Lifetime study of electronic devices for extreme radiation conditions

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Background

- Radiation technology development and its applications bring new requirements on related electronic devices.
- The study of radiation effect on electronic devices is important for increasing their lifetime and the reliability of the whole technology, when used in radiation harsh environment like space, large accelerators, nuclear reactors etc.
- We have studied the effect of the X-rays and the high energy electrons on lifetime of devices used in radiation extreme conditions:
  - the CERN accelerator component (by electrons)
  - the semiconductor devices for the first Slovak satellite (by X-rays)
  - the semiconductor detectors for radiation imaging and dosimetry (by electrons)

Methodology


UCEA ,Trenčín, SK

Method of lifetime study

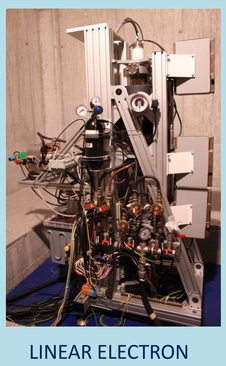
1. Monte Carlo simulations of irradiation geometry and tested device together with dose-depth distribution in it
2. Irradiation of phantom of tested device
3. Irradiation of tested device
4. Electrical and /or mechanical functional tests of irradiated device in collaboration with: Slovak University of Technology in Bratislava, SK, ZTS VVÚ KOŠICE Ltd., SK
5. Proposal of measures for longer device operational life in real radiation fields

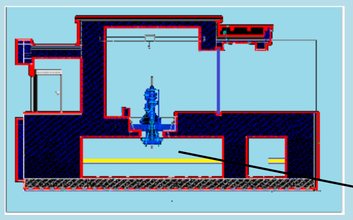
Irradiation

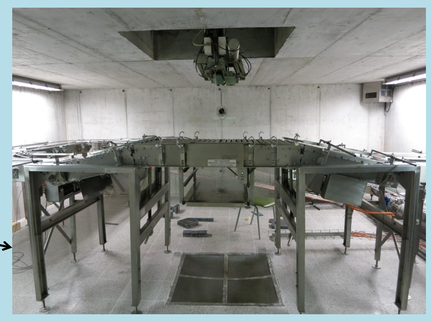
Linear electron accelerator UELR 5-1S

- ❖ Producer NIIEFA, St. Petersburg
- ❖ Maximum beam power 1 kW
- ❖ Electron energy (3.6 - 6.2) MeV
- ❖ Beam repetition rate 5, 10, 20, 40, 120 or 240 Hz
- ❖ Converted X-rays up to 6.2 MeV
- ❖ Beam scanning width: 40 cm, 45 cm, 50 cm
- ❖ Beam diameter at window 11 mm
- ❖ Conveyor velocity: 0.1 mm/s - 100 mm/s
- ❖ Three modes of irradiation:

I. the static scientific irradiation
II. the in-line routine irradiation on conveyor
III. the rotational irradiation


LINEAR ELECTRON ACCELERATOR UELR 5-1S


ACCELERATOR IN CROSS-SECTION VIEW OF THE BUILDING

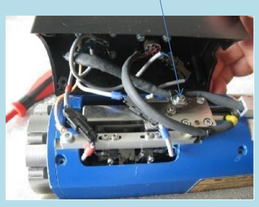

IRRADIATING ROOM

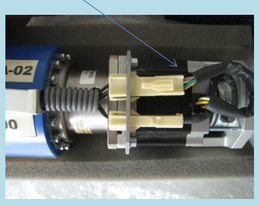
Conclusions

- The CERN accelerator component, the engine for dipole precise positioning, tested up to 2 MGy of electrons, only its plastic were mechanically destroyed.
- The commercial semiconductor devices for skCUBE satellite power unit from various manufacturers were tested up to a dose of 1300 Gy of X-rays, representing the dose obtained by satellite on its orbit during about 3 years.
- The semiconductor detectors were irradiated up to 120 kGy of electrons preserving the functionality with initial improvement of energy resolution followed by its degradation.

CERN accelerator component

- Engine for precise positioning of dipole magnets in Super LHC accelerator in CERN
- Made in ZTS VVÚ KOŠICE Ltd., SK
- Tested by PC controlled tester at ZTS VVÚ KOŠICE Ltd. SK


Radiation sensitive wires

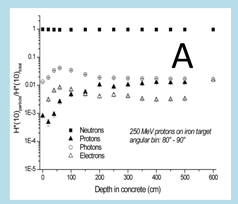

Radiation sensitive connectors

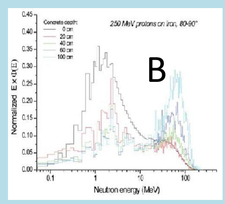
Irradiation	Partial dose [kGy]	Total dose [kGy]	Type of radiation	Functional test result
1.	250	250	X-rays	Functional
2.	500*	750	electrons	Functional
3.	500*	1250	electrons	Functional
4.	750*	2000	electrons	Functional
Beam repetition rate 10 Hz, scanning width 40 cm, steady mode				

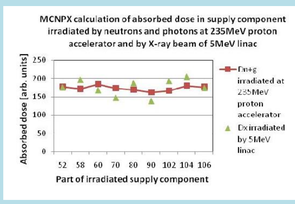
Results:
- After 250 kGy – connector mechanically destroyed
- After 750 kGy – significant color change of plastic parts
- After 2 MGy – engine still functional

Simulation of operating radiation environment:
Stray radiation fields are created at high-energy particle accelerators by the intentional interaction of the accelerated beam with targets, beam dumps, collimators and by unintentional beam losses on structural components of the machine.
At electron accelerators (UCEA), the most important secondary radiation is **bremsstrahlung photons and high-energy electrons** produced in electromagnetic cascades.
At proton accelerators (CERN), interaction of the beam with materials generates a hadron cascade containing **neutrons, charged hadrons, muons, photons and electrons.** Dominant are neutrons.

Simulation of secondary particles of 250 MeV protons at various depths of concrete shield impinging on an iron target thicker than the proton range (A) and neutron energy distributions in iron after various concrete thicknesses penetration (B):







Absorbed dose distributions in supply components irradiated at CERN proton accelerator and by X-rays of 5 MeV linac are **similar** within relative deviation of 20% according to MC simulation.

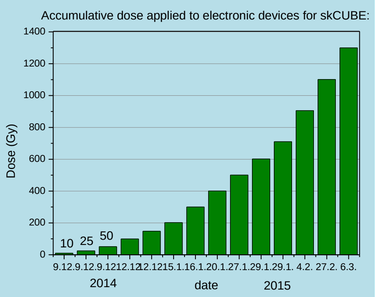
Optimization of supply component irradiation:
- Electron to X-ray conversion efficiency only 15-17 %
- 2 MGy: 200 h X -ray or 20 h electron irradiation
- e^- and X-rays: similar radiation damage, electron range in material has to be considered (only for low density components).

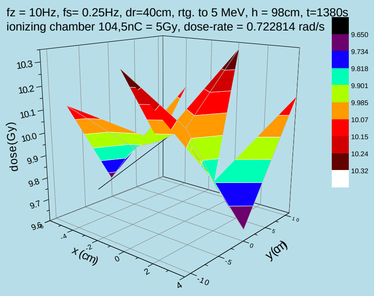
Suggestion for making supply component more radiation resistant :
Shielding of supply component by 8 cm thick polyethylene (CH_2) with 3% B will decrease the absorbed dose by 12%.

Semiconductor devices for skCUBE

SkCUBE, the first Slovak satellite:
- made by Slovak Organization for Space Activities
- ready for launch in 2017
- Circular Earth's orbit with 500 km altitude with an inclination angle of 98° gives estimated ionizing dose exposure of 400 Gy/year (40 kRad/y)
- Mission duration from 1 to 2 years
- Commercial semiconductor devices for the skCUBE power supply unit were chosen according to their radiation hardness evaluated by X-ray irradiation

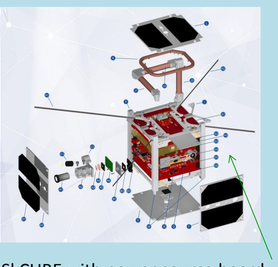
Irradiation:
- By continuous spectrum of X-rays up to 5 MeV
- Beam repetition rate 10 Hz, scanning width 40 cm, steady mode
- Doses obtained in 13 steps

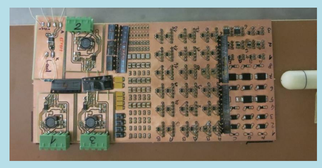




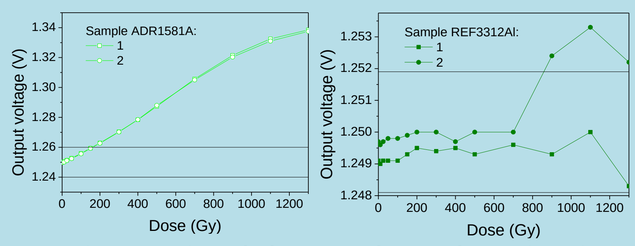
Homogeneity of irradiating field.


7.1.2016: presentation of final skCUBE .

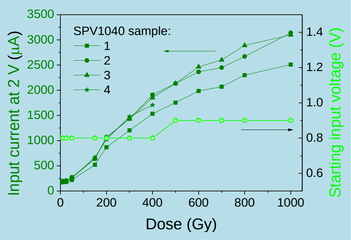

SkCUBE with power source board.


Electronic devices for satellite power supply mounted on PCB (Printed Circuit Board) with ionizing chamber on the right.

Results:
Two kinds of degradation with increasing applied dose:
- the output voltage of device degraded and the input current preserved with applied dose (voltage references)
- the functionality of device is preserved, but the input current dramatically increases (battery chargers)



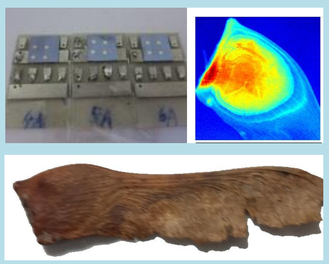
The output voltage of references as a function of accumulative dose.



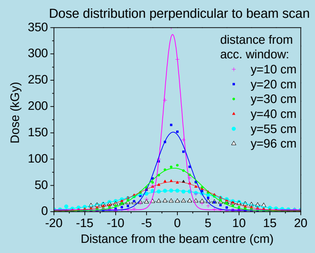
The input current of battery chargers as a function of accumulative dose.

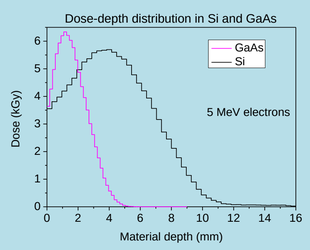
Semiconductor detectors of radiation

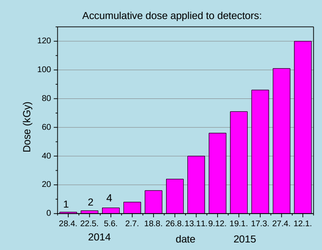
GaAs detectors of ionizing radiation
- Made by Slovak Academy of Sciences in Bratislava, SK
- Working in single photon counting mode
- Prepared from 230 μm thick semi-insulating GaAs. *Top Schottky contact:* circle: ∅ 1 mm, Ti/Pt/Au (10/35/90 nm) , *Back ohmic contact:* full-back-side, Ni/AuGe/Au (30/50/90 nm)
- Developed for digital imaging with X-ray tube and particle tracking in space and accelerators


SI GaAs DETECTORS for digital radiation imaging

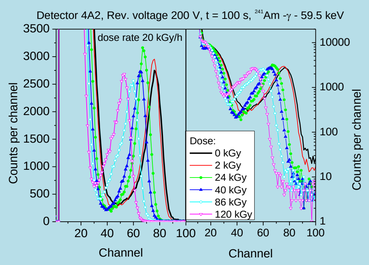
Irradiation:
By 5 MeV electrons, Beam repetition rate 10 Hz, scanning width 40 cm, steady mode, Doses obtained in 12 steps



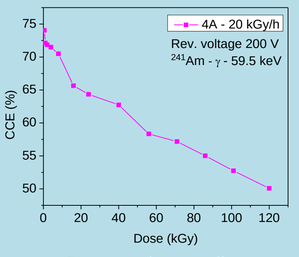




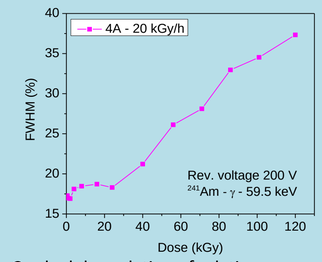
Results:



Detector ability to measure spectra after radiation degradation.



Detector charge collection efficiency (CCE) systematically decreases with applied dose.



Gradual degradation of relative energy resolution (FWHM) with accumulative dose in the range of doses of 24 up to 120 kGy.