[1], J. Xing[1], P. Pour Momen[1], R. Chen[1], D. Lambert[1], J. Cardenas[1], Z.-R. Li[1], R. Fung[2], S.-J. Wen[2], L. Chen[1]

1. University of Saskatchewan, Canada

2. Cisco Systems, USA

Flip-flops using LVT/RVT/HVT options and ring-oscillators were designed and fabricated in a 12-nm FinFET node. Radiation testing results showed significant resilience to SEE and TID effects compared to planar bulk technologies.

DW-25 **SEL Characterization of a Frontgrade QCOTS 18GB DDR4 Memory for Space Applications**

P. Nelson[1], T. Meade2, M. Von Thun[1], B. Baranski2, A. Turnbull[1], R. Dmitru[1], E. Self[1]

1. Frontgrade Technologies, USA

Single-event latchup (SEL) radiation characterization was performed on a Frontgrade quantified-off-the-shelf (QCOTS) 16Gb DDR4 memory. Testing will determine the latchup threshold for the device.

DW-26 **Heavy Ion and Laser-Induced Single-Event Effects Test Results for a Low-Dropout Regulator and Voltage Feedback Amplifiers**

E. Auden[1], J. George[1], T. Fairbanks[1], S. Turner[1]

1. Los Alamos National Laboratory, USA

Heavy ion and single photon absorption laser testing results are reported for the investigation of destructive and transient single-event effects in three radiation-hardened, commercial-off-the-shelf analog parts: one low-dropout regulator and two voltage feedback amplifiers.

DW-27 **SEE and Total Dose Results of the ISL71148SLHM 8-Channel High Precision 14-bit, 900ksps SAR ADC**

W. Newman[1], N. Van Vonno[1], M. Campanella[1], J. Harris[1], J. Brik[1], D. Thornberry[1], C. Michalski[1], E. Thomson[1]

1. Renesas Electronics America, USA

We report the single-event performance and low dose rate TID results of the radiation-hardened ISL71148SLHM 8 channel, high precision, 14-bit, SAR analog to digital converter.

DW-28 **Total Ionizing Dose and SEE Testing of the TPS7H4011-SP 14V, 12A Synchronous Buck Converter**

K. Rakos[1], T. Hubbard[1], A. Marinelarena[1], T. Lew[1]

1Texas Instruments, USA

We test and report single-event effects and total ionizing dose of the TPS7H4011-SP, a radiation-hardened, 14V, 12A synchronous buck converter optimized for use in a space environment.

DW-29 **Proton Testing of Texas Instruments TDA4VM SoC**

S. Davis[1], N. Belsten[1], J. Crook[1], D. Enright[1], J. Taggart[1]

1. The Aerospace Corporation, USA

Some processors developed for ground-based edge applications could support space mission activities. This work evaluates the performance of the Texas Instruments TDA4VM heterogeneous SoC when irradiated with high energy protons.

DW-30 **LDR Testing of JFET and 2.5V Reference for Europa Clipper UVS**

Z. Olson[1], R. Monreal[1]

1. Southwest Research Institute, USA

The 2N4861 JFET and RH1009 2.5V reference intended for the Europa Clipper mission were tested under low dose rate conditions (10 mrad/s). Both devices performed within acceptable tolerances of their applications up to 100 krad.

DW-31 **Total Non-Ionizing Dose Characterization of Microchip LX7720**

M. Leuenberger[1], R. Stevens[1], D. Johnson[1]
1. Microchip Technology, USA

The total non-ionizing dose characterization results of Microchip Technology's motor driver, the LX7720, with four half-bridge drivers, rotation and position sensing IC, are presented.

DW-32 **Recent Heavy Ion and Laser Probe SEE Test Data for Texas Instruments LMX2615-SP 40 MHz to 15 GHz Wideband Synthesizer**

K. Kruckmeyer[1]
1. Texas Instruments, USA

The LMX2615-SP is a frequency synthesizer (clock) with integrated PLL and VCO that can generate frequencies up to 15 GHz. SEE characterization data are presented from testing at LBNL and TAMU and with a laser.

DW-33 **Radiation Characterization Results of AF54RHC 300 krad(Si) Logic Family**

A. Ghoshal[1], A. Quiroz[1], M. Hamlyn[1], A. Billings[1], T. Farris[1]
1. Apogee Semiconductor, USA

This paper details the results for TID testing up to 400 krad(Si) and SEE testing at a maximum LET_{EFF} of 93.3 MeV·cm^2/mg for Apogee Semiconductor's AF54RHC product family. These results demonstrate suitability for space applications.

DW-34 **High Energy, Heavy Ion Testing at BNL: Facility and Operations Update**

T. Olsen[1], K. Brown[2]
1. NASA Space Radiation Lab (BNL), USA
2. Brookhaven National Laboratory, USA

The heavy ion synchrotron at BNL provides high energy SEE testing capability to a large, international community. Updates on NSRL and plans for a new beamline dedicated to electronics testing are discussed.

DW-35 **Single-Event Upset Characterization of the LS1046A Microprocessor Using Proton Irradiation**

D. Hiemstra[1], N. Hu[1]
1. MDA, Canada

Experimental single-event upset characterization of the LS1046A microprocessor using proton irradiation is presented. Results for various cache memory configurations, running an operating system, bare-metal, floating-point and fixed-point algorithms are compared.

DW-36 **Single-Event Upset Characterization of the Versal® XCVC1902 Dual-Core ARM® Cortex™A72 Application Processor Unit Using Proton Irradiation**

D. Hiemstra[1], N. Hu[1]
1. MDA, Canada

The proton induced SEU cross-section of the Versal XCVC1902 dual-core ARM® Cortex™-A72 Application Processor Unit is presented. Upset rate in the space radiation environment is estimated.

DW-37 **Single-Event Upset Characterization of Microsemi RISC-V Softcore CPUs on Polarfire MPF300T-1FCG1152E Field Programmable Gate Arrays Using Proton Irradiation**

D. Hiemstra[1], D. Ramaswami[2], S. Shi[2], Z. Wang[2], L. Chen[2]
1. *MDA, Canada*
2. *University of Saskatchewan, Canada*

SEU cross-sections of the Polarfire FPGA programmed with various Microsemi RISC-V Softcore CPUs are presented. Upset rates in the space radiation environment are estimated and found to be acceptable for low-orbit missions.

DW-38 **New Fusion Linear Accelerator for Radiation Effects (FLARE™) Testing Facility Proof of Concept Tests and Potential Use Cases**

C. Kolb[1], M. Wissink[1]
1. *SHINE Technologies, USA*

SHINE Technologies has conducted two radiation effects tests with customers to demonstrate functionality and collect data at its new 14-MeV fusion neutron radiation testing facility, FLARE. Planned facility upgrades will increase user and test throughput.

DW-39 **Radiation Test Results from a Survey of Recent e.MMC Managed Flash Devices**

I. Troxel[1], M. Gruber[1]
1. *Troxel Aerospace Industries, USA*

Heavy ion DSEE and NDSEE and gamma-induced TID characterization results are presented for recent-generation e.MMC managed flash devices.

DW-40 **TID and SEE Response of AD524CDZ Instrumentation Amplifier**

J. Cardenas Chavez[1], D. Hiemstra[2], A. Noguera Cundar[1], B. Johnson[1], D. Baik[1], L. Chen[1]
1. *University of Saskatchewan, Canada*
2. *MDA, Canada*

TID effects on AD524CDZ instrumentation amplifier were studied using low dose rate Co-60 chamber. SEE behavior was studied using high energy protons and two-photon absorption laser to identify sensitive areas of the device.

DW-41 **TID and SEE Response of the COTS LI-OV9712-USB-M8 Camera**

A. Noguera Cundar[1], D. Hiemstra[2], J. Cardenas Chavez[1], N. Phonsavath[1], M. Pajuelo[3], L. Chen[1]
1. *University of Saskatchewan, Canada*
2. *MDA, Canada*
3. *University of Victoria, Canada*

The LI-OV9712-USB-M8 camera was studied using low dose rate Co-60 chamber and 105 MeV proton beams. Results revealed the camera presented high robustness against total ionizing dose but failed rapidly in proton irradiation.

DW-42 **TID and SEE Evaluation of the ADALM PlutoSDR Transceiver**

R. Moody[1], J. Yang[2], D. Hiemstra[3], B. Sun[1], J. Cardenas Chavez[1], A. Noguera Cundar[1], L. Chen[1]

1. *University of Saskatchewan, Canada*
2. *University of Alberta, Canada*
3. *MDA, Canada*

TID and SEE evaluation of the PlutoSDR transceiver were performed using low dose rate Co-60 radiation and high energy protons, respectively. TID tolerance up to 50 krad was demonstrated. Only non-destructive SEFIs were observed.

DW-43 **TID Response of Various COTS Operational Amplifiers**

B. Sun[1], R. Moody[1], D. Hiemstra[2], J. Yang[3], A. Noguera Cundar[1], J. Cardenas Chavez[1], L. Chen[1]

1. *University of Saskatchewan, Canada*
2. *MDA, Canada*
3. *University of Alberta, Canada*

Total ionizing dose effects on various COTS operational amplifiers were studied using low dose ^{60}Co irradiation. Total dose tolerance to 30 krad(Si) is demonstrated.

DW-44 **Irradiation of Commercial Equipment for Robotic Applications in a Highly Ionizing Radiation Field**

K. Stoev[1], E. Simova[1]

1. *Canadian Nuclear Laboratories, Canada*

Performance of commercial equipment suitable for application in high radiation fields on robotic platforms was evaluated at various dose rates. Total ionizing dose (TID) for catastrophic failure was determined for some of the tested equipment.

DW-45 **Radiation Effects Testing of the LTC3115-1 DC/DC Voltage Converter with Heavy Ions and Protons**

R. Koga[1], S. Davis[1], A. Yarbrough[1]

1. *The Aerospace Corporation, USA*

Observations of heavy ion and proton induced single event effects on the LTC3115-1 DC/DC converter were made. The DC/DC converter was sensitive to SEE including SET and DSEE.

DW-46L **Electron Transport in Solid and Shell Geometries**

T. Jordan[1], P. Calvel[2], M. Marin[3]

1. *EMPC, USA*
2. *RADCONSULT, France*
3. *Alter Technology Tüv Nord, France*

Adjoint Monte Carlo gives fast, accurate space radiation effects analysis for space environments using point detectors. Ray-trace approximations are accurate in solid geometries, but 10x too high for electrons in space system shell geometries.

DW-47L **Single Event Effects Testing for Integrated GaN Power Devices**

S. Yang[1], A. Barchowsky[2], G. Allen[2], S. Vartanian[2], K. Smedley[1]
1. *University of California, Irvine, USA*
2. *Jet Propulsion Laboratory, California Institute of Technology, USA*

We are presenting the results from an investigation into CoTS integrated GaN devices. Parts were introduced to ionizing radiation at LBNL in July 2023. Testing methods of integrated parts are considered, and recommendations are given.

DW-48L **Protons Evaluation of 7nm Versal AI Engine (AIE) Based Radiation Tolerant Platform for Deep Learning Applications**

P. Maillard[1], A. Davhlle[1], Y. Chen[1], N. Fraser[1], Y. Chen[1], N. Vacirca[1], J. Barton[1], M. Voogel[1], M. Sawant[1]
1. *AMD Inc., USA*

This paper presents the SEE evaluation of a platform to enable radiation-tolerant deep learning acceleration in proton environments. The platform uses 7nm Versal™ AI Engine and includes solutions to mitigate SEFIs and network datapath errors.

DW-49L **Proton, Heavy-Ion and SPA Laser Characterizations on Microchip PolarFire® SoC FPGA Microprocessor Subsystem**

S. Toguchi[1], N. Rezzak[1], M. Madugoda[1], R. Chipana Quispe[1], R. Mahmud[1], D. Mcnamara[2], I. Bryant[1]
1. *Microchip Technology, USA*
2. *Microchip Technology, Ireland*

This research reveals preliminary results on the impact of protons, heavy-ions and SPA laser on the PolarFire® SoC RISC-V Microprocessor Subsystem (MSS) with Si-Five design, demonstrating its potential suitability for space applications.

DW-50L **TID Effects on Random Telegraph Signals in GF 12LP FinFET Devices**

J. Neuendank[1], S. Bonaldo[2], F. Mamun[1], Z. Giorno[1], H. Barnaby[1], T. Wallace[1], M. Nour[3], M. Spear[1], T. Kirby[1], R. Dempsey[1]
1. *Arizona State University, USA*
2. *University of Padova, Italy*
3. *SkyWater Technology, USA*

12LP FINFETs from GlobalFoundries are tested under 60Co γ-rays. Low frequency noise measurements evidence random telegraph noise at various gate voltages in both pre- and post-rad conditions, revealing pre-existing and TID-induced prominent defects.

DW-51L **Radiation Effects Characterization of TI AFE11612-SEP High Density General Purpose Monitor and Control Systems**

R. Jain[1], V. Narayanan[1]
1. *Texas Instruments Inc, USA*

AFE11612-SEP highly integrated analog monitor and control device released for space applications. It passed total dose of 20Krads and is latch-up immune up to 48 MeV-cm^2/mg at 125C. Single Event Upset cross section was 9.33E-5 cm^2/Ions.

DW-52L **Radiation Effects Characterization of TI ADC128S102-SEP Analog to Digital Converter (ADC)**

V. Narayanan[1], R. Jain[1], R. Gooty[1]

1. Texas Instruments, USA

Radiation study of ADC128S102-SEP 8-channel, CMOS, 12-bit analog-to-digital converter released for space applications. Device passed 30Krad total dose and is latch-up immune up to 48 MeV-cm²/mg at 125C. SEU was characterized at 48 MeV-cm²/mg.

4:00 PM END OF THURSDAY SESSIONS

4:45 PM - 6:30 PM
OTTAWA SALON **RADIATION EFFECTS COMMITTEE ANNUAL OPEN MEETING**

OTTAWA SALON
INVITED TALK
8:00 - 9:00 AM

Mādahòkì Farm – Indigenous Experiences
Workshop: Introduction to Indigenous Culture

After 20 plus years of offering their cultural programming on Victoria Island, Indigenous Experiences were inspired by the Ojibwe spirit horses to find a new location that allowed the organization to offer more land-based cultural and culinary programming. With the mission of sharing the land, stories and food from an Indigenous perspective, the vision of Mādahòkì Farm became a reality when the National Capital Commission approved a 25-year lease on the beautiful 164-acre property in Ottawa's Greenbelt. The Farm is also the new home for a series of Indigenous events celebrating the seasons; Sīgwan (Spring), Tagwàgi (Autumn), and Pibòn (Winter), and the annual Summer Solstice Indigenous Festival formerly held at Vincent Massey Park. Mādahòkì is the year-round home of an Indigenous marketplace that promotes products made by Indigenous makers and artisans as well as the permanent home for a growing herd of endangered Ojibwe Spirit Horses. Led by our team of Indigenous cultural ambassadors, they will introduce the audience to the rich diversity of our nations, the common beliefs and way of life among our communities, and some of the most common questions they receive. This introduction to our diverse Indigenous cultures will end with an opportunity for the guests to engage with our ambassadors with any questions.

OTTAWA SALON
SESSION H
9:00 AM

HARDENING BY DESIGN
SESSION INTRODUCTION
Chair: Dakai Chen (Zero-G Radiation Assurance)

H-1
9:05 AM

RHBD Current-Mode Bandgap with SET Isolation Using PVT-Independent Inverters

J. Cardenas Chavez[1], T. Sandhu[2], K. El-Sankary[3], M. Yan[3], A. Noguera Cundar[1], L. Chen[1]
1. *University of Saskatchewan, Canada*
2. *The Six Semiconductor Inc, Canada*
3. *Dalhousie University, Canada*

This manuscript introduces an SET insolation technique by using PVT-independent SET detectors and apply it into a current mode bandgap circuit to reduce the output SET magnitude. Simulation and proton experimental results revealed its effectiveness.

H-2
9:20 AM

12-bit High-Voltage Current-Steering-Assisted R-2R DAC with RCM and Parallel Switch for Satellite-Applications

C. Tahar[1], C. Lee[2], H. Kim[3], K. Kwon[3], S. Ryu[1]
1. *Korea Advanced Institute of Science and Technology (KAIST), Korea, Republic of*
2. *Korea Advanced Institute of Science and Technology (KAIST), Korea Aerospace Research Institute (KARI), Korea, Republic of*
3. *Korea Aerospace Research Institute (KARI), Korea, Republic of*

Circuit and architectural techniques for a RH high-voltage DAC are introduced. A prototype 12V 12-bit DAC with a current-steering-assisted R-2R configuration preserves the performance well up to 226-krad TID.

H-3 9:35 AM

Effects of Total-Ionizing-Dose Irradiation on Single-Event Upset for Double-SOI SRAM

S. Chen[1], Y. Wang[1], F. Liu[1], B. Li[1], J. Gao[1], P. Zhao[2], L. Wang[1], J. Li[1], C. Wang[1], S. Ma[1], G. Zhang[1], Y. Liao[1], P. Cui[1], L. Gao[1], H. Zhou[1], C. Wang[1], J. Liu[2], J. Wan[3], Y. Xu[4], B. Li[2], T. Ye[2]

1. *Institute of Microelectronics, Chinese Academy of Sciences, China*
2. *Institute of Modern Physics, Chinese Academy of Sciences, China*
3. *State key lab of ASIC and System, Fudan University, China*
4. *College of Electronic and Optical Engineering, Nanjing University of Posts and Telecommunications, China*

The single event upset cross-section is experimentally demonstrated to be enhanced by total ionizing dose due to increasing NMOS charge collection and reducing hold static noise margin. Back-gate biasing can significantly mitigate synergistic radiation damage.

POSTER PAPERS

PH-1

Charge Trap Layer Supercharging for Improved Bit Reliability in 3D NAND Flash Under Proton Irradiation

A. Teijeiro[1], M. Breeding[1], J. Young[1], E. Wilcox[2], D. Hughart[1]

1. *Sandia National Laboratories, USA*
2. *NASA Goddard Space Flight Center, USA*

Multiple write cycles were observed to harden bits against single-event upset in 176L 3D NAND Flash under proton irradiation. Cross sections monotonically decreased in single level cell operations with additional writes.

PH-2

RIERA: Redundancy Insertion Automation and Optimization for Large-Scale RTL Designs

O. Atli[1], P. Mohan[1], M. King[2], K. Mai[1]

1. *Carnegie Mellon University, USA*
2. *Intel Corporation, USA*

We introduce RIERA, a toolset that can automatically insert common redundancy schemes into different modules and instances in an RTL design as well as iteratively pick the optimal redundancy assignment for each design element.

PH-3

Impact of Latch Interleaving on DICE Flip-Flop SEU Rates at the 12-nm FinFET Node

C. Elash[1], P. Pour Momen[1], J. Xing[1], R. Chen[1], D. Lambert[1], J. Cardenas[1], Z. Li[1], R. Fung[2], S. Wen[3], L. Chen[1]

1. *University of Saskatchewan, Canada*
2. *Cisco, USA*
3. *Cisco, USA*

DICE Flip-Flops with sensitive node interleaving are designed and tested with a 12-nm FinFET node. Heavy ion testing shows that DICE with proper layout arrangement can significantly reduce SEU, are sensitive to angled ion strikes.

PH-4 **Update on the Development and Test of a Radiation Tolerant Power Supply for LHC's Quench Detection System**

J. Steckert[1], T. Pridii[1], R. Denz[1], A. Hollos[1], G. Martin Garcia[1], T. Podzorny[1], J. Spasic[1]

1. CERN, Switzerland

Design and test of a linear regulated AC-DC power supply for the quench detection system of LHC. Based on operational amplifiers, voltage references and MOSFETs prototypes were tested in CERN's CHARM radiation test facility.

OTTAWA SALON
SESSION I **SINGLE-EVENT EFFECTS: DEVICES AND INTEGRATED CIRCUITS**
9:50 AM SESSION INTRODUCTION

Chair: Daniel Limbrick (North Carolina A&T State University)

I-1 **Vision Transformer Reliability Evaluation on the Coral Edge TPUP.**
9:55 AM

Bodmann[1], C. Frost[2], P. Rech[3]

1. UFRGS, Brazil

2. ISIS Neutron and Muon Facility, United Kingdom

3. University of Trento, Italy

We test six vision transformer models and four micro-benchmarks on TPUs irradiated with neutrons. A greater number of heads and a higher residual blocks usage increase the model FIT rate while using convolutions reduces it.

I-2 **The Impact of Heavy-Ion Single Events on the Accuracy of SONOS Analog In-Memory**
10:10 AM

W. Donald[1], P. Xiao[2], M. Spear[1], D. Hughart[2], C. Bennet[2], V. Agrawal[3], H. Puchner[3], A. Sapan[2], M. Marinella[1]

1. Arizona State University, USA

2. Sandia National Laboratories, USA

3. Infineon Technologies, USA

The sensitivity of 40nm SONOS analog accelerator accuracy to single event effects from heavy ion irradiation is simulated, and a statistical model for these effects is discussed.

10:25 AM – 10:55 AM BREAK
RIDEAU CANAL ATRIUM

I-3 **Single-Event Upset Laser Testing of Various SRAM Resources of a 7nm FinFET System-on-Chip and Correlation with Heavy Ion Data**
10:55 AM

S. Achaq[1,2], V. Pouget[2], L. Artola[1], F. Manni[3], A. Dufour[3], J. Boch[2]

1. ONERA, France

2. IES, University of Montpellier, CNRS, France

3. CNES, France

We present the SEU laser testing of different SRAM resources of a 7nm FinFET programmable SoC. Results provide insights on the physical organization of the device and testing challenges are discussed. Correlation with heavy ion data is presented and discussed using charge collection modelling.

I-4
11:10 AM

Multiple-Cell Upset Analysis on 16/12-nm Bulk FinFET SRAM Caused by Proton Irradiation

K. Sakamoto[1], K. Takeuchi[1], Y. Tsuchiya[1], N. Ohtani[1], K. Kume[2], S. Mizushima[2], S. Sando[2], S. Hatori[2], T. Makino[3], A. Takeyama[3], T. Ohshima[3], T. Kato[4], R. Nakamura[4], H. Shindou[1]

1. *Japan Aerospace Exploration Agency, Japan*
2. *The Wakasa wan Energy Research Center, Japan*
3. *QST, Japan*
4. *Socionext Inc., Japan*

The effects of proton-induced MCUs on 16 and 12-nm FinFET SRAMs were studied and compared with 20-nm bulk planar SRAM. We discovered that FinFET SRAMs have an advantage in MCU tolerance even with angular irradiation.

I-5
11:25 AM

Evaluation of SEU Cross-Section Trends for Threshold Voltage Options from the 16-nm to the 3-nm Bulk FinFET Nodes

Y. Xiong[1], N. Pieper[1], J. Kronenberg[1], M. Delaney[1], C. Nunez[1], D. Ball[1], M. Casey[2], R. Fung[3], S. Wen[3], B. Bhuva[1]

1. *Vanderbilt University, USA*
2. *NASA, USA*
3. *Cisco, USA*

SEU cross-section scaling trends for four bulk FinFET nodes are investigated using D-FF designs with different VT options at each node. Results show that SEU cross-sections vary significantly for different VT options at each node.

I-6
11:40 AM

Extrapolating SER by Cache Level Memory Accesses Instead of Per Bit

C. Corley[1], H. Quinn[2], E. Swartzlander, Jr.[1]

1. *University of Texas at Austin, USA*
2. *Air Force Research Laboratory, USA*

A method of using hardware performance counters to characterize neutron cross section per cache access instead of per bit of the unmitigated Raspberry Pi 3B+ improves scaling accuracy of benchmarks to applications of other sizes.

I-7
11:55 AM

Post-Radiation Fault Injection for Complex FPGA Designs

N. Baker[1], E. Campbell[1], M. Wirthlin[1]

1. *Brigham Young University, USA*

This paper presents a methodology for extracting additional insights from FPGA radiation tests using fault injection. Post-irradiation fault injection is applied to a complex FPGA design to identify the specific failure-inducing CRAM upsets.

POSTER PAPERS

PI-1 Real-Time SER Measurements of CMOS Bulk 40 nm and 65 nm SRAMs Combined with Neutron Spectrometry at the JET Tokamak During D-D and D-T Plasma Operation

M. Dentan[1,3], S. Moindjie[2], M. Cecchetto[3], J. Autran[2,4], R. Garcia Alia[3], R. Naish[5], J. Waterhouse[5], A. Horton[5], X. Litaudon[1], D. Munteanu[2], J. Bucalossi[1], P. Moreau[1], V. Malherbe[6], P. Roche[6], D. Rastelli[7]

1. *CEA-IRFM, France*
2. *Aix-Marseille University, France*
3. *CERN, Switzerland*
4. *University of Rennes, France*
5. *UK Atomic Energy Authority, United Kingdom*
6. *STMicroelectronics, France*
7. *Raylab s.r.l., Italy*

We performed SER characterization of decananometer SRAMs combined with neutron spectrometry in the deuterium-tritium-fueled JET tokamak, demonstrating the impact of machine operation on the reliability of electronics in conditions approaching those of future fusion reactors.

PI-2 Processor Cache Validation Under Neutron Radiation Testing

N. Harris[1], J. Goeders[1], M. Wirthlin[1]

1. *Brigham Young University, USA*

This work reviews three approaches for measuring the cross-section of processor caches. These approaches were tested for multiple caches on the Zynq MPSoC at LANSCE and ChipIR.

PI-3 Complex Single Event Effects Behaviour in Nanometric Commercial Static Random Access Memories

M. Barker[1], K. Ryden[1]

1. *University of Surrey, United Kingdom*

This paper provides a summary of micro-SELs and non-linear SEU behavior affecting significant clusters of SRAM cells observed during both neutron and proton SEE testing. A new characterization of micro-SEL types is proposed.

PI-4 Multicell Upsets in Flip-Flops at Advanced FinFET Nodes

N. Pieper[1], Y. Xiong[1], J. Kronenberg[1], C. Nunez Sanchez[1], M. Delaney[1], D. Ball[1], M. Casey[2], R. Fung[3], B. Bhuva[1]

1. *Vanderbilt University, USA*
2. *NASA, USA*
3. *Cisco, USA*

Multiple-cell upsets (MCUs) are observed in flip-flops in 5-nm and 3-nm FinFET technologies. Primary factors responsible for increased MCU vulnerability include cell spacing and threshold voltage options.

PI-5 Effects of Total-Ionizing-Dose Irradiation on Neutron-induced Single-Event Burnout for SiC Power MOSFET

X. Li[1], X. Wang[1], Z. Qiwen[1], C. Jiangwei[1], Y. Li[1], W. Lu[1], Q. Guo[1]

1. Xinjiang Technical Institute of Physics and Chemistry, Chinese Academy of Science, China

We investigate the effect of total ionizing dose (TID) on neutron-induced single-event burnout (SEB) for SiC MOSFETs. The results demonstrate that the synergistic effect of TID on SEB for SiC devices does in fact exist.

PI-6 The Influence of the Ion Incidence Angle on the Single-Event Upset of the D Flip-Flop in the Multi-Fin FinFET Process

Y. Gao[1], Y. Chi[1], Q. Sun[1]

1. National University of Defense Technology, China

The nonmonotonic relationship of SEU susceptibility and heavy-ion incidence angle is observed and analyzed for the Data Flip-Flop in the multi-fin FinFET process for the first time, which is totally different in conventional bulk-silicon process.

PI-7 Atmospheric Neutron Single Event Effect on a Non-von Neumann AI Chip

W. Yang[1]

1. Xidian University, China

This paper assesses SEEs on a non-von Neumann AI Chip. Results from spallation neutron irradiation, fault injection, and fault tree analysis reveal the chip's vulnerability to SEE while YOLOV5 execution.

PI-8 Study on Single Event Burnout in 4H-SiC Schottky Diodes

Z. Wang[1], R. Chen[1], Y. Liang[1], J. Han[1], Q. Chen[1], S. Shangguan[1]

1. National Space Science Center Chinese Academy of Sciences, China

A "step current" is observed when the reverse current of the 4H-SiC SBD increases under irradiation. The SEB process has avalanche amplification and recombination, and the "step" trend emerges when the two achieve dynamic equilibrium.

PI-9 Soft Error Detection and Execution Observation for ARM Microprocessors

M. Pena Fernandez[1], B. Verdasco[1], L. Entrena[2], A. Lindoso[2]

1. Arquimea Group S.A., Spain

2. University Carlos III Madrid, Spain

We present an IP to detect errors and observe the behavior of ARM architectures using the information provided by the trace interface. Experimental results with heavy ions demonstrate the high capabilities of the proposed IP.

PI-10 **Soft-Error Reliability Analysis and Error Rate Estimation for RISC-V Processors in High Energy Physics Environments**

A. Nookala[1], J. Prinzie[2], R. Pejasinovic[1], A. Lauridsen[1], K. Kloukinas[1], A. Jantsch[3], M. Andorno[1], A. Caratelli[1]

1. CERN, Switzerland

2. KU Leuven, Belgium

3. TU Wien, Austria

Micro-processor ASICs are unproven for flux rates of high energy physics detector environments. We present the reliability analysis, by simulation-based fault injection, of a RISC-V micro-processor against expected single-event upset rates encountered in CERN on-detector systems.

12:10 PM TO 12:15 PM CONFERENCE CLOSING

RESG NEWS

The purposes of the Radiation Effects Committee (REC) of the IEEE Nuclear and Plasma Sciences Society are to advance the theory and application of radiation effects and its allied sciences, to disseminate information pertaining to those fields, and to maintain high scientific and technical standards among its members.

Robert Reed
Chair

The Committee aids in promoting close cooperation and the exchange of technical information among its members. This is done by running conferences for the presentation and discussion of original contributions, assisting in the publication of technical papers on radiation effects in the IEEE Transactions on Nuclear Science, coordinating development of radiation effects measurement definitions and standards within IEEE and other standards organizations, providing a sounding board for radiation effects specialists, providing for the continued professional development and needs of its members, and providing liaisons between IEEE and other technical organizations in the areas of radiation effects.

Kay Chesnut,
Raytheon Technologies
Executive Vice-Chair

Each year, the REC provides a forum for the technical exchange of information by holding the Nuclear and Space Radiation Effects Conference (NSREC). The NSREC is an international forum for presentation of research papers on nuclear and space radiation effects. This includes effects on electronic and photonic materials, devices, circuits, sensors, and systems, as well as semiconductor processing technology and design techniques for producing radiation-tolerant (hardened) devices and integrated circuits. Papers presented at the NSREC are submitted for possible publication in the January issue of the IEEE Transactions on Nuclear Science.

NSREC 2024 will be held in Ottawa, Canada, July 22-26 at the Shaw Center. Heather Quinn, Air Force Research Laboratory is the Conference Chair. Supporters of the 2024 NSREC include Aerospace Corporation, EPC Space, FLARE, Frontgrade, Honeywell, IR HiRel, (an Infineon Technologies Company), Jet Propulsion Laboratory, L3Harris, Northrop Grumman, Radiation Test Solutions, Renesas, SkyWater Technologies, Southwest Research Institute and The Boeing Company. We thank our supporters for their significant and continuing commitments to the conference and welcome other organizations to consider becoming supporters of the IEEE NSREC.

Dolores Black, Sandia National Laboratories, is the Conference Chair for NSREC 2025 in Nashville, Tennessee. Philippe Paillet was selected as the 2026 NSREC Conference Chair. Jonathon Pellish, NASA GSFC was selected as the 2027 NSREC Chair.

Papers presented at the 2024 NSREC are eligible for publication in the January 2025 issue of the IEEE Transactions on Nuclear Science. Authors must upload their papers prior to the conference for consideration for publication in the January 2025 TNS Special Issue. Detailed instructions can be found at ***www.nsrec.com.***

Keep visiting our web site for author information, paper submission details, exhibitor links, on-line registration, and the latest NSREC information.

EDITORS

Dan Fleetwood
Vice-Chair of Publications

All papers accepted for oral or poster presentation in the technical program will be eligible for publication in a special issue of the *IEEE Transactions on Nuclear Science* (to be published in early 2025), based on a separate submission of a complete paper. Each paper will be subject to the standard full peer review given all papers submitted to the *IEEE Transactions on Nuclear Science*. All papers must be submitted on IEEE ScholarOne. Instructions for submitting papers can be found at the Conference web site
www.nsrec.com. The deadline for submission of papers is July 19, 2024. Data Workshop papers are published in a Workshop Record and are not candidates for publication in the *IEEE Transactions on Nuclear Science*. The process for the Workshop Record is managed by the Workshop Chair.

The review process for papers submitted to the *Transactions* is managed by a team of editors. To provide consistent review of papers, this editorial team manages the review process for all radiation effects papers submitted to the *Transactions* throughout the year. The editorial team consists of a senior editor and associate editors who are technically knowledgeable in one or more specializations and are experienced in the publication process. If you would like to serve as a reviewer for the NSREC special issue of the *Transactions* or for radiation effects papers submitted throughout the year, please contact one of the editors. The editors for the 2024 NSREC are:

Dan Fleetwood, Senior Editor, Vanderbilt University
Email: dan.fleetwood@vanderbilt.edu

Heather Quinn, Associate Editor, Air Force Research Laboratory
Email: heather.quinn.2@spaceforce.mil

Steven Moss, Associate Editor, The Aerospace Corporation, retired
Email: scmosshb@aol.com

Vincent Goiffon, Associate Editor, ISAE-SUPAERO
Email: vincent.goiffon@isae.fr

Philippe Paillet, Associate Editor, CEA
Email: philippe.paillet@cea.fr

Lili Ding, Associate Editor, NINT, China
Email: lili03_ding@126.com

Daniel Loveless, Associate Editor, Indiana University
Email: dlovele@iu.edu

Jeffrey Black, Associate Editor, Sandia National Laboratories
Email: jefblac@sandia.gov

Federico Faccio, Associate Editor, CERN
Email: Federico.Faccio@cern.ch

Janet Barth, Associate Editor, NASA, retired
E-mail: jbarth@ieee.org

ARE YOU A MEMBER OF IEEE?

Now is the time to join the Institute of Electrical and Electronics Engineers (IEEE) and the Nuclear Plasma Sciences Society (NPSS). Why? First of all, you'll become a member of the largest professional engineering society in the world. About 60% of NSREC attendees are IEEE members. The cost of membership in the IEEE depends on your country and your career phase. IEEE members receive access to a broad range of benefits, including a terrific insurance program, on-line access to IEEE publications, and reduced rates at all IEEE sponsored conferences, including, of course, the IEEE NSREC and Short Course!

NPSS membership is $35. NPSS members receive a free subscription to NPSS News, and free on-line electronic access via IEEE Xplore to the IEEE Transactions on Nuclear Science (TNS) and the NSREC Data Workshop Record. Now members can search and view digital copies of all IEEE TNS papers on-line all the way back to the first IEEE NSREC in 1964. NPSS members get to vote in our NSREC elections, held at the annual open meeting held during the conference. What are you waiting for? Apply for membership at ***http://ieee-npss.org/why-join-npss-and-ieee/*** or visit the IEEE registration desk at the conference.

NSREC PUBLICATIONS

NSREC has two publications each year:

- ***IEEE Transactions on Nuclear Science.*** This IEEE journal is the official archive of research papers presented at NSREC. Papers presented at the conference undergo an additional review before they are accepted for the January 2025 issue.
- ***Radiation Effects Data Workshop Record.*** Published each year in October, this IEEE proceedings has become the source for radiation test data on semiconductor components.

A complimentary copy of the 2024 *IEEE Radiation Effects Data Workshop Record* and the January 2024 special NSREC issue of the *IEEE Transactions on Nuclear Science* will be mailed to each NSREC technical session attendee if the attendee registered to be listed on the attendee list.

RADITION EFFECTS COMMITTEE ANNUAL OPEN MEETING

You are invited to attend the IEEE Radiation Effects Committee's Annual Open Meeting on Thursday, July 25, 4:45 – 6:30 All conference attendees are encouraged to attend.

THURSDAY, JULY 25
4:45 PM – 6:30 PM

During the meeting we will discuss the 2024 conference and future IEEE Nuclear and Space Radiation Effects Conferences. A report on the nomination processes for the 2024 Junior Member-at-Large on the Radiation Effect Steering Group will be presented. Voting instructions for IEEE NPSS members will be provided.

2023 OUTSTANDING PAPER AWARD

Effect of Energy, Flux and Bias Conditions on Proton-Irradiated CMOS Single Photon Avalanche Diodes
A. Jouni, V. Malherbe, B. Mamdy, T. Thery, V. Correas, S. De- Paoli, V. Lalucaa, C. Virmontois, G. Gasiot, and V. Goiffon

2023 MERITORIOUS PAPER AWARDS

In-Situ Observation of Circuit Behavior Using Pump-Probe Laser Voltage Probe Technique
M. King, J. Beutler, N. Smith, I. Kohl, T. Meisenheimer, O. Atli, P. Mohan, and K. Mai

Awards

Ion-Induced Stuck Bits in 5-nm bulk FinFET SRAMs at High Fluences
Y. Xiong, N. Pieper, N. Dodds, G. Vizkelethy, N. Nowlin, and B. Bhuva

2023 OUTSTANDING STUDENT PAPER AWARD

Effect of Energy, Flux and Bias Conditions on Proton-Irradiated CMOS Single Photon Avalanche Diodes
A. Jouni, V. Malherbe, B. Mamdy, T. Thery, V. Correas, S. De- Paoli, V. Lalucaa, C. Virmontois, G. Gasiot, and V. Goiffon

2023 OUTSTANDING DATA WORKSHOP PRESENTATION AWARDS

NASA Goddard Space Flight Center's Current Radiation Effects Test Results
M. O'Bryan, E. Wilcox, M. Joplin, T. Carstens, J. Barth, M. Casey, J. Lauenstein, M. Campola, J. Osheroff, E. Wyrwas, A. Antonsanti, A. Le Roch, L. Ryder, K. Ryder, R. Austin, M. Berg, P. Majewicz, and J. Pellish

Comparison of Figure of Merit Calculations to On-Orbit Data
R. Sean, C. David, B. Vermeire, and D. Hansen

2024 RADIATION EFFECTS AWARDS

The winners of the 2024 Radiation Effects and Radiation Effects Early Achievement Awards will be announced Tuesday, July 23 at the opening. The purpose of the Radiation Effects Award is to recognize individuals who have had a sustained history of outstanding and innovative technical and/or leadership contributions to the radiation effects community. The purpose of the Radiation Effects Early Achievement Award is to recognize an individual early in his or her career whose technical contributions and leadership have had a significant impact on the field of radiation effects.

2025 RADIATION EFFECTS AWARD

Nominations are currently being accepted for the 2025 IEEE Nuclear and Plasma Sciences Society (NPSS) Radiation Effects Award. The basis of the award is for individuals who have: (1) a substantial, long-term history of technical contributions that have had major impact on the radiation effects community. Examples include benchmark work that initiated major research and development activities or a major body of work that provided a solution to a widely recognized problem in radiation effects; and/or (2) a demonstrated long-term history of outstanding and innovative leadership contributions in support of the radiation effects community. Examples include initiation or development of innovative approaches for promoting cooperation and exchange of technical information or outstanding leadership in support of the professional development of the members of the radiation effects community.

Nominations are currently being accepted for the 2025 Radiation Effects Early Achievement Award. The basis of the award is for individuals whose technical contributions and leadership during the first ten years of the recipient's career that have had a major impact on the Radiation Effects Community. Examples include work that provides a solution to important technical problems in radiation effects or work that identifies significant new issues in the field. Other factors are cumulative research contributions over the first part of the career, internationally recognized leadership, and mentorship. It is the intent of the RESG to give special consideration for this award to members of the community who are IEEE/NPSS members.

Cash awards and plaques will be presented at the NSREC in Nashville, Tennessee in July 2025. Nomination forms are available electronically in PDF Format or in Microsoft Word format at ***http://ieee-npss.org/technical-committees/radiationeffects/.*** Forms should be sent to Megan Casey, Member-at-Large, NAS GSFCC at ***megan.c.casey@nasa.gov***

Conference Information

CONFERENCE LOCATION

Photo courtesy of The Westin Ottawa

The Westin Ottawa with the adjoining Shaw Centre is the location for NSREC 2024. Ottawa is Canada's capital, a dynamic showcase city of more than one million people. Located in Ontario at the Quebec border, it's a place where you'll hear English and French spoken in the streets; where you can discover Canada's proud heritage at impressive national sites and famous landmarks, including the Rideau Canal, a UNESCO World Heritage Site. It's a city steeped in culture, with world-class museums and galleries displaying stunning national collections and special exhibitions from Canada and around the world.

This city is a uniquely beautiful place: an urban centre on the edge of nature where you can enjoy the great outdoors either just outside your hotel room or nearby in the surrounding countryside. There's an easy cosmopolitan vibe here, and Ottawa is known for being both welcoming and walkable. Explore the distinctive local neighbourhoods, including the historic ByWard Market: by day this area boasts a bustling farmers' market and chic shops, by night it hums with activity at the restaurants, pubs, and nightclubs.

This is also a city that enjoys the finer things in life, with a culinary community that's earning wide acclaim, unique boutiques and shopping districts, a lively local music and art scene, and always exciting nightlife. The Westin Ottawa is ideally located right downtown, mere steps away from the historic sites and landmarks, and only a short drive from Ottawa's international airport.

This is Ottawa, Canada's capital. Please join us for NSREC 2024 and experience it for yourself.

The location for NSREC 2024 will be the Westin Ottawa and the adjoining Shaw Centre Convention Space in Ottawa, Canada.

Westin Ottawa, 11 Colonel By Dr, Ottawa, ON K1N 9H4, Canada. Website: ***https://www.marriott.com/en-us/hotels/yowwi-the-westin-ottawa/overview/***

Shaw Centre, 55 Colonel By Drive, Ottawa, ON K1N, Ottawa, ON K1N 9J2, Canada Website: ***https://shaw-centre.com/***

Photo courtesy of The Shaw Centre

Conference Information

BREAKFASTS, LUNCHES AND BREAKS

The 2024 IEEE NSREC will provide breakfast and refreshments at breaks during the NSREC Short Course and Technical Sessions. Additionally, lunch will be included on Monday for the Short Course attendees. These meals and refreshments are for *registered conference attendees only.* Please see the schedule for times and locations.

The exhibitors will host a lunch on Tuesday, July 25th and Wednesday, July 26, in the Exhibit Hall. This lunch is for ***registered conference attendees and Exhibit Booth Staffers only.***

BUSINESS CENTER

The Westin Ottawa has a Business Center. Designed to accommodate those traveling on business, this self-service facility allows guests to fax, copy, and print documents and surf the web. Take advantage of black and white printers as well as reliable parcel service.

ROOMS FOR SIDE MEETINGS

A few "side meeting rooms" are available for use by any registered conference attendee at the Shaw Centre on a first-come, first-served basis. *NSREC encourages side meetings to be scheduled at times other than during technical sessions.* Send an e-mail to ***j.teehan@ieee.org*** to make side meeting reservations before the conference. To make a side meeting room reservation during the conference, see the NSREC Registration staff in the Rideau Canal Atrium.

Notes: You must register for the conference before a side meeting room can be reserved! All audio/visual equipment and refreshments must be coordinated directly with the convention center and are the responsibility of the attendee hosting the meeting.

HEALTH AND WELLNESS PROTOCOLS/COVID-19 PREPAREDNESS:

IEEE NSREC will implement health and wellness protocols appropriate to the public health recommendations existing at the time of the conference. Compliance with the protocols adopted by IEEE NSREC may be mandatory for in-person attendance and participation at the conference. We will communicate any additional information regarding the specific health and safety measures, and any necessary consents by you, to attendees and exhibitors before the conference.

Registration and Travel

CONFERENCE REGISTRATION

NSREC encourages Pre-Registration and offers a lower registration rate, "Early Registration," if the payment is received no later than Friday, June 28. After that date, the "Late Registration" rates apply.

Registrations can be submitted using the NSREC website link: ***www.nsrec.com.*** All Registrations must be completed online using the Registration Portal. Telephone registrations will not be accepted.

There are three acceptable forms of payment for registration and activity fees: 1) check made payable to "IEEE NSREC" in U.S. dollars and drawn on a U.S. bank, 2) Wire Transfer, or 3) MasterCard, VISA, Discover, and American Express credit card.

John Teehan
IEEE Registration Services

ON-SITE REGISTRATION LOCATION & TIMES IN OTTAWA

Rideau Canal Atrium

Registration hours are:

Sunday, July 21	**5:00 PM – 8:00 PM**
Monday, July 22	**7:30 AM – 5:00 PM**
Tuesday, July 23	**7:30 AM – 5:00 PM**
Wednesday, July 24	**7:30 AM – 3:00 PM**
Thursday, July 25	**7:30 AM – 3:00 PM**
Friday, July 26	**7:30 AM – 10:00 AM**

CONFERENCE CANCELLATION POLICY

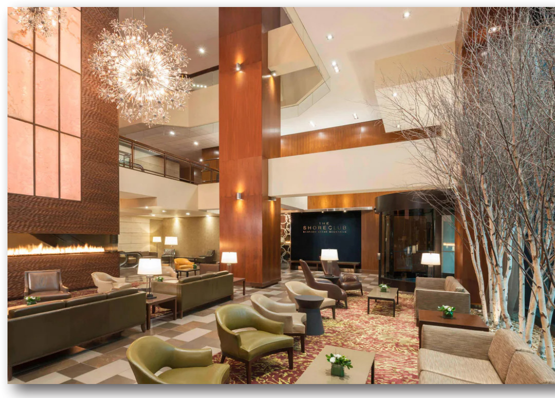
A $50 processing fee will be withheld from all refunds. Due to advance financial commitments, refunds of registration fees requested after June 28, 2024, cannot be guaranteed. Consideration of requests for refunds will be processed after the conference. To request a refund, you must notify NSREC at ***NSRECreg@ieee.org***

HOTEL ACCOMMODATIONS:

Westin Ottawa
11 Colonel By Dr.
Ottawa, ON K1N 9H4, Canada

Accommodations for the 2024 IEEE NSREC are available at the **Westin Ottawa**

Rest assured with our Commitment to Clean experience at The Westin Ottawa hotel. Our modern downtown Ottawa hotel is located in the Ottawa business district across from the Rideau Canal, an UNESCO World Heritage Site. Our renowned Shore Club restaurant is a popular dining choice for hotel guests and Ottawa locals alike. Stay active during your visit to Canada with our hotel's fitness offerings, including our indoor saltwater pool, our modern fitness center and our private squash courts. Host your next conference or event in our dynamic venues, connected to the Shaw Convention Centre, and take advantage of our state-of-the-art AV equipment and expert planning services. Enjoy a restful night sleep in refined hotel rooms and suites with enriching amenities and stunning views of the Ottawa cityscape at our hotel on Colonel By Drive, Ottawa



Photos courtesy of The Westin Ottawa

Westin Ottawa room rates for a standard king or two queen are:

NEGOTIATED GROUP RATE:
$259.00 CAD single/double per night

Room taxes currently at 18.45% will be added to all rates listed above.

If you prefer, you can also call *Marriott Reservations* to confirm your room: Tel. +1 613-560-7000. Ask for the group named IEEE NSREC.

Registration and Travel

HOTEL RESERVATIONS

The preferred method to make reservations is by using the following weblinks:

Westin Ottawa – Group rate
https://www.marriott.com/event-reservations/reservation-link.mi?id=1700583106932&key=GRP&app=resvlink

In any case, enter your arrival and departure dates and follow the prompts.

Room reservations require a credit card as a guarantee. The cut-off for IEEE NSREC reservations is at 5:00 PM Eastern Daylight Time (EDT) on June 21, 2024. Once the room block has been filled OR after the cut-off date (whichever comes first!), it is at the hotel's discretion as to whether they can book more rooms and at what room rate will be offered. Early reservations are strongly suggested!

Please be certain to notify the hotel of any change to your arrival or departure dates. When you check into the hotel, be sure to verify your departure date.

AIRPORT AND TRANSPORTATION INFORMATION

Ottawa Macdonald-Cartier International Airport (code: **YOW**) is located approximately 15 KM from the Westin Ottawa. Traveling outside of normal commuting hours, the drive typically takes between 20-30 minutes. During heavy commuting times, the drive can take up to 60 minutes.

TAXI SERVICE & RIDESHARE

Airport to Hotel Transportation:
There is no scheduled shuttle service between the Hotel and the airportAirport, but there are other options.

1) Taxi Service is available at the Ottawa International Airport. Courtesy phones for taxi service are located both inside and outside the terminal at each bag claim area and at other strategic locations outside the terminal exits. Make sure that you give the dispatcher your exact location.

   Fares may be pro-rated (shared) when the originating passenger requests it and all other passengers agree.

   Rates will be around $30 - $50 CAD. Rates may vary due to traffic delays and waiting time.

2) OC Transpo is the public transit provider in Ottawa. Bus Route 97 serves the airport using low-floor, fully accessible buses that can accommodate mobility devices. ***www.octranspo.com***

3) Uber Website: ***https://www.uber.com/***

4) Lyft Website: ***https://www.lyft.com/***

PARKING AND DRIVING DIRECTIONS

On-Site Parking: $30 CAD

Valet: $55 CAD

Ottawa Macdonald-Cartier International Airport to the Westin Ottawa:

- Head northeast on Airport Parkway Private/Airport Pkwy
- Keep left to continue on Bronson Ave/Route 79 N
- Turn right onto Findlay Ave
- Turn right onto Broadway Ave
- Turn right onto Torrington PL
- Turn left onto Queen Elizabeth Driveway
- Turn right onto Hawthorne Ave/Pretoria Bridge/Ottawa Regional Rd 91
- Turn left onto Colonel By Dr
- Turn right onto Daly Ave
- Destination will be on your left

GETTING AROUND TOWN

The NSREC optional tours are the easiest way to explore the area. Still, there is much to see and do within walking distance of the hotels. The city is quite safe, so feel free to experience it at your leisure.

TIPS WHEN VISITING OTTAWA

Weather: July is a hot summer month in Ottawa, Canada, with an average temperature fluctuating between 60°F (15°C) and 80°F (26°C).

Driving: Be patient in traffic and mindful of pedestrians. Obey all traffic rules and be alert, whether driving or walking.

Restaurants & Tipping: Be aware that upscale restaurants might require reservations, especially during the busy dining hours of 6:00pm – 8:00pm. Most restaurants accept “casual” dress, although some are less “casual” than others. Standard tipping is 20 percent of the bill. Some restaurants add a “service charge” (gratuity) for groups of 6 or more, so check your bill to see if this has already been added.

Industrial Exhibits

Nadia Rezzak
Industrial Exhibits Chair
Microchip Technology Inc.

The **2024 NSREC Industrial Exhibits** will feature the leading worldwide suppliers of radiation hardened products, related materials, services, and research and development. This will be an excellent opportunity for key suppliers, technical engineers and managers to meet and discuss the needs and solutions for electronics used in space vehicles, military electronics, and applications requiring radiation tolerance in harsh environments.

The 2024 NSREC Industrial Exhibits is held in Canada Hall 2 and 3 on Tuesday and Wednesday. Breakfast and conference breaks will be in the Exhibit Area on Tuesday and Wednesday for registered attendees, with an Exhibitor Lunch is held on Tuesday and Wednesday. NSREC badges must be worn at all times.

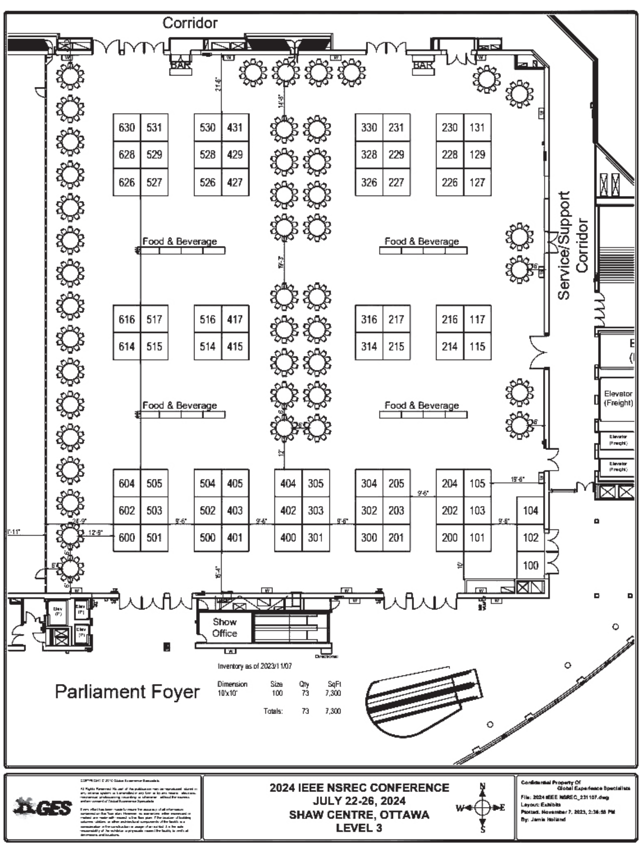
Tuesday evening, the exhibitors will host the Industrial Exhibits Reception featuring light hors d'oeuvres in the Exhibit Area. The Reception is open to all NSREC attendees and their guests.

NOTE: Children under 16 must be accompanied by an adult in the Exhibit Area.

For more information contact:

Nadia Rezzak
Phone: 1-615-968-4010
Email: nadia.rezzak@microchip.com

Or visit the 2023 NSREC Industrial Exhibits web site:
Please visit https://nsrec2024.expofp.com/ for a full sized interactive map



Industrial Exhibits

Please check our web site (***www.nsrec.com***) for a current listing of companies exhibiting at 2024 NSREC.

NSREC
INDUSTRIAL EXHIBITS

SHAW CENTER

CANADA HALL 2 & 3

EXHIBIT HALL HOURS

TUESDAY, JULY 23

7:00 AM – 4:30 PM
10:00 AM - 10:30 AM
MORNING BREAK

11:50 AM - 1:00 PM
LUNCH

2:25 PM - 2:55 PM
AFTERNOON BREAK

5:30 PM – 7:30 PM
RECEPTION

WEDNESDAY, JULY 24

7:00 AM – 1:30 PM
10:05 AM - 10:35 AM
MORNING BREAK

11:25 AM - 1:15 PM
LUNCH

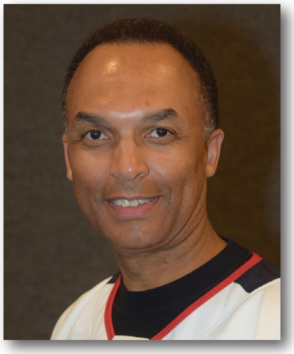
12:45 PM RAFFLES

(All of the exhibit events are for Registered Attendees; the Exhibit Reception is for Registered Attendees and Guests)

EXHIBITORS

Organization	Internet Site	Booth
3D PLUS USA, INC.	3d-plus.com	404
88-Inch Cyclotron	https://cyclotron.lbl.gov/	214
Air Force Research Laboratory	afrl.af.mil/RV/	115
Alphacore Inc.	https://www.alphacoreinc.com/en	202
AMD	https://www.xilinx.com/	403
Apex Microtechnology	https://www.apexanalog.com/	227
Apogee Semiconductor	apogeesemi.com/	314
Boeing	https://www.boeing.com/	101
Boeing LMTF	https://www.boeing.com/defense/strategic-deterrence-systems	302
Brookhaven National Lab	BNL | Tandem Van de Graaff | Home	630
Cyclo Technologies Inc.	https://www.cyclotechnologies.com/	401
Crane Aerospace & Electronics	craneae.com	305
Defense Microelectronics Activity	https://www.acq.osd.mil/asds/dmea/	301
Electro Magnetic Applications, Inc.	ema3d.com	515
EMPC	empc.com	216
EPC Space	epc.space/	415-417
EXAIL	https://www.exail.com/	105
FLARE – a SHINE Technologies Company	https://www.shinefusion.com/flare	402
FRIB	frib.msu.edu/fsee	626
Foss Therapy Services, Inc.	fosstherapyservices.net/	303
Frontgrade	frontgrade.com	602-604
Honeywell	honeywellmicroelectronics.com	300
IR HiRel, an Infineon Technologies company	infineon.com/hirel	514-516
J.L. Shepherd & Associates	http://jlshepherd.com/	528
Magics Technologies NV	https://www.magics.tech/	304
Microchip	https://www.microchip.com/	231
Micropac	micropac.com	205
Micross Components	micross.com	226
NASA NEPP Program	https://nepp.nasa.gov/	431
Northrop Grumman	https://www.northropgrumman.com/	204
Phoenix LLC	https://www.phoenixneutronimaging.com/	402
ProNova Solutions	ProNovaRadEffects.com	502
PULSCAN	pulscan.com/	117
QuickLogic Corporation	quicklogic.com/	200
Radiation Test Solutions	radiationtestsolutions.com	503-505
RADNEXT & PAC-G	radnext.web.cern.ch/ and https://irtnanoelec.fr/pac-g/.	504
Renesas Electronics America Inc.	renesas.com/us/en/products/	427-429
Robust Chip	robustchip.com	316
Sandia National Laboratories	https://www.sandia.gov/	330
Synopsys	https://www.synopsys.com/aerospace-government.html	328
SkyWater Technology	www.skywatertechnology.com	326
STMicroelectronics	st.com	614-616
Teledyne Brown Engineering	www.tbe.com	500
Texas A&M University Cyclotron Institute	cyclotron.tamu.edu	400
Texas Instruments	https://www.TI.com/Space	201-203
TRAD Tests and radiations	https://www.trad.fr/en/	526
Triad Micro Devices	www.triadmicrodevices.com	517
Trusted Semiconductor Solutions	trustedsemi.com	501
TTM Technologies	www.ttm.com	405
UNITES Systems a.s.	https://unites-systems.com/	127
University of Saskatchewan (STARR-LAB)	https://research-groups.usask.ca/starr-lab/	527
Vanderbilt University (ISDE)	http://www.isde.vanderbilt.edu/	600
VPT, Inc.	www.vptpower.com/	215-217
Zero-G Radiation Assurance	https://www.zerogradiation.com/	529

Social Program



"Welcome to the Westin Ottawa hotel located in the heart of the Ottawa business district across from the Rideau Canal. Stay active during your visit to Canada with the hotel's fitness offerings, including an indoor saltwater pool, modern fitness center, and private squash courts. We present our social program that will take you to Parliament Hill in Ottawa, Ontario, the capital of Canada to the French Canadian area of Gatineau in Quebec. Come see why Ottawa is so much more than a hockey town."

Anthony Sanders
NASA Goddard Space Flight Center
Local Arrangements Chair

OTTAWA

Courtesy Ottawa Tourism

The Westin Ottawa with the adjoining Shaw Centre is the location for NSREC 2024. Ottawa is Canada's capital, a dynamic showcase city of more than one million people. Located in Ontario at the Quebec border, it's a place where you'll hear English and French spoken in the streets; where you can discover Canada's proud heritage at impressive national sites and famous landmarks, including the Rideau Canal, a UNESCO World Heritage Site. It's a city steeped in culture, with world-class museums and galleries displaying stunning national collections and special exhibitions from Canada and around the world.

This city is a uniquely beautiful place: an urban centre on the edge of nature where you can enjoy the great outdoors either just outside your hotel room or nearby in the surrounding countryside. There's an easy cosmopolitan vibe here, and Ottawa is known for being both welcoming and walkable. Explore the distinctive local neighbourhoods, including the historic ByWard Market: by day this area boasts a bustling farmers' market and chic shops, by night it hums with activity at the restaurants, pubs, and nightclubs.

This is also a city that enjoys the finer things in life, with a culinary community that's earning wide acclaim, unique boutiques and shopping districts, a lively local music and art scene, and always exciting nightlife. The Westin Ottawa is ideally located right downtown, mere steps away from the historic sites and landmarks, and only a short drive from Ottawa's international airport.

The conference committee has designed a social program that will provide you with the highlights of popular and historic sites in Ottawa. **Rideau Hall** and **Parliament Hill** will be the focus of the Tuesday's companion events. Experience the rich history of the Canadian government walking the halls of the **House of Commons.** On Thursday, we will cruise down the **Rideau Canal** and visit the **Canadian War Museum** that serves as both an educational facility on Canadian military history and a place of remembrance.

Wednesday's conference social will be at the **Canadian Museum of History**, Canada's most-visited museum presents the events, people and objects that have shaped the nation. This architectural gem is in Gatineau, Quebec, directly across the Ottawa River from Parliament Hill.

This is Ottawa, Canada's capital. Please join us for NSREC 2024 and experience it for yourself.

Children must be accompanied by an adult during all tours and social events.

Social Program

SUNDAY, JULY 21, 2024
6:00 PM TO 9:00 PM

REGISTRATION WELCOME RECEPTION

TRILLIUM

Join us for **complimentary refreshments** in the Trillium Ballroom, located on level 4 of the Shaw Conference Center. The reception is **open to Short Course attendees and registered guests** and is a great time to meet new friends and renew old acquaintances. NSREC attendees and guests must wear **NSREC badges for entrance to the Welcome Reception**. The conference registration desk is open from 5:00 to 8:00 PM to secure badges.

The NSREC 2024 short course and technical sessions will be held in the adjoining Shaw Centre. Experience a renowned convention center in Canada's capital. Known for attention to detail, extensive event resources, and cordial customer service staff. The Shaw Centre boasts three stories of exquisite space with beautiful views of the river and Parliament.

Photo Courtesy: Shaw Centre

TUESDAY, JULY 23, 2024
8:30 AM TO 4:30 PM

RIDEAU HALL AND PARLIAMENT HILL

Rideau Hall is a national historic site set in an idyllic, 79-acre urban oasis located only a few minutes from downtown Ottawa and Gatineau. It has been the official residence of every governor general of Canada since 1867 and their workplace since 1940. This site has nearly two centuries of history and has become an important gathering place and site of official activities.

Photo Courtesy: Michael Gatti

The villa, which forms the main part of Rideau Hall, was built in 1838 by Thomas MacKay as a home for his family. A stonemason and contractor, he was also involved in building the entrance locks of the Rideau Canal and the mills at Rideau Falls. Rideau Hall is named after these landmarks. Period photographs show Rideau Hall as a stone villa with a three-storey, semi-circular south façade overlooking the gardens.

At the time when Ottawa—previously known as Bytown—was about to become the new capital of the province of Canada, the Canadian government leased and expanded the residence for Lord Monck, 21st governor general of British North America, who later became Canada's first governor general. A long wing was added to resemble his Québec residence, Spencer Wood (which was renamed Bois-de-Coulonge in 1950). It was also during Lord Monck's mandate that the handsome path leading to the front of the house was laid out.

In 1868, the year after Confederation, the Government of Canada purchased the house and grounds for $82,000 and declared it the official residence for Canada's governors general.

Come visit the residence and workplace of the governor general and the grounds!

THE CANADIAN HERITAGE GARDEN

Photo Courtesy: National Capital Commission

Photo Courtesy: Getty Images

Parliament Hill is home to Canada's federal government, where representatives from across Canada gather to make laws that affect the lives of every Canadian. It is also much more. A place to meet, a place to celebrate, and a place to visit, Parliament Hill is the symbolic heart of Canada. It's an area of Crown land on the southern bank of the Ottawa River in downtown Ottawa, Ontario, Canada. It accommodates a suite of Gothic revival buildings whose architectural elements were chosen to evoke the history of parliamentary democracy. Parliament Hill attracts approximately three million visitors each year. The Parliamentary Protective Service is responsible for law enforcement on Parliament Hill and in the parliamentary precinct, while the National Capital Commission is responsible for maintaining the nine-hectare (22-acre) area of the grounds.

Development of the area, which in the 18th and early 19th centuries was the site of a military base, into a governmental precinct began in 1859 after Queen Victoria chose Ottawa as the capital of the Province of Canada. Following several extensions to the Parliament and departmental buildings, and a fire in 1916 that destroyed the Centre Block, Parliament Hill took on its present form with the completion of the Peace Tower in 1927. In 1976, the Parliament Buildings and the grounds of Parliament Hill were designated as National Historic Sites of Canada. Since 2002, an extensive $3 billion renovation-and-rehabilitation project has been underway throughout the precinct's buildings that is expected to be completed after 2028.

We will tour the **House of Commons**, which came into existence in 1867, when the British Parliament passed the British North America Act 1867, uniting the Province of Canada (which was divided into Quebec and Ontario), Nova Scotia and New Brunswick into a single federation called Canada. The new Parliament of Canada consisted of the monarch (represented by the governor general, who also represented the Colonial Office), the Senate and the House of Commons. The Parliament of Canada was based on the Westminster model (that is, the model of the Parliament of the United Kingdom). Unlike the UK Parliament, the powers of the Parliament of

Canada were limited in that other powers were assigned exclusively to the provincial legislatures. The Parliament of Canada also remained subordinate to the British Parliament, the supreme legislative authority for the entire British Empire. Greater autonomy was granted by the Statute of Westminster 1931, after which new acts of the British Parliament did not apply to Canada, with some exceptions. These exceptions were removed by the Canada Act 1982.

Photo Courtesy: Library of Parliament

The House of Commons has 338 members, each of whom represents a single electoral district (also called a riding). The constitution specifies a basic minimum of 295 electoral districts, but additional seats are allocated according to various clauses. Seats are distributed among the provinces in proportion to population, as determined by each decennial census, subject to the following exceptions made by the constitution. Unlike the members of Parliament in the House of Commons, the 105 senators are appointed by the governor general on the advice of the prime minister.

Timeline

- 8:30am: Depart from the Westin hotel to Rideau Hall
- 9:00am: Guided tour Rideau Hall and Grounds
- 11:00am: Depart Rideau Hall
- 11:45am: Arrive to Social Restaurant
- 1:45pm: Depart Social restaurant
- 2:00pm: Arrive to Parliament Hill
- 2:30pm: Security check
- 3:00pm: Guided Parliament House of Commons tour
- 4:00pm: Depart Parliament Hill
- 4:30pm: Arrive Westin hotel

TUESDAY, JULY 23, 2024
6:00 PM TO 8:00 PM

INDUSTRIAL EXHIBITS RECEPTION

CANADA HALL 1 & 2

Join us for the 2024 Industrial Exhibits Reception hosted by your NSREC exhibitors. **All NSREC attendees and their registered guests are invited for complimentary drinks and hor d'oeurves.** Drinks will be served in Canada Hall in the Shaw Convention Center. All registered attendees should be sure to visit the booths and participate in the raffles. NSREC attendees and guests must wear **NSREC badges for entrance to the Exhibits and Reception.**

Social Program

WED. JULY 24, 2024
11:30 AM TO 1:00 PM

IEEE YOUNG PROFESSIONALS LUNCHEON

VENUE TWENTYTWO (WESTIN HOTEL)

IEEE youngprofessionals

The annual IEEE Young Professionals lunch will be held on Wednesday in the TwentyTwo room high atop the Westin hotel. IEEE members who are Young Professionals (those who have graduated their first professional degree in the last 15 years; (**https://yp.ieee.org**) are especially invited to register (at no cost) for this unique event. This lunch represents an excellent opportunity to step away from the main conference floor for an hour to mingle with other early career attendees and a few veteran attendees as well.

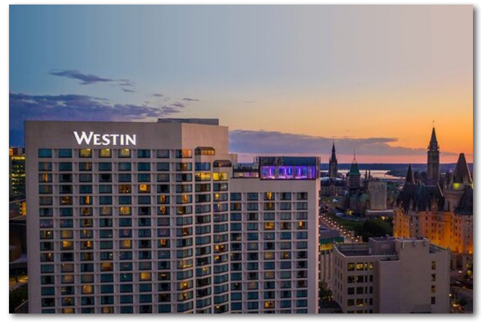


Photo Courtesy: Tripadvisor

We heard your suggestions last year, and we'll be mixing our lunch with a little more fun and games this year, not to mention enjoying a spectacular view of downtown Ottawa. Our purpose is to encourage professional development, make new friends, and grow more comfortable within this special community at NSREC. To do that, we'll have some casual games available at each table to get to know each other, and we'll have a fun exercise to work through your questions for the other Young Professionals and any veteran attendees who join us for lunch. Don't worry, you'll have time to eat, too!

Have a brief question you'd like to ask the group about career options, technical growth, workplace personalities, or something else? Submit it to a marked box at registration and we'll do our best to add it to a collective "Jenga tower" of questions!

Please join us atop the Westin Ottawa to enjoy lunch and make some new friends while taking in the fantastic, unique, and panoramic view of Ottawa from twenty-two floors up in the aptly named TwentyTwo.

Note: Tickets are required so check the box for this lunch when you register for the conference.

WED. JULY 24, 2024
4:45 PM TO 10:30 PM

CONFERENCE SOCIAL

CANADIAN HISTORY MUSEUM

Join your colleagues and friends for dinner, beverages, and entertainment at the **Canadian National Museum of History.** The buses will depart from the Westin hotel around 4:45pm and return starting around 9:00pm. While you are catching up with old friends and meeting new ones, explore the grounds and admire the Canadian architect, Douglas Cardinal. Tickets are not included in the conference registration so be sure to purchase them with your registration.


Photo Courtesy: History Hit

Social Program

The Canadian Museum of History is a museum of the history of Canada including the culture and heritage of its Aboriginal people, the Vikings and stories of the leaders and figures who have shaped the nation over time.

The Canadian Museum of History is the most visited Museum in Canada and welcomes over 1.2 million visitors each year to its celebrated complex in the heart of the National Capital Region. In addition to its ongoing exhibitions, including the spectacular Grand Hall and First Peoples Hall, each year the Museum presents a number of outstanding exhibitions focusing on Canadian and world history and civilisations. These exhibitions include those developed by the Museum as well as many produced by other Canadian or international institutions. The Museum is also home to the Canadian Children's Museum, a 500-seat theatre and a 295-seat movie theatre equipped with a giant 3D screen and a giant dome.

Timeline

- 4:45pm: Depart from Westin hotel to National History Museum
- 5:00pm: Arrive to museum exhibit tour (no drinks allowed in exhibit hall)
- 6:30pm: Cocktails in main hall
- 7:15pm: Seating for dinner
- 7:30pm: Plated dinner served
- 9:00pm: First bus return

THURSDAY, JULY 25, 2024
9:00 AM TO 4:30 PM

RIDEAU CANAL CRUISE & CANADIAN WAR MUSEUM

The **Rideau Canal** is a 202 kilometre long canal that links the Ottawa River, at Ottawa, with the Great Cataraqui River, and then at Lake Ontario at Kingston, Ontario, Canada. Its 46 locks raise boats from the Ottawa River 83 metres upstream along the Rideau River to the Rideau Lakes, and from there drop 50 metres downstream along the Cataraqui River to Kingston.

Photo Courtesy: Trip Canvas

Opened in 1832 for commercial shipping, freight was eventually moved to railways and the St. Lawrence Seaway, and it remains in use today for pleasure boating, operated by Parks Canada May to October. It is the oldest continuously operated canal system in North America, and is a UNESCO World Heritage Site. Discover the richness of the region's historical landmarks during the 90-minute cruise.

Social Program

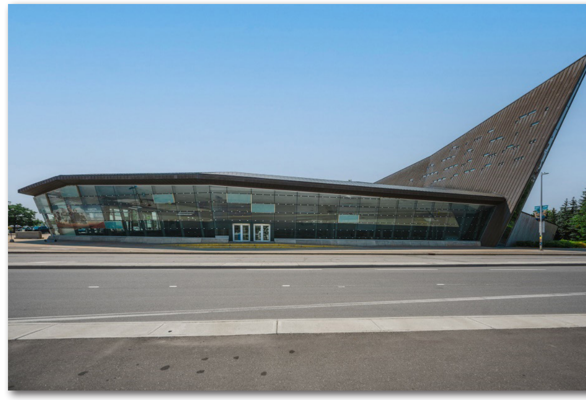


Photo Courtesy: Dominik Gehl

The **Canadian War Museum** was formally established in 1942, although portions of the museum's collections originate from a military museum that operated from 1880 to 1896. The museum was operated by the Public Archives of Canada until 1967, when the National Museums of Canada Corporation was formed to manage several national institutions, including the war museum. In the same year, the war museum was relocated from its original building to the former Public Archives of Canada building. Management of the museum was later assumed by the Canadian Museum of Civilization Corporation (later renamed the Canadian Museum of History Corporation) in 1990. Plans to expand the museum during the mid-1990s resulted in the construction of a new building at LeBreton Flats. Designed by Moriyama & Teshima Architects and Griffiths Rankin Cook Architects, the new Canadian War Museum building was opened to the public in 2005.

The museum's collection contains over 500,000 pieces of materials related to military history, including over 13,000 pieces of military art. In addition to its permanent exhibition, the museum has hosted and organized a number of travelling exhibitions relating to Canadian military history.

Timeline

- 9:00am: Depart from Westin hotel to cruise
- 10:00am: Cruise departs
- 11:30am: Cruise returns
- 12:00pm: Lunch on canal at Elgin Restaurant
- 1:30pm: Depart to Canadian War Museum
- 2:00pm: Tour Canadian War Museum
- 4:00pm: Depart Museum and return to hotel
- 4:30pm: Arrive to Westin hotel

Social Program

THURSDAY, JULY 25, 2024
11:30 AM TO 1:05 PM

WOMEN IN ENGINEERING LUNCHEON

VENUE TWENTYTWO (WESTIN HOTEL)

NSREC hosted its first IEEE Women in Engineering (WIE) event in 2011 in Las Vegas with general chair Kay Chesnut. Thirteen years later, the annual WIE event is going strong, and attendees have enjoyed hearing speakers from industry, academia, and government. This year we want to hear from you, our NSREC community, to shape future WIE events. Heather Quinn, general chair of the 2024 NSREC, will share her experiences as past chair of the IEEE WIE International Leadership Conference. Join us for lunch, conversation, and networking. What do you want to experience in future NSREC WIE events? How can the IEEE WIE society positively impact your career and life balance? Let's frame the next few years together!

Note: Tickets are required so check the box for this lunch when you register for the conference.

ACTIVITIES POLICIES

Participation: All participants in the NSREC activities must be conference attendees, registered guests of a conference attendee, registered exhibitors or registered guests of an exhibitor. Any children under 18 years of age must be accompanied by an adult at all times; no children will be allowed to attend any function without this adult supervision.

Cancellation: To encourage advance registration for conference social activities, NSREC will refund all activity fees for conference attendees and/or their companions who, for any reason, are unable to attend the conference as long as that notice is provided as follows. If your plans change after your Activities Registration form is submitted, simply request a refund by notifying **John Teehan** via e-mail ***(j.teehan@ieee.org)*** by no later than July 3rd.

Wheelchairs and Strollers: Both wheelchairs and strollers can be stored in the luggage compartment of the buses but please note that you must provide your own personnel to push these devices.

FITNESS CLASSES

Olga Paillet received her PhD degree in Sports Physiology from the University of Health and Sports in Saint Petersbourg, Russia in 1992. She also graduated from the University of Paris as a sport trainer in 2001, and from the Faculty of Medicine of the Paris University as a nutritionist in 2012. She has been practicing in Paris for the last 20 years. Alongside her professional activities, she is also a highly-level professional and trained instructor in fitness and gymnastics, as well as a dance teacher and choreographer. She is a personal trainer and teaches Group Workout fitness.

Workout schedule:
Monday: 5:15PM after sessions
Tuesday: 4:30PM after sessions
Wednesday-Friday: 6:30 AM before breakfast

Classes are 45-60 minutes. The workout consists of fitness cardio/strength circuit training accompanied by top-hits of popular music. The workouts have simple but efficient exercises and movements designed to boost cardiovascular health, strength, muscle tone, and endurance. Participants will receive one-on-one attention from Olga during class and can ask Olga questions before or after class. Suitable for all fitness levels. Join this fun group class workout!
Classes are held in the British Columbia/Manitoba room in the Westin. Wear your workout clothes!

Local Activities

GENERAL INFORMATION

RIDEAU CENTRE SHOPPING MALL

The Westin is connected to the 3-level Rideau Centre Shopping Mall with 180 retailers including Nordstrom, Coach, Lacoste, Marciano, and Swarovski along with many restaurants, movies, and a food court.

Photo Courtesy: Shaw Centre

Photo Courtesy: Getty Images

BYWARD MARKET

ByWard Market is a buzzing hub of outdoor farmers' market stalls and specialty food shops selling Canadian cheese and maple-infused chocolate. It's also known for its colorful street art and hip stores filled with crafts and clothes by local designers.

- Other nearby shopping:
  - City Centre Mall
  - Ottawa Train Yards
  - St. Laurent Shopping Centre treasures as well.

Local Activities

MUSEUMS AND GALLERIES

THE ROYAL CANADIAN MINT

The Royal Canadian Mint's headquarters occupies the same historic building in Ottawa where it was founded in 1908. Today, the facility proudly produces world-renowned collector coins, gold and silver bullion, and medals and medallions that honour those who have made a significant impact on our country.

Photo Courtesy: The Royal Canadian Mint

THE CANADIAN MUSEUM OF NATURE

The Canadian Museum of Nature is a national natural history museum based in downtown Ottawa. The museum's exhibitions and public programs are housed in the Victoria Memorial Museum Building.

Photo Courtesy: Viator

Local Activities

THE CANADIAN AVIATION AND SPACE MUSEUM

The Canadian Aviation and Space Museum houses the national aeronautical collection and Canada's national aviation history. ***https://ingeniumcanada.org/aviation***

Photo Courtesy: Canadian Aviation and Space Museum

OTHER HIGHLIGHTS TO SEE:

Parliament Hill: ***www.parl.ca***
Ottawa Locks: ***www.rideau-info.com/canal/locks/01-08-ottawa.html***
National War Memorial: ***www.cdli.ca/monuments/on/nationalwar.html***
National Gallery of Canada: ***www.gallery.ca***
Notre Dame Basilica: ***https://notredameottawa.com***
Ottawa Art Gallery: ***https://oaggao.ca***
National Arts Centre: ***https://nac-cna.ca/en/***
Canada Agriculture and Food Museum: ***https://ingeniumcanada.org/agriculture***
Laurier House National Historic Site: ***https://parks.canada.ca/lhn-nhs/on/laurier***
Major's Hill Park: ***https://ncc-ccn.gc.ca/places/majors-hill-park***
Jacques-Cartier Park: ***https://ncc-ccn.gc.ca/places/jacques-cartier-park***
Prince of Wales Falls: ***https://www.world-of-waterfalls.com/waterfalls/canada-hogs-back-falls/***

Local Activities

MONTREAL – OLD TOWN

Montreal is approximately 2 hours east of Ottawa. Explore Montreal's cobblestoned Old Port with buildings dating to the 1700s. Visit Notre-Dame Basilica of Montreal, a 19th century masterpiece of Gothic Revival architecture with stained-glass windows depicting Montreal's history. Rue Saint-Paul is Montreal's oldest street and is lined with shops and restaurants.
https://www.frommers.com/slideshows/848530-what-to-do-in-old-montr-al-if-you-have-just-one-day

Photo Courtesy: National Geographic

GETTING AROUND

Once you're in Canada's Capital, getting around is easy! Ottawa is a walkable city with easy access to most sites on foot. Ottawa also offers many transportation options such as public transit, light rail system, taxi services, ride sharing and more!
https://ottawatourism.ca/en/plan-your-visit/getting-around

Rideau metro station on the O-Train Confederation Line on Rideau Street on the border of the Sandy Hill and ByWard Market neighbourhoods in Central Ottawa. Entrance is on the lower level of the Rideau Shopping Mall.

Photo Courtesy: OC Transpo

Local Activities

Ottawa Hop-On Hop-Off Bus Sightseeing Tour
https://www.grayline.com/tours/ottawa-24-hour-hop-on-hop-off-tour/

Photo courtesy: Gray Line Ottawa

BIKING ***https://ottawatourism.ca/en/ottawa-insider/cycling-ottawa-region***

GOLFING
Royal Ottawa Golf Club: ***https://royalottawagolfclub.com/golf/#ifg/***
Pine View: ***www.pineview.com/en***
Ottawa Hunt Club: ***https://ottawahuntclub.org***
The Marshes: ***www.marshesgolfclub.com***
Camelot: ***https://camelotgolf.ca***

CENTENNIAL FLAME: PARLIAMENT HILL

Photo Courtesy: Tripadvisor

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ANNOUNCEMENT and FIRST CALL FOR PAPERS

2025 IEEE NUCLEAR AND SPACE RADIATION EFFECTS CONFERENCE

Short Course and Radiation Effects Data Workshop

July 14-18, 2025
Renaissance Nashville Hotel
Nashville, Tennessee

www.nsrec.com

Sponsored By
IEEE/NPSS Radiation Effects Committee

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You are cordially invited to attend the 2025 IEEE Nuclear and Space Radiation Effects Conference to be held July 14-18, 2025 at the Renaissance Nashville Hotel, Nashville, Tennessee. The conference features a technical program consisting of eight to ten technical sessions of contributed papers describing the latest observations in radiation effects, a Short Course on radiation effects issues, a Radiation Effects Data Workshop, and an Industrial Exhibit. The technical program includes oral and poster sessions.

Papers on nuclear and space radiation effects on electronic and photonic materials, devices, circuits, sensors and systems, as well as semiconductor processing technology and design techniques for producing radiation-tolerant (hardened) devices and integrated circuits, will be presented at this meeting of engineers, scientists, and managers. International participation is strongly encouraged.

We are soliciting papers describing significant new findings in the following or related areas:

Basic Mechanisms of Radiation Effects in Electronic Materials and Devices
- Single-Event Charge Collection Phenomena and Mechanisms
- Ionizing Radiation Effects
- Displacement Damage
- Radiation Transport, Energy Deposition, and Dosimetry
- Materials and Device Effects
- Processing Related Radiation Effects

Hardness Assurance Covering Piece Parts, Systems, and Testing Approaches
- New Modeling and Testing Techniques, Guidelines, and Hardness Assurance Methodologies
- Unique Radiation Exposure Facilities, Test Facility Developments, Novel Instrumentation Methods
- Dosimetry

Radiation Effects on Electronic and Photonic Devices, Circuits, and Systems
- Single Event Effects, Total Dose, and Displacement Damage
- MOS, Bipolar, and Advanced Technologies
- Systems on a Chip, GPUs, FPGAs, Microprocessors, and Neuromorphic Devices
- Isolation Technologies, such as SOI and SOS
- Methods for Hardened Design and Manufacturing
- Modeling and Hardening of Devices and Circuits
- Cryogenic or High Temperature Effects
- Novel Device Structures, such as MEMS and Nanotechnologies
- Emerging Modeling and Experimental Techniques for Hardening Systems

Space, Atmospheric, and Terrestrial Radiation Effects
- Characterization and Modeling of Radiation Environments
- Space Weather Events and Effects
- Spacecraft Surface and Internal Charging
- Predicting and Verifying Soft Error Rates (SER)

New Developments of Interest to the Radiation Effects Community

PAPER SUMMARY DEADLINE: FEBRUARY 7, 2025

PROCEDURE FOR SUBMITTING SUMMARIES

Summaries must be received by February 7, 2025

Detailed submission and formatting instructions will be available after December 1, 2024 at www.nsrec.com

Authors must conform to the following requirements:

1. Prepare a single Adobe Acrobat file consisting of a cover page and an informative two to four page summary describing results appropriate for 12-minute oral or poster presentation. The cover page must provide an abstract no longer than 35 words, the title, name and company affiliation of the authors, and company address (city, state, country). Identify the author presenting the paper and provide telephone, and email address. The summary must include sufficient detail about the work to permit a meaningful technical review. In the summary, clearly indicate (a) the purpose of your work, (b) significant new results with supporting technical material, and (c) how your work advances the state of the art. Show key references to other related work. The summary must be no less than two and no more than four pages in length, including figures and tables. All figures and tables must be large enough to be clearly read. Note that this is more than an abstract, but do not exceed four pages.
2. Prepare your summary in single-column or IEEE TNS standard two-column format, using 11 point or greater font size, formatted for either U.S. Standard (8.5 x 11 inch) or A4 (21 x 29.7 cm) page layout, with 1 inch (2.5 cm) margins on all four sides.
3. Obtain all corporate, sponsor, and government approvals and releases necessary for presenting your paper at an open attendance international meeting.
4. Summary submission is electronic only, through ***www.nsrec.com.*** The submission process consists of entering the paper title, author(s) and affiliation(s), an abstract no longer than 35 words, and uploading the summary. Authors are prompted to state their preference for presentation (oral, poster, or data workshop poster) and for session. Details of the submission process may be found at ***www.nsrec.com.*** The final category of all papers will be determined by the Technical Program Committee, which is responsible for selecting final papers from initial submissions.

Papers accepted for oral or poster presentation at the technical program are expected to be submitted for publication in the IEEE Transactions on Nuclear Science (January 2026). Selection for this issue will be based on a separate submission of a complete paper. These papers will be subject to the standard full peer review given all papers submitted to the IEEE Transactions on Nuclear Science. Further information will be sent to prospective authors upon acceptance of their NSREC summary. It is not necessary to be an IEEE member to present a paper or attend the NSREC. However, we encourage IEEE and NPSS membership of all NSREC participants.

RADIATION EFFECTS DATA WORKSHOP

The Radiation Effects Data Workshop is a forum for papers on radiation effects data on electronic devices and systems. Workshop papers are intended to provide radiation response data to scientists and engineers who use electronic devices in a radiation environment, and for designers of radiation-hardened systems. Papers describing new simulation techniques and results, or radiation facilities are also welcomed. **The procedure for submitting a summary to the Workshop is identical to the procedure for submitting NSREC summaries.** Radiation Effects Data Workshop papers will be published in a Workshop Record and are not candidates for publication in the Conference issue of the *IEEE Transactions on Nuclear Science.*

NASHVILLE, TENNESSEE

The NSREC 2025 is at the Nashville Renaissance in downtown Nashville adjacent to the famous 5th and Broadway. Nashville, nicknamed, Music City, is the capital of the U.S. state of Tennessee and home to Vanderbilt University. Legendary country music venues include the Grand Ole Opry House, home of the famous "Grand Ole Opry" stage and radio show. The Country Music Hall of Fame and Museum and historic Ryman Auditorium are steps away from the Renaissance.

Courtesy Nashville Convention & Visitors Corp.

Music is the universal language and there is not better place to experience music than in Nashville, a city of storytellers and dreamers. It is a city where all are welcome with an authentic, friendly, creative spirit. It's a city for you to discover all it has to offer and you can write your own Music City story. Nashville is the culinary destination of today, with chef-driven restaurants and classic dining spots serving up hot chicken, barbecue, and of course, meat and three. With nearly 200 new restaurants opening in the past two years, a one-of-a-kind culinary adventure awaits.

Beyond the music, food and drink, there is never a shortage of inspiring things to do. From the museums, the arts, sports and shopping, there is an "only in Nashville" experience waiting for you.

Please join us and find your Nashville inspiration. Experience the creative energy. Discover the neighborhoods. Seek out the hidden gems. Uncover the history and history in the making. And of course, enjoy the music.