# Irradiation Experiments for EU-XFEL/TESLA Electronics

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TESLA — The LC cold option


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## Current research:

- **Evaluate radiation level in LINAC II and compare to environment expected in EU-XFEL/TESLA**
- **Determine Single Event Effects (SEEs) in electronics representative for EU-XFEL/TESLA LLRF (SEE in memory: data, configuration and logic)**
- **Determine radiation impact on different kinds of electronic components**
- **Develop redundancy concepts and evaluate performance in presence of radiation**

## Tasks to perform:

- **Determine Total Ionizing Dose (TID) effects**
  - **- measurement of leakage current (supply current to various chips)**
  - **- malfunction of components (permanent damage)**
- **Carry out fault tolerant software tests in radiation environment**
- **Predict performace and life-time of electronic components for EU-XFEL/TESLA experiments**
- **Develop criterions for radiation tolerant hardware**

## Radiation effects in semiconductors and radiation dosimetry

**High energy neutrons predominantly cause NIEL (displacement) damage as well as Single-Event-Upset (SEU) in semiconductor devices. On the other hand, the damaging effect of photons is many order magnitude less than that caused by neutrons (Figure 1). High flux of Photoneutrons is produced near the Linac-2 (Figure 2) as well as TTF-2 linac mainly via the Giant-Dipole-Resonance (GDR) process (*V.Vylet and J. C. Liu, Radiat. Prot. Dosim. 96(2001)333. W. P. Swanson, Hlth. Phys. 35(1978)353*). Some typical photoneutron spectra relevant to present work are shown in Figure 3. We have developed two types of passive devices using: (a) Thermo-Luminescent-Dosimeter ($^7$LiF and $Al_2O_3$ dosimeter pairs) and (b) Light-Emitting-Diodes (GaAs) to explicitly estimate the neutron and gamma KERMA-doses. The neutron fluence (energy spectrum) and KERMA (Kinetic-Energy-Released-in Matter) coefficients for GaAs (*A. M. Ougoug et al. IEEE Trans. NS. 37(1990)2219*), Si and $^7$LiF (*R. S.Caswell et al. Int. J.. Appl. Radiat. Isot. 33(1982)1227*) were used to calculate neutron KERMA (J kg$^{-1}$ = Gy) in the materials of interest (Figure 4) and correlated with corresponding radiation induced damage.**

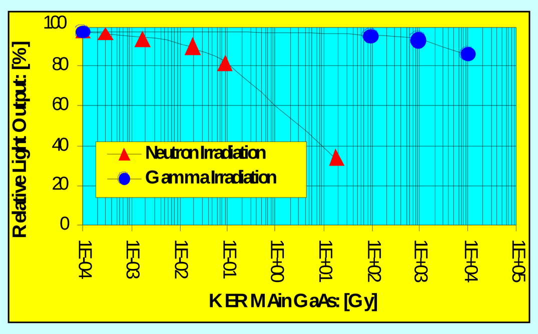


Figure 1: Relative light output of GaAs LED irradiated with $^{60}$Co gamma rays ($E_G$ = 1.25 MeV) and fast neutrons ($E_N$ = 16 MeV) from a Medical Cyclotron.

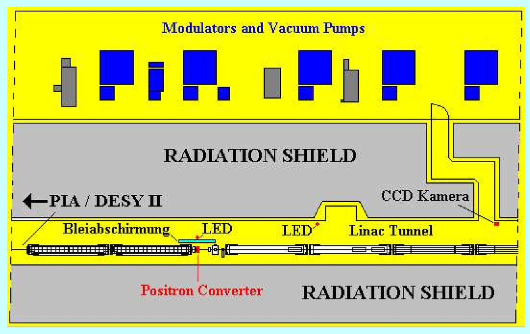


Figure 2: The irradiation set up in the Linac-2 Tunnel.

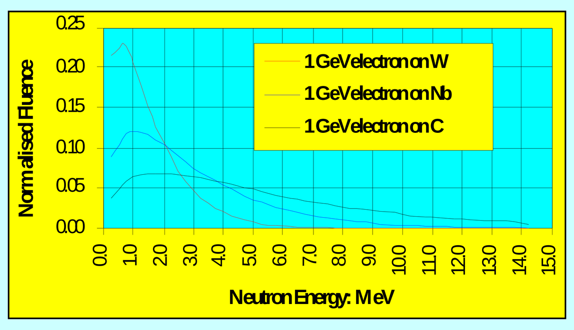


Figure 3: Photoneutron spectra of 1 GeV electrons produced in some important accelerator building materials.

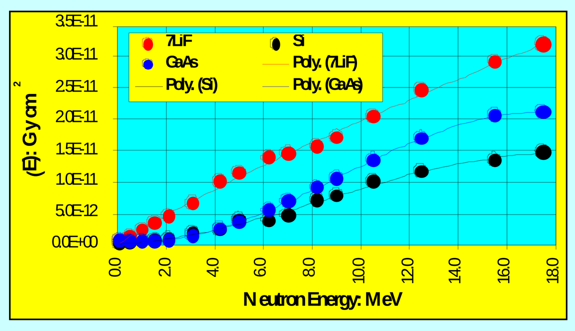


Figure 4: Neutron KERMA coefficient κ(E) is plotted as a function of neutron energy.

### TLD Glow-Curve Analysis

**The $Al_2O_3$ (TLD-500) dosimeters possess very low sensitivity for neutrons (*B. Mukherjee and A. C. Lucas, Radiat. Prot. Dosim. 47(1993)177*) and are highly responsive to gamma rays. The Computerised Glow Curve Analysis (*Y. Horowitz and D. Yossian, Radiat. Prot. Dosim 60(1995)21*) method was used to isolate the high temperature glow peak of the TLD-700 ($^7$LiF) dosimeter (*B. Mukherjee, Nucl. Instr. Meth. A 385 (1997)179. S. Miljanic et al. Nucl. Instr. Meth. A 519 (2004)667*) and correlated with the neutron KERMA in $^7$LiF (TLD-700). The results are shown in Figure 5.**

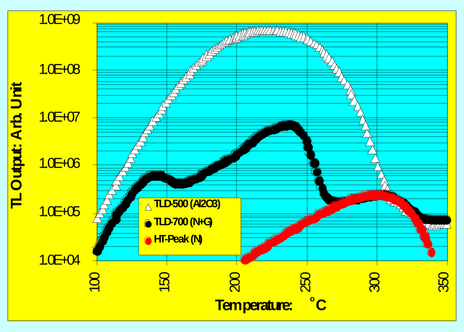


Figure 5: The TL-glow curves of TLD-500 and TLD-700 chips and deconvoluted high-temperature (HT) peak of TLD-700 dosimeter. The area under the HT (300 °C) peak is proportional to neutron dose.

### Calibration of the LED Dosimeter

**The Yellow GaAs LEDs were irradiated with high energy neutrons from a Medical Cyclotron (Figure 1). The Light attenuation of the LED (Figure 6) was measured with a digital photometer (*Dominik Rybka, M.Sc. Thesis project, under preparation*).**

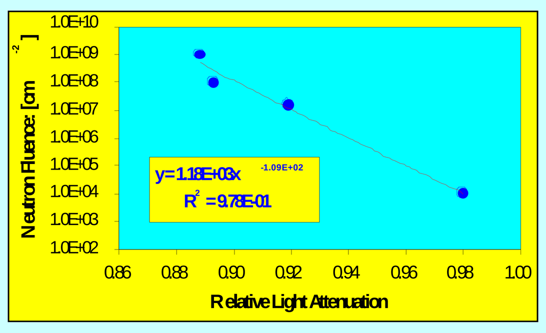


Figure 6: The Calibration curve of the LED dosimeter. The graph is fitted with a power function shown inset.

### Summary

**We have successfully evaluated the neutron KERMA dose in semiconductor components caused by photoneutrons produced in a thick Tungsten positron generating target. Neutron KERMA was evaluated using the deconvoluted TL-Glow curve (Figure 5) and the light attenuation curve of LEDs (Figure 6). The dosimetry techniques are summerised in the Table 1:**

| Important features of the Dosimetry methods | Photoneutron Dosimetry using | |
|---|---|---|
| | TLD | LED |
| Device Sensitivity | High | Low |
| Read-out method | Indirect | Direct |
| Cost of the Sensor/Detector | Low | Low |
| Cost of the read-out Instrument | High | Low |

Table 1: Two dosimetry methods devloped for the estimation neutron dose produced by the photoneutrons.

## NIEL (Non-Ionising Energy Loss) and SEE (Single Event Effects) in electronic components in High Energy Neutron/Gamma mixed radiation field

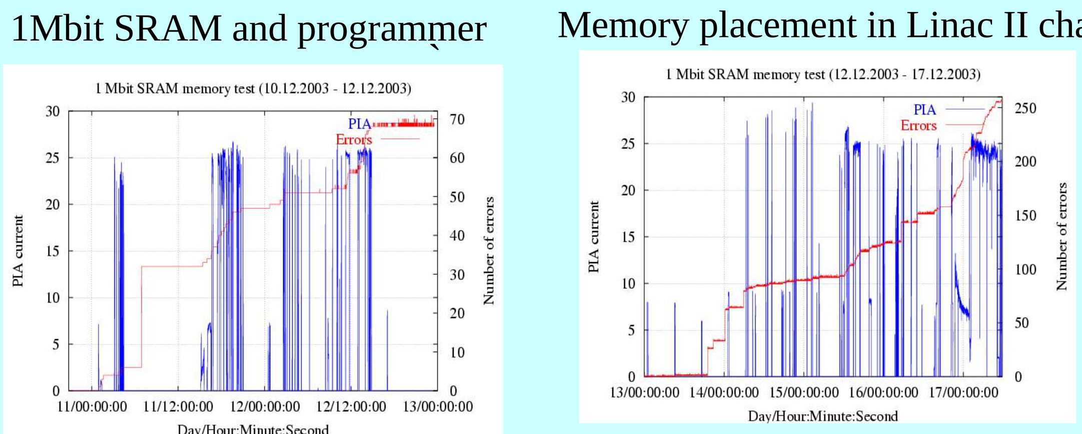
### On-line memory experiment

**UT621024 Memory chip**

- Capacity: 1 Mbit, organised as 131.072 8-bits words
- Low power CMOS Static Random Access memory chip 5V power supply, all inputs and outputs fully compatible with TTL
- Access time: 70ns,
- Power consumption: 40mA
- Package: 32-pin, 600mil PDIP
- Data retention voltage: min. 2V

1Mbit SRAM and programmer

Memory placement in Linac II chamber



Number of errors and PIA current

| Date | PIA | Time | Errors | Errors/day | PIA/error |
|---|---|---|---|---|---|
| 10.12-12.12.03 | 618 | 51 | 68 | 32 | 9 |
| 12.12-17.12.03 | 1743 | 108 | 257 | 57 | 7 |
| 17.12-04.01.04 | 2523 | 432 | 254 | 14 | 10 |
| 10.01-02.08.04 | 6343 | 698 | 696 | 24 | 9 |

Results obtained for SRAM memory

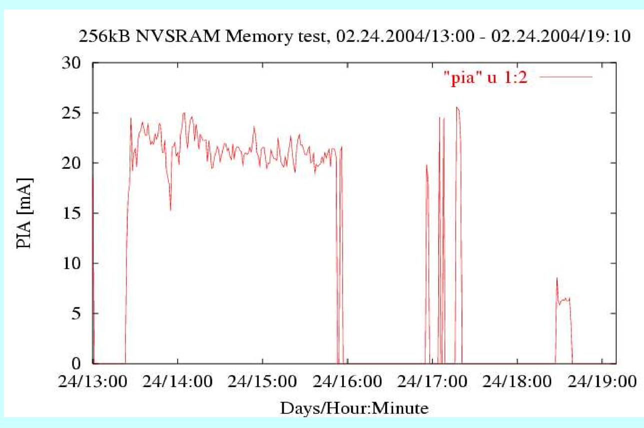
**Conclusions**

- Number of generated errors is proposional to Accumulated PIA current
- Only one-bit errors were generated
- Gamma rays have no damage producing effects (SEU) in SRAM.
- No SEL (Single Event LatchUp) was detected

### NVSRAM memory experiment

**Nonvolatile CMOS Static Random Access Memories were used in the experiment**

- 256kB NVRAM (BQ4014-85, 262.144x8)
- 128kB NVRAM (BQ4013-70, 131.072x8)
- The memories are equipped with lithium energy source, with 10 years retention time.
- 5V power supply, all inputs and outputs fully
- Compatible with TTL
- Access time: 256kB-85ns and 128kB-70ns
- Power consumption: 256kB-110mA, 128kB-105mA



PIA current while experiment

NVSRAM with attached dosimeters

| Irradiation Time | Accumulated PIA Charge | N-KERMA in: $^7$LiF [mGy] | N-KERMA in: Si [mGy] | SRAM Error (SEU) |
|---|---|---|---|---|
| 13.10 – 16.50 | 246 | 20.2 | 7.8 | 198 (256KB) |
| 13.10 – 19.15 | 266 | 21.8 | 8.4 | 205 (256KB) |
| 13.10 – 19.15 | 266 | 21.8 | 8.4 | 161 (128KB) |

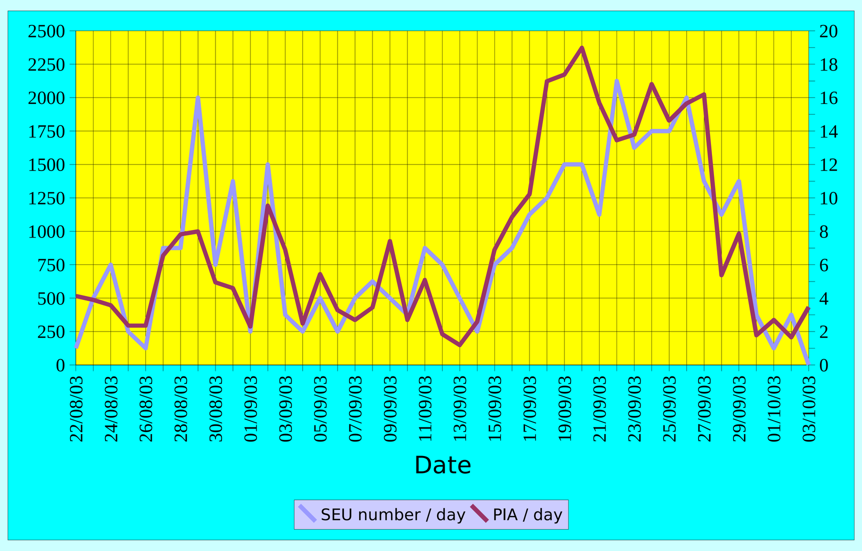
Number of NVSRAM errors related to the accumulated PIA. Charge and Neutron KERMA in $^7$LiF and Si.

### FPGA irradiation experiment

**Virtex-II LC 1000 Memec Development Kit Configuration memory test**

- Based on the Xilinx Virtex-II XC2V1000
- Board placed in Linac II in LED-2 position
- Test: Readback function of configuration memory
- Programming done every 1 hour
- Reading back configuration done every 2 minutes
- JTAG transmission by LVDS standard

Virtex-II LC 1000 Memec Development Board

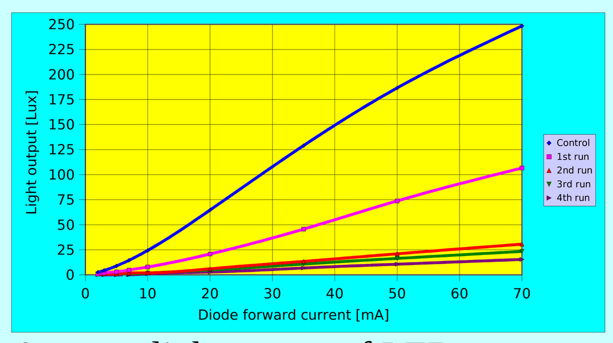


Number of errors vs PIA accumulated current

### LED irradiation experiment

PHOTO

Light output measurement aparature



Avarage light output of LEDs after irradiation runs (postion LED-1)

| Irradiation run | 24.07.03@10:47-29.07.03@14:00 | 04.08.03@16:40-11.08.03@11:50 | 11.08.03@12:02-18.08.03@10:37 | 18.08.03@10:43-22.08.03@13:15 | Light output [Lux] | Relative light attenuation | Accumulated PIA |
|---|---|---|---|---|---|---|---|
| control | | | | | 64.64 | 1.00 | 0.00 |
| 1st run | x | | | | 20.80 | 0.32 | 792.89 |
| 2nd run | x | x | | | 6.00 | 0.09 | 6824.42 |
| 3rd run | x | x | x | | 4.80 | 0.07 | 9000.60 |
| 4th run | x | x | x | x | 2.80 | 0.04 | 12566.65 |

LEDs irradiation runs results

**Conclusions**

- Possibillity of using Light Emitting Diodes as a neutron detector proved.
- Number of static errors is proposional to Accumulated PIA current.
- Dynamic SEUs in configuration memory caused mainly by neutrons.
- Number of errors in FPGAs not very big, but radiation-hardened FPGA projects are needed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