Radiation Effects on Electronic

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Introduction

- The electronics in the TESLA tunnel will be exposed to a moderate dose of neutron and gamma radiation. The integrated flux of fast neutrons close to the cryomodule will be of the order of up to 1e12 / cm**2 / 20 years. The gamma dose rate close to the crymodule cannot exceed 10 rad / hour based on a maximum permitted additional cryo heatload of 0.1W / m. The impact of this radiation levels on the electronics will be :

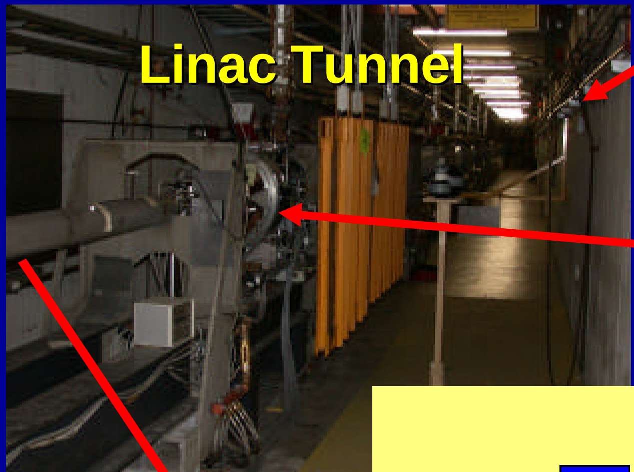
- Single event upset
  - Flipping bits in memory or hanging system may cause errors in digital signal processing
- total ionizing dose effects
  - limits life time of electronic (typically 1-10 kRad is limit for CMOS)
- Displacement damage could be problem > 1e12 / cm**2

Objectives

- Evaluate radiation level in VUV-FEK to estimate what is expected in the X-FEL and ILC
  - Develop dosimetrie adequate for on-line measurements
- Determine SEU effects, and TID and displacement damage in electronics which is representative for X-FEL in the VUV-FEL
- Develop countermeasures against radiation effects
  - including shielding
  - SEU immunity

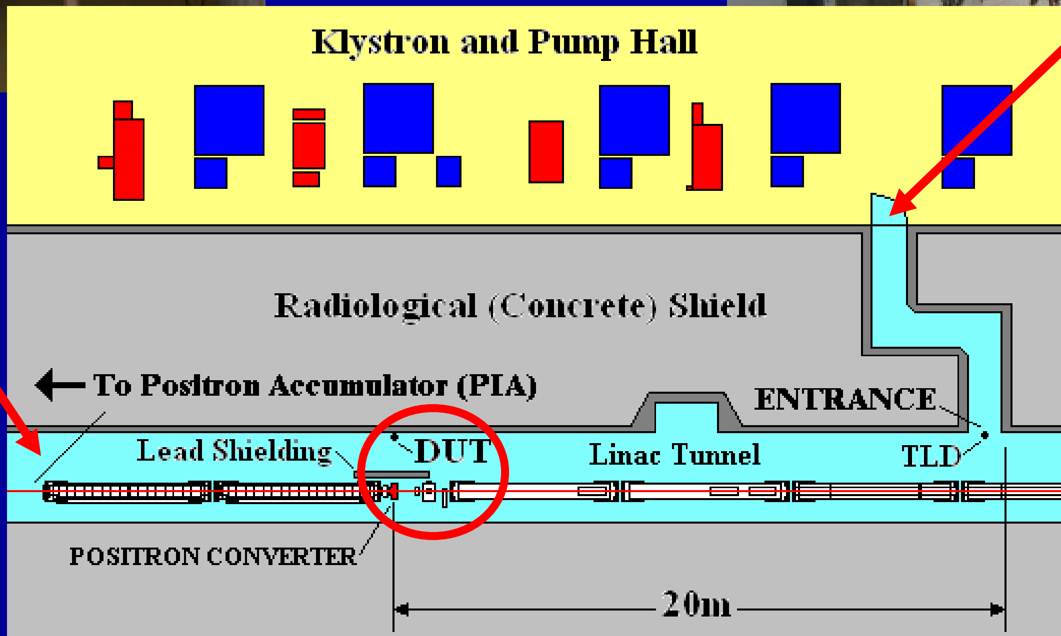
THE 450 MEV ROOM TEMPERATURE ELECTRON LINAC

(Showing a small section of the 70 m long Linac II tunnel)

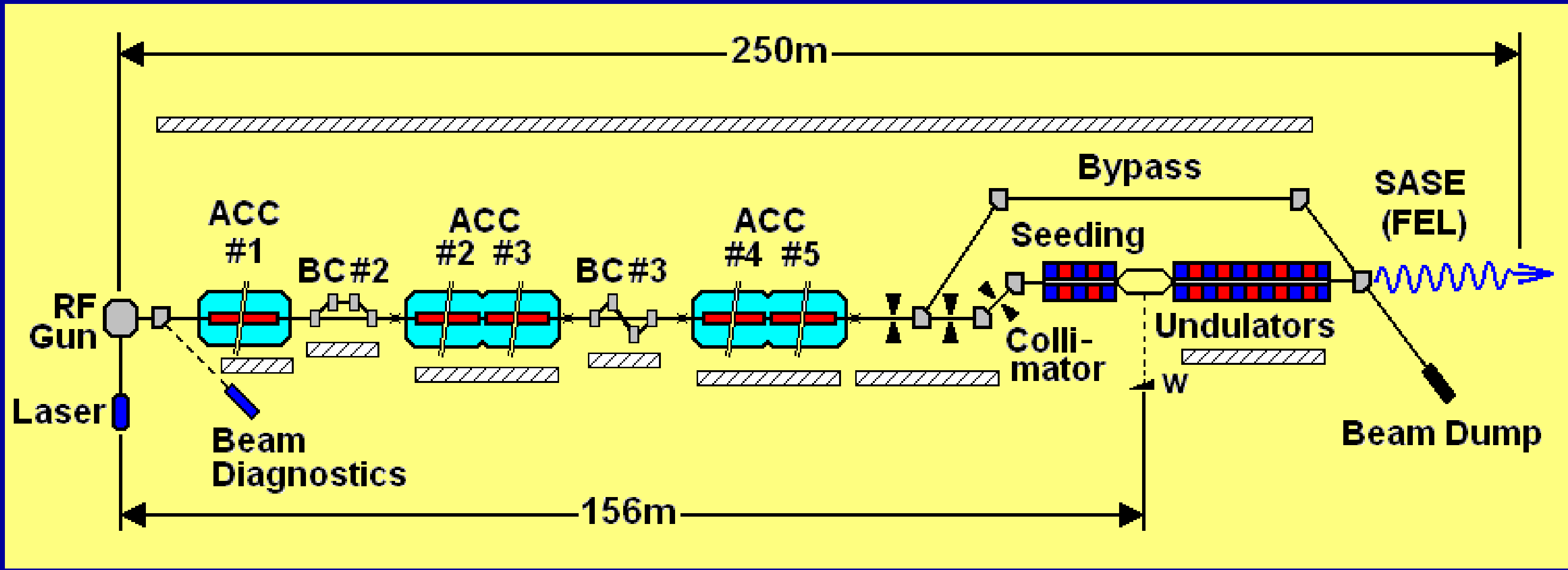


Device Under Test (DUT)

Positron Converter (Neutron Source)



SCHEMATIC LAYOUT OF THE VACUUM ULTRA VIOLET FREE ELECTRON LASER (VUV FEL)



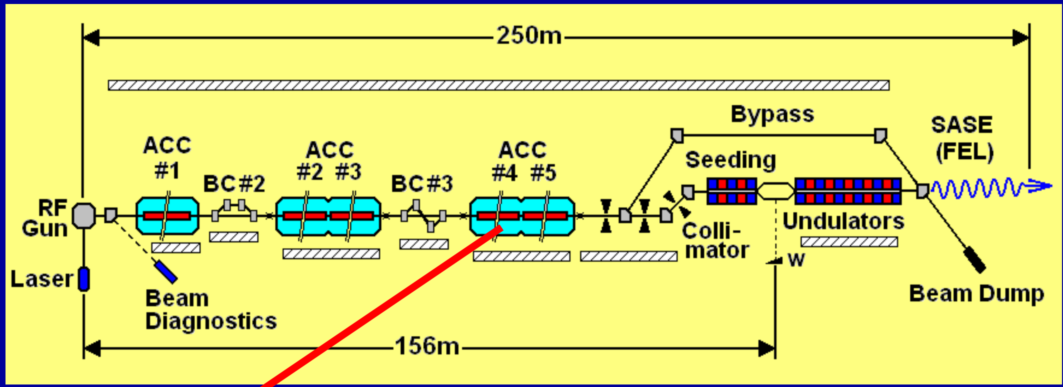
ACC #1 - ACC #5 => Accelerator module, each consists of 8 Superconducting cavities made of Niobium

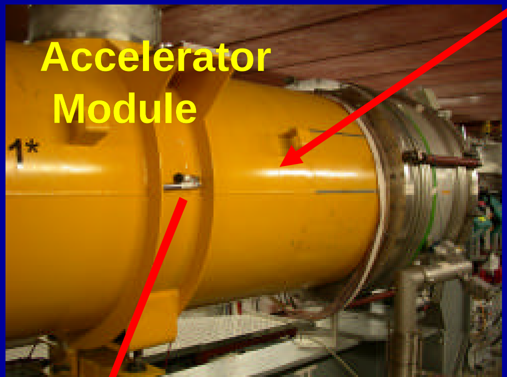
BCC #2, BCC #3 => Bunch compressors

"W" represents the location of experimental set-up (estimation of the Bremsstrahlung spectrum)

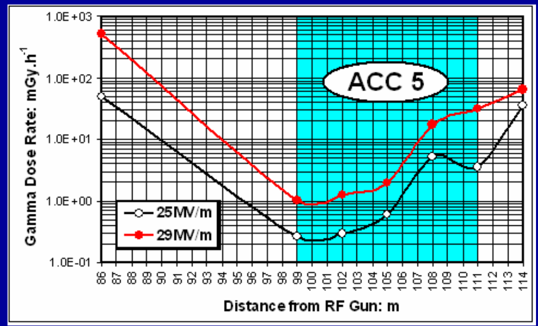
The hatched areas represent the locations of the micro-electronic devices

IN-SITU DOSIMETRY AT TESLA CAVITIES
(Radiation from Field Emission - Dark current)

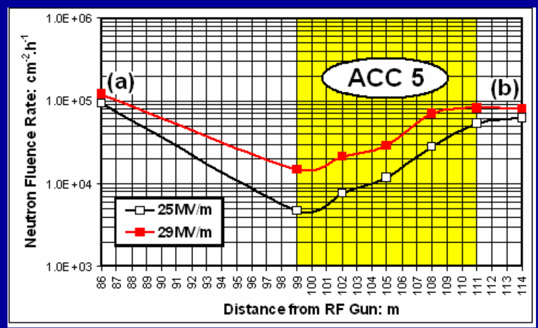




Neutron/Gamma Dosimeter pairs

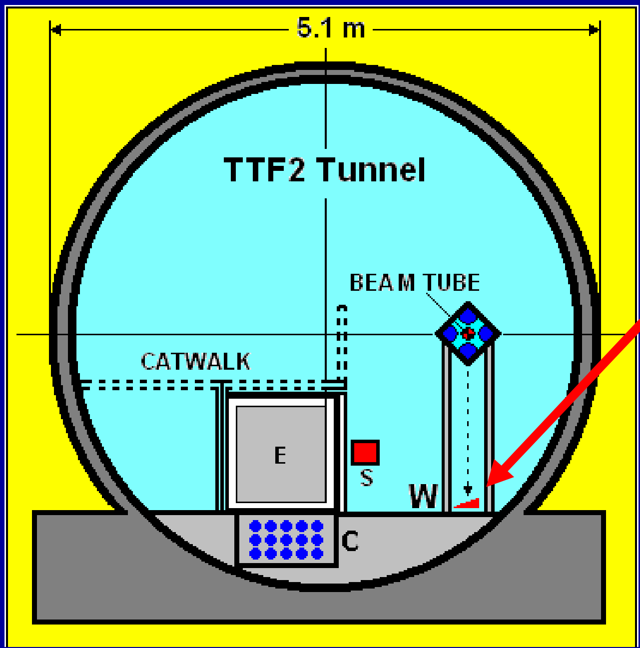


Gamma Dose Rate along the module tank, 0.5m from the module axis evaluated with PorTL (Al_2O_3) TLDs.

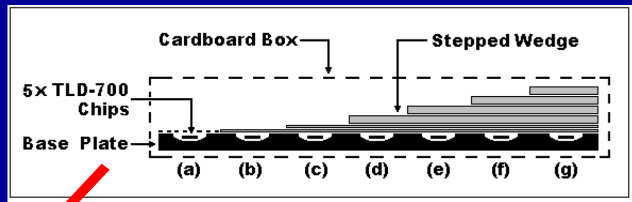


Neutron Fluence Rate along the module tank, 0.5m from the module axis evaluated with BDPND Superheated Emulsion (Bubble) dosimeters.

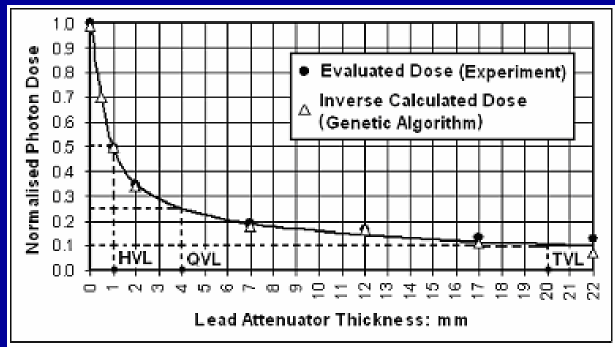
EXPERIMENTAL ESTIMATION OF BREMSSTRAHLUNG (BS) ENERGY SPECTRUM



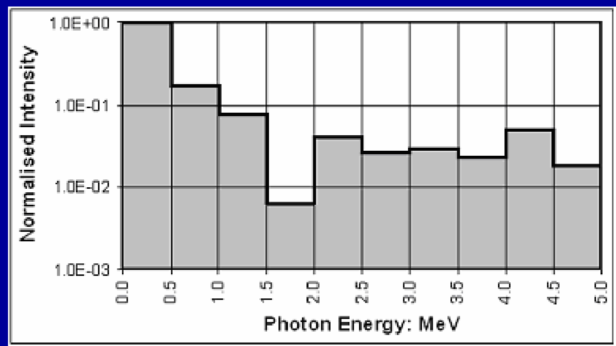
Cross Section of the TTF 2 tunnel showing: E=> Electronics Cabinet S=>Device Under Test, C=> Cables W=> Stepped (Pb) wedge with TLD



(a) Pb-wedge with TLD chips was exposed to BS generated in the Beam Tube.



(b) TLDs evaluated, Results plotted against Pb-thickness, HVL, QVL and TVL thicknesses of Pb were calculated.

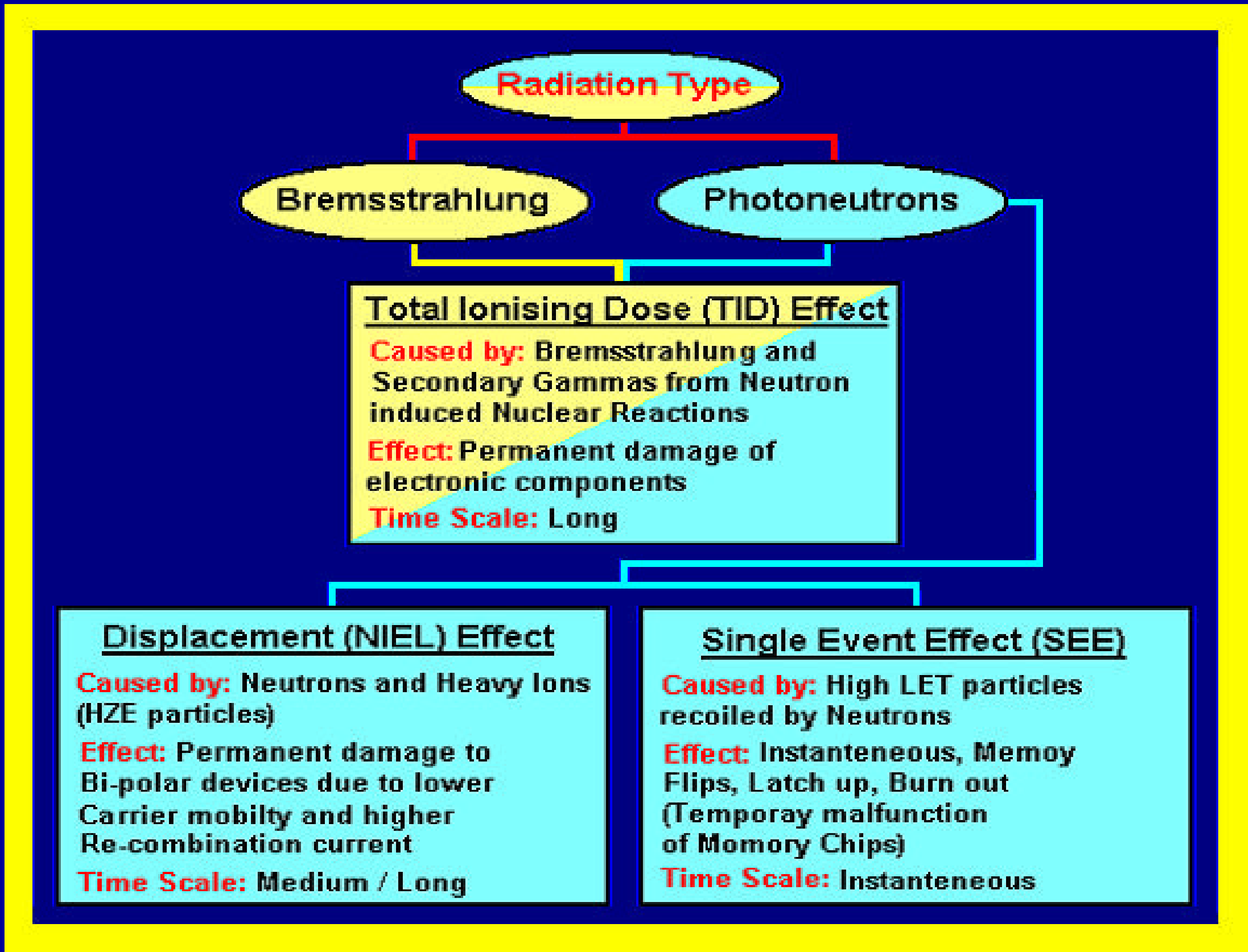


(c) Attenuation curve was analysed using a Genetic Algorithm, the BS spectrum was unfolded.

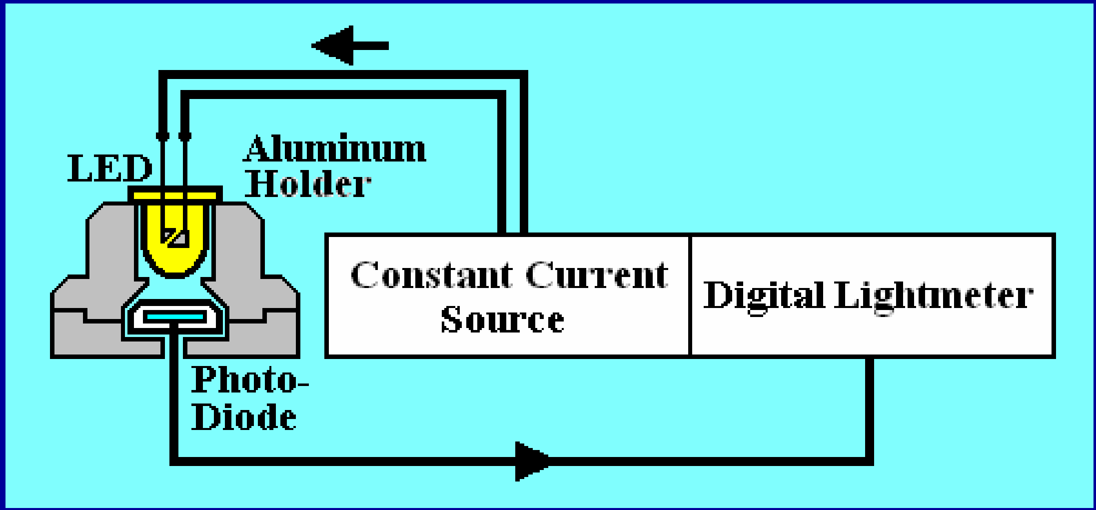
Results

E_G(peak) => 0.5 MeV
E_G(average) => 0.9 MeV

RADIATION EFFECTS ON MICROELECTRONICS



PRINCIPLE OF A SIMPLE DIGITAL GaAs LED READER (DOSI PHOTOMETER)



<u>We have assembled a simple digital photometer system using</u>

a) Aluminium (light tight) LED holder

b) Constant current source

c) Digital light meter

d) Photodiode (BPW34) connected to the digital light meter

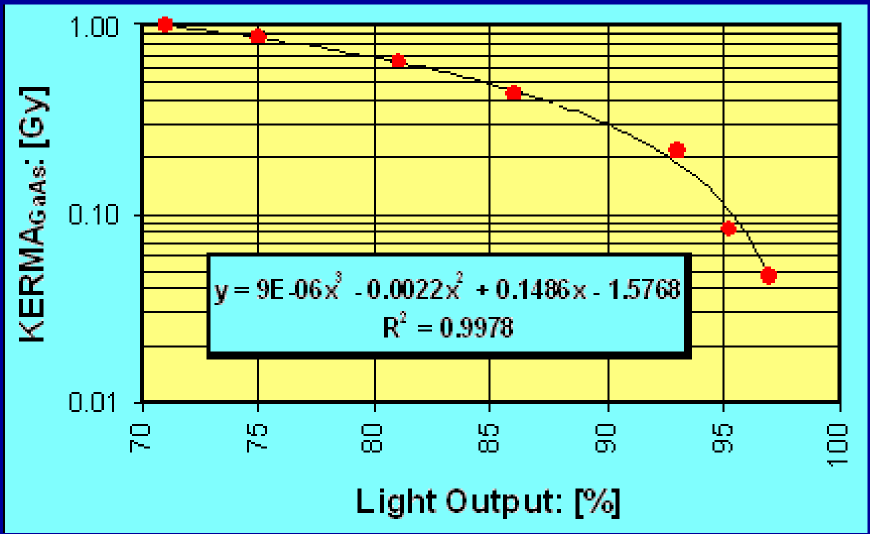
All measurements reported in this presentation were carried out using the DOSI-PHOTOMETER developed by us.

KERMA CALIBARTION OF THE GaAs LED (COTS)

Neutron KERMA in GaAs-LED is calculated as: K [Gy] = f. t. k

f [$n.cm^{-2}.s^{-1}$] = neutron fluence rate, t = exposure time [s], k [$Gy.cm^2$] = KERMA Coefficient

The KERMA of ^{241}Am/Be neutrons in GaAs LED was calculated using the above formula and plotted as a function of Light Output
=> KERMA Calibration Curve



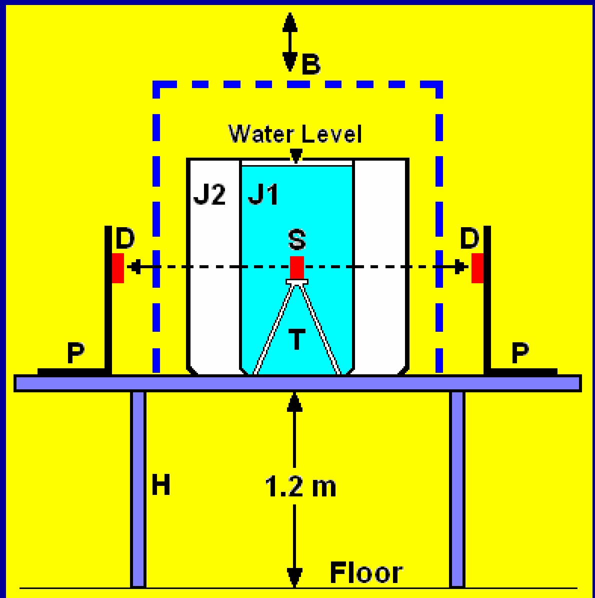
<u>We have planned to use the COTS - GaAs LED as:</u>

(a) Fast neutron Dose (KERMA) meter for High-Energy Accelerators

(b) Displacement Damage Precursor (long term Prediction)

NEUTRON IRRADIATION OF SRAM CHIPS

512 kB non-volatile SRAM chips were irradiated with ^{241}Am-Be neutrons and stray neutrons existing in the TTF 2 tunnel.

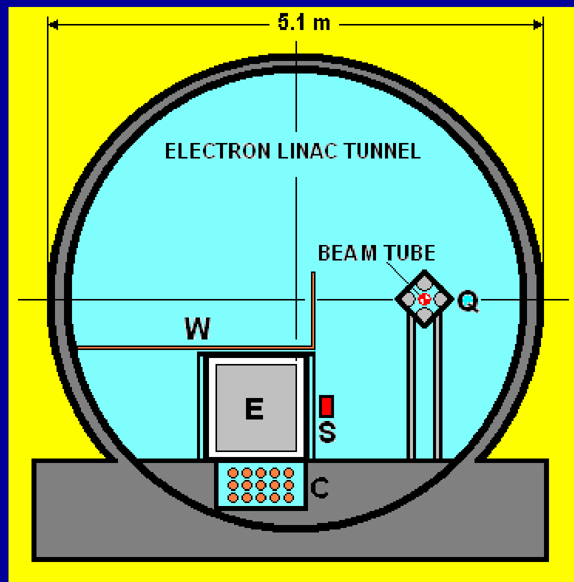


(1) ^{241}Am-Be Neutron Irradiation Device

B: Thermal Neutron Shield (Borated Polyethylene)
D: Device under Test (DUT)
H: Table
J1, J2: Jars (16 and 33 cm radius respectively)
P: Stand
S: ^{241}Am-Be Neutron source
T: Tripod (Source holder)

(2) In the TTF 2 (Electron Linac) Tunnel, warm side

C: Cable Duct
E: Electronic Instrument Cabinet
Q: Quadrupole Lens
S: SRAM Chips
W: Catwalk

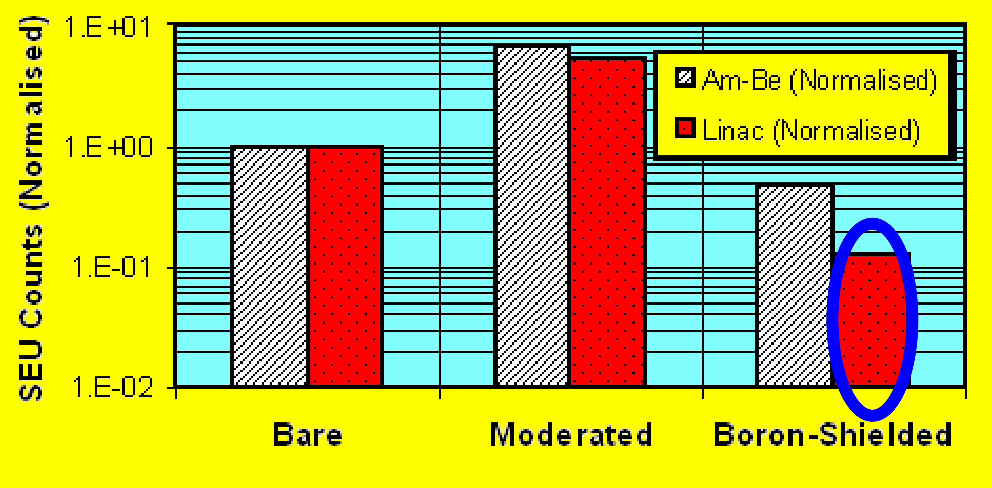


INTERPRETATION OF EXPERIMENTAL RESULTS

The number of SEU counted after neutron irradiation of the 512 kB SRAM chips are shown in the Table below:

SRAM Nr.	Irradiation Mode	SEU Counted
1	Am-Be (Bare)	40
2	Am-Be (Water Mod)	275
3	Am-Be (Water Mod + B-Shield)	19
4	Linac (Bare)	117
5	Linac (Polyeth. Mod)	619
6	Linac (Polyeth. Mod + B-Shield)	15

The normalised SEU counts of the bare, polyethylene-moderated and shielded with Borated Polyethylene (Poly-Boron) sheet are shown in the next Figure.



The lowest number SEU in the Poly-Boron shielded SRAMs irradiated at the Linac confirms the existence of a high number of thermal neutrons in the tunnel.

NEUTRON IRRADIATION EFFECTS ON CCD CAMERA

Two miniature CCD Cameras (COTS, Model: 166750-Conrad), were irradiated with ^{241}Am-Be neutrons (moderated with 6.5 cm thick water layer) resembling the photoneutron spectrum in TTF2 tunnel.

One CCD Camera was kept unshielded, the other was covered with a 3 mm thick thermal neutron shield (DESY-Shield)

Both cameras were interfaced to a PC via USB port and the and the number of SEU (hot pixels) were counted in real-time (s. below).

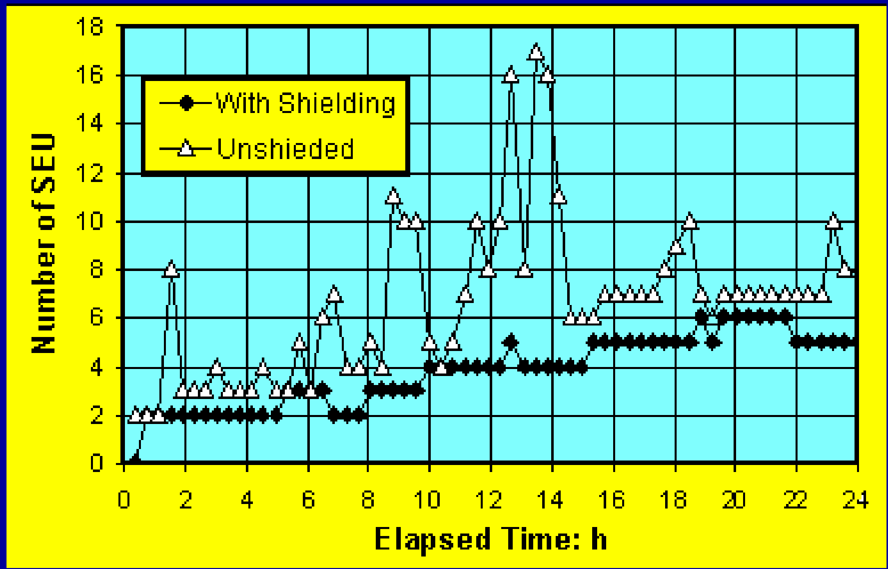
Test Summary

A custom designed image processing software written on Linux based C++ language was used

(i) Grab image from camera

(ii) Find radiation induced Hot-Pixels

(iii) Fold the image using HBP – Filter to reduce background noise



(iv) Count Hot-Pixels and store the numerical image in the computer memory.

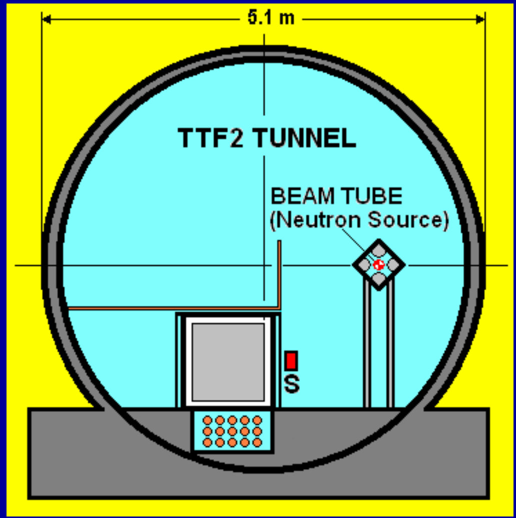
TOPIC 3: A NOVEL THERMAL NEUTRON SHIELD TO MITIGATE THE SEU IN SRAM CHIPS

Recent experiments confirmed the existence of a high thermal neutron fluence in the vicinity of high-energy electron accelerators.

The alpha particles produced in the Glassification (BPSG) layer of the SRAM chip via the thermal neutron induced $^{10}B(n, \alpha)^{7}Li$ reaction trigger the SEU.

Using Monte Carlo Simulation we have developed a shielding material (DESY-Shield) , which attenuates thermal neutrons with a very high efficacy.

We have tested the DESY-Shield with together with two most common shielding materials, i.e. Poly-Boron and Cadmium, by irradiating them in the TTF2 tunnel for about 4 days (s Figure at LHS).



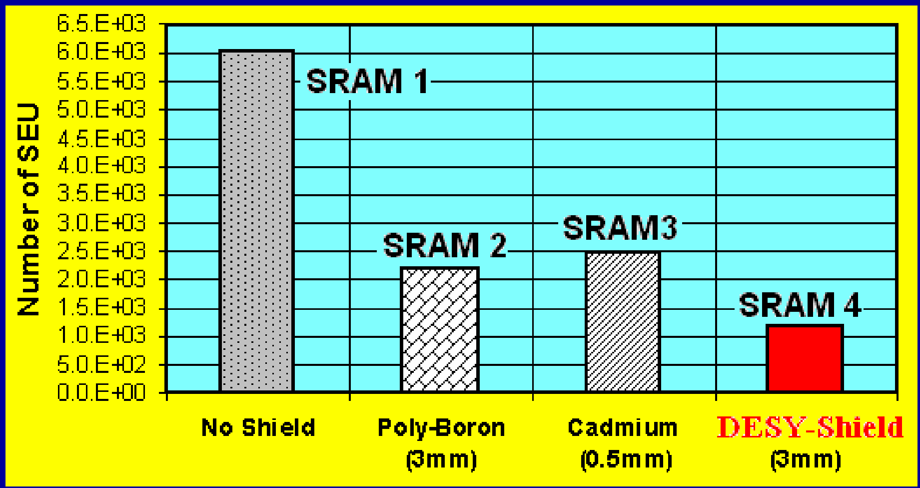
Schematic diagram of the SRAM irradiation in TTF 2 Tunnel. The "red box-S" indicates the location of the SRAMs. Primary Photoneutrons are generated when the high-energy electrons (defocused) and hitting the Beam-Tube.

TOPIC 3: (contd.)

Test Summary

Four 512 kB SRAM chips, Unshielded (1), and shielded with Poly-boron (2) , Cadmium (3) and DESY-Shield (4) were exposed to thermal neutron field at TTF 2 for 4 days.

The SEU in the SRAM chips were counted off-line and are shown in the histogram below.



The thermal neutron attenuation coefficient k is defined as the ratio of SEU counts in the shielded and un-shielded SRAMs:

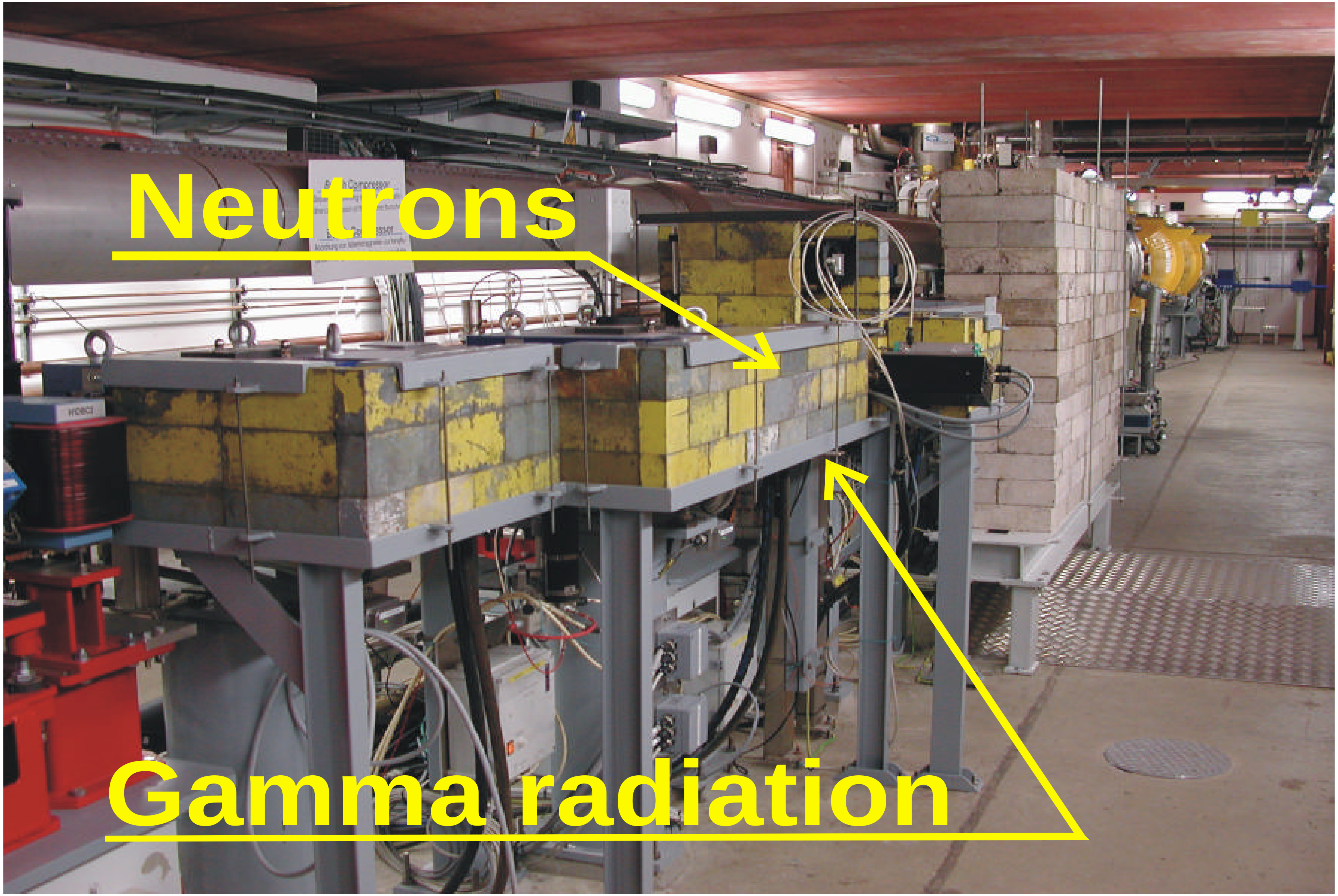
k(Poly-Boron) => 0.36

k(Cadmium) => 0.41

k(DESY-Shield) => 0.20

Evidently, the DESY-Shield outperforms the Poly-Boron Shield (Best thermal neutron shield material available in market) by a factor of 2

VUV-FEL tunnel



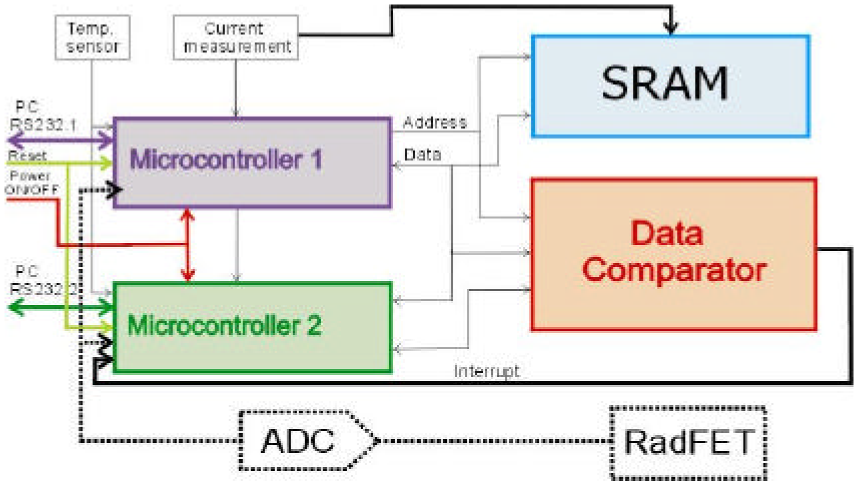
Radiation monitoring in VUV-FEL

The gamma and neutron radiation sensors are connected to the microcontroller-based read-out system. The system was built with the usage of redundant elements to assure radiation tolerance.

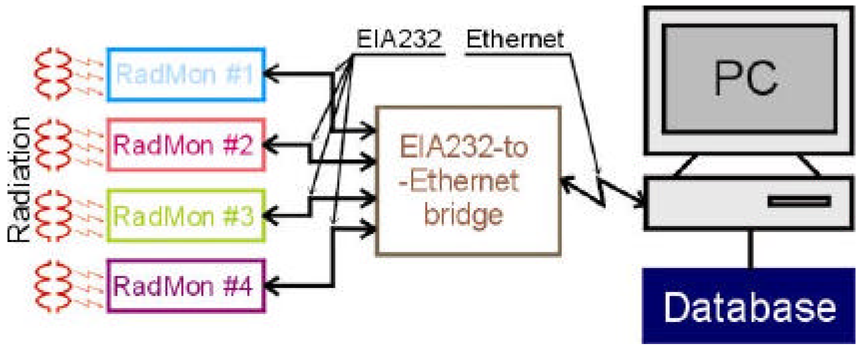
Detectors used to measure radiation:

- **SRAM chip** was used to measure neutron fluence, counting SEU induced in memory.
- **RadFET** silicon dosimeter allows to measure gamma radiation.

RadMon devices installed in the most critical places in accelerator allows to monitor radiation in real time.
Measured data are gathered in a database, thus gamma radiation and neutron fluence history is accessible.

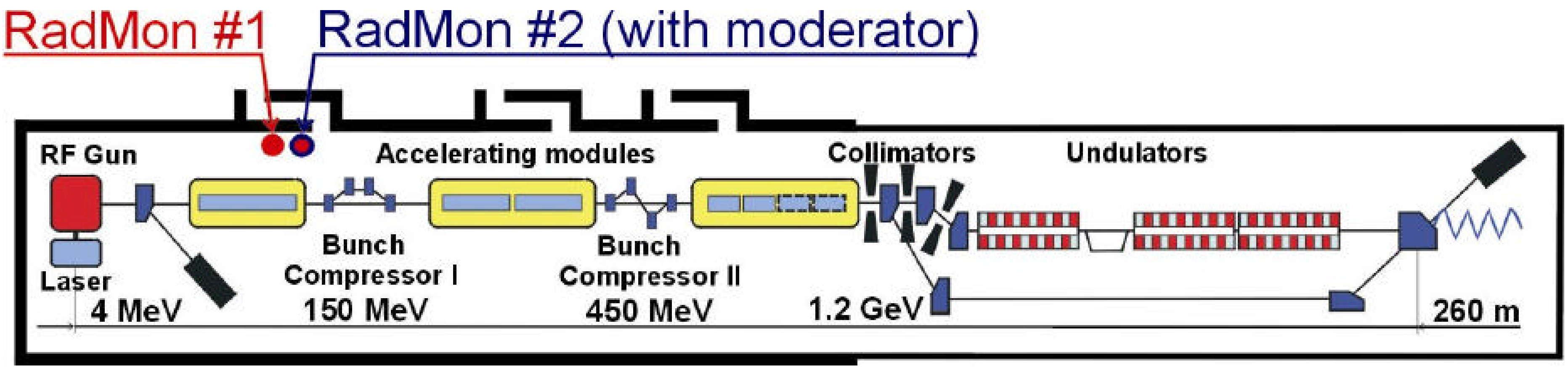


Schematic diagram of RadMon



Distributed system based on RadMon detectors

Radiation monitoring in VUV-FEL



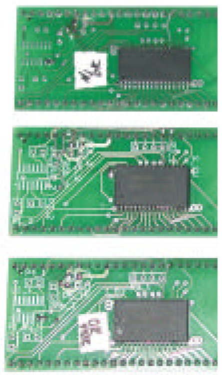
The lauout of the VUV-FEL with installad detectors

Two types of detectors were installed in the VUV-FEL:

- RadMon with conventional SRAM,
- RadMon with a memory witn an external moderator.

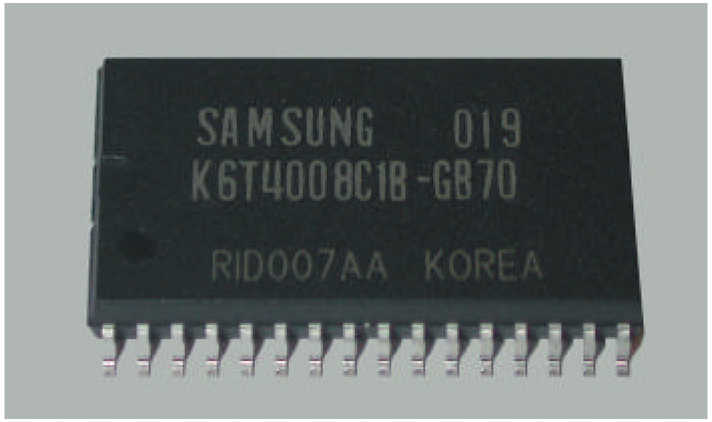
SRAM irradiation results

RadMon d memories.
All memori ne neutron
source (^{241}/

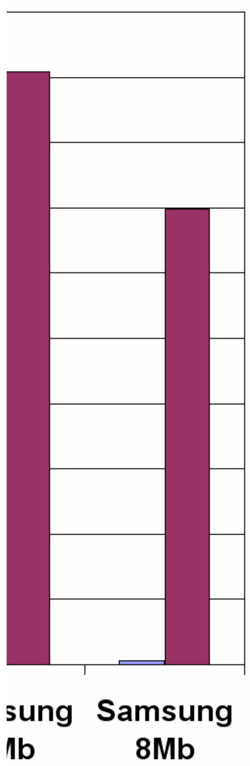


A) Samsung 4Mb
B) Samsung 4Mb
C) Toshiba 4Mb

The mem
during the



512 kB Samsung memory, which has the highest sensitivity factor, was finally chosen as the neutron detector.



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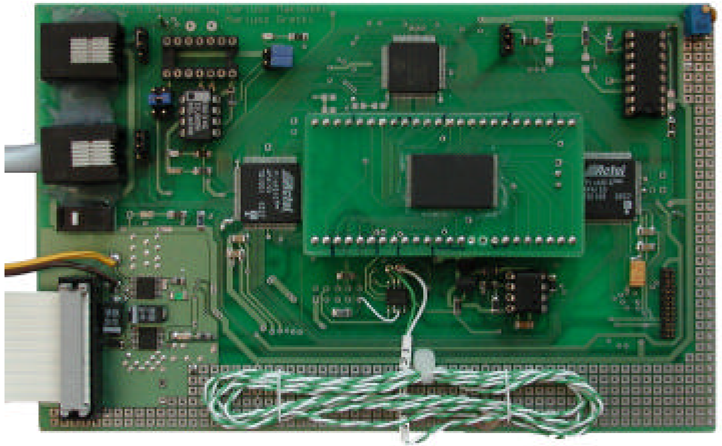
Radiation monitoring in VUV-FEL

RadMon detectors installed in VUV-FEL:

a) with conventional memory

b) with the polyethylene moderator

a)



b)

The appropriate neutron moderator assures a flat characteristics response for a wide spectrum of neutrons and allows to increase the detectors' sensitivity. Current version of moderator allows to increase sensitivity more than 6 times. Carried out calclulations proved that the sensitivity can be enhanced up to 10 times

SEU registered in VUV-FEL

Plans for the future

1. Installation of RadMon detectors near modules 2-5 in VUV-FEL,
2. Further sensitivity enhancement of SRAM detector,
3. Calibration of neutron detector equipped with 4x512 kB Samsung memory,
4. Temperature compensation of RadFET detector,
5. Calibration of gamma detector RadFET,
6. Integration with DOOCS system.