Radiation response of *RADMON* sensors

T. Wijnands (TS/LEA), C. Pignard (TS/LEA)

NMRC Radfets 100 – 400 – 1000 nm

Toshiba TC554001AF-70 SRAM

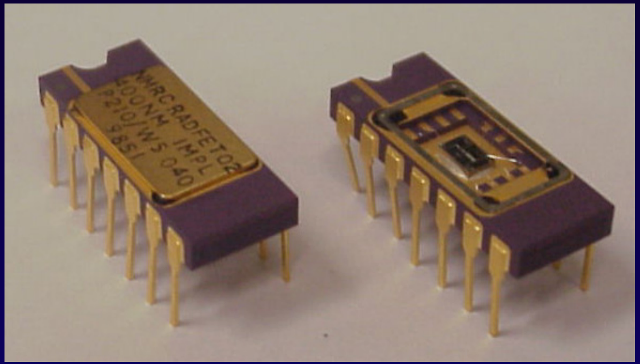
SIEMENS BPW34FS – PIN diode

Acknowledgements :

UCL Louvain-La-Neuve, PSI Villingen, TSL Uppsala, CIS-BIO (CEA Saclay), PROSPERO (CEA-Valduc), A. Jaksic (Tyndall/NMRC)

Radiation Sensors

- *RADFET*
  - Measure trapped charge in gate oxide
  - At constant current : ΔV proportional to Total Ionising Dose

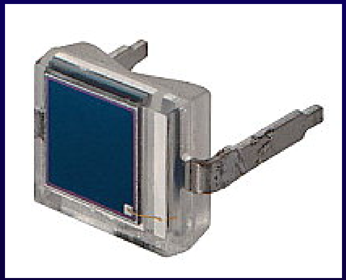


NMRC 300/50 400 nm

- *Static RAM*
  - Measure radiation induced voltage spikes over a reversed biased p-n junction
  - Number of “0-1 or 1-0” in SRAM proportional to the hadron fluence (E> 20 MeV)

TOSHIBA TC554001AF-70L

- *P-I-N Diode*
  - Measure conductivity variation at high forward injection
  - At constant current : ΔV proportional to 1 MeV eq. neutron fluence



SIEMENS BPW34

NMRC Radfets - Electrical properties at 0 Gy

Manufacturer	NMRC	NMRC	NMRC
Oxide	1000 nm	400 nm	100 nm
Type	300/50 W/L	300/50 W/L	300/50 W/L
Readout Current	8.7 μA	8.7 μA	8.7 μA
Threshold voltage	5.43 V	1.57 V	2.72 V
Temp Coefficient	-1.6 mV/ºC	-0.9 mV/ºC	-0.7 mV/ºC
Co-60 sensitivity	215 mV/Gy	65 mV/Gy	2.4 mV/Gy

Die size 1 mm x 1 mm

250 mm Kovar lid (Ni, Co, Fe)

NMRC Radfets - Readout design

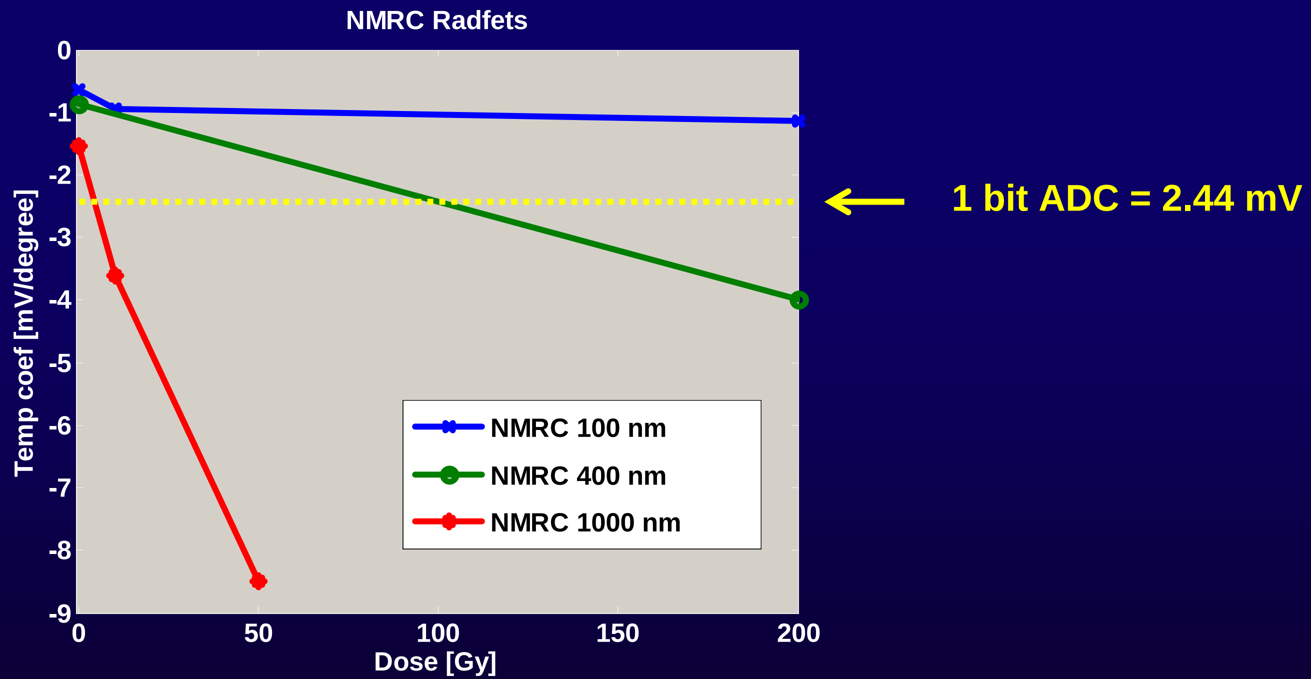
RADMON design choice : TID tolerance = 200 Gy

⇒ CMOS analog switching at maximum V_{dd} = 10 V
⇒ 12 bit ADC at 10 V (2.44 mV/bit)
⇒ Maximum ΔV under irradiation :
- 100 nm : ΔV = 10 V – 2.72 V = 7.28 V (3 kGy)
- 400 nm : ΔV = 10 V – 1.57 V = 8.43 V (130 Gy)
- 1 μm : ΔV = 10 V – 5.43 V = 4.57 V (21 Gy)

⇒ Resolution :
- 100 nm : 1 bit = 100 rad
- 400 nm : 1 bit = 3.8 rad
- 1 μm : 1 bit = 1.1 rad

NMRC Radfets - Thermo compensation

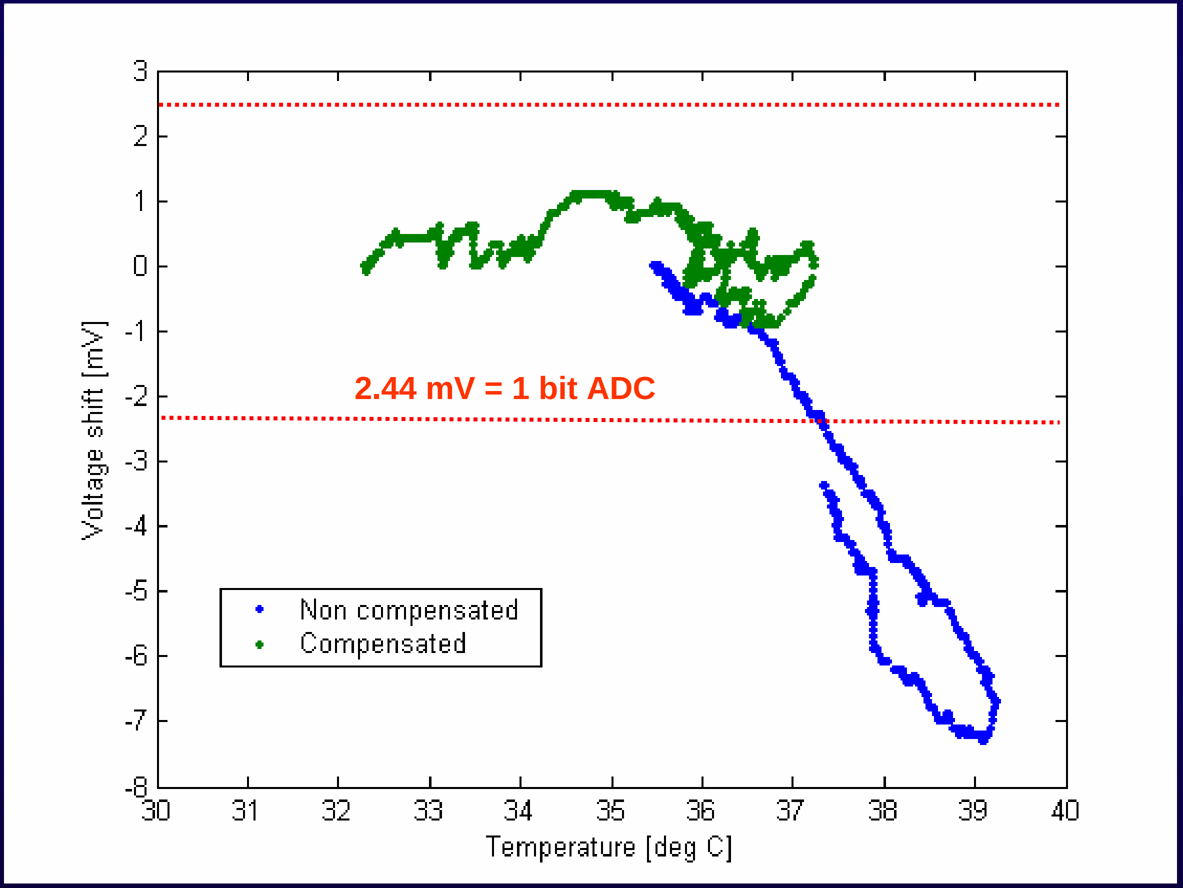
Oxide Thickness	1000 nm	400 nm	100 nm
Temp Coeff 0Gy	-1.6 mV/ºC	-0.9 mV/ºC	-0.7 mV/ºC
Temp Coeff 200 Gy	< -10 mV/ºC	-4 mV/ºC	-1.14 mV/ºC
Co-60 sensitivity	215 mV/Gy	65 mV/Gy	2.4 mV/Gy



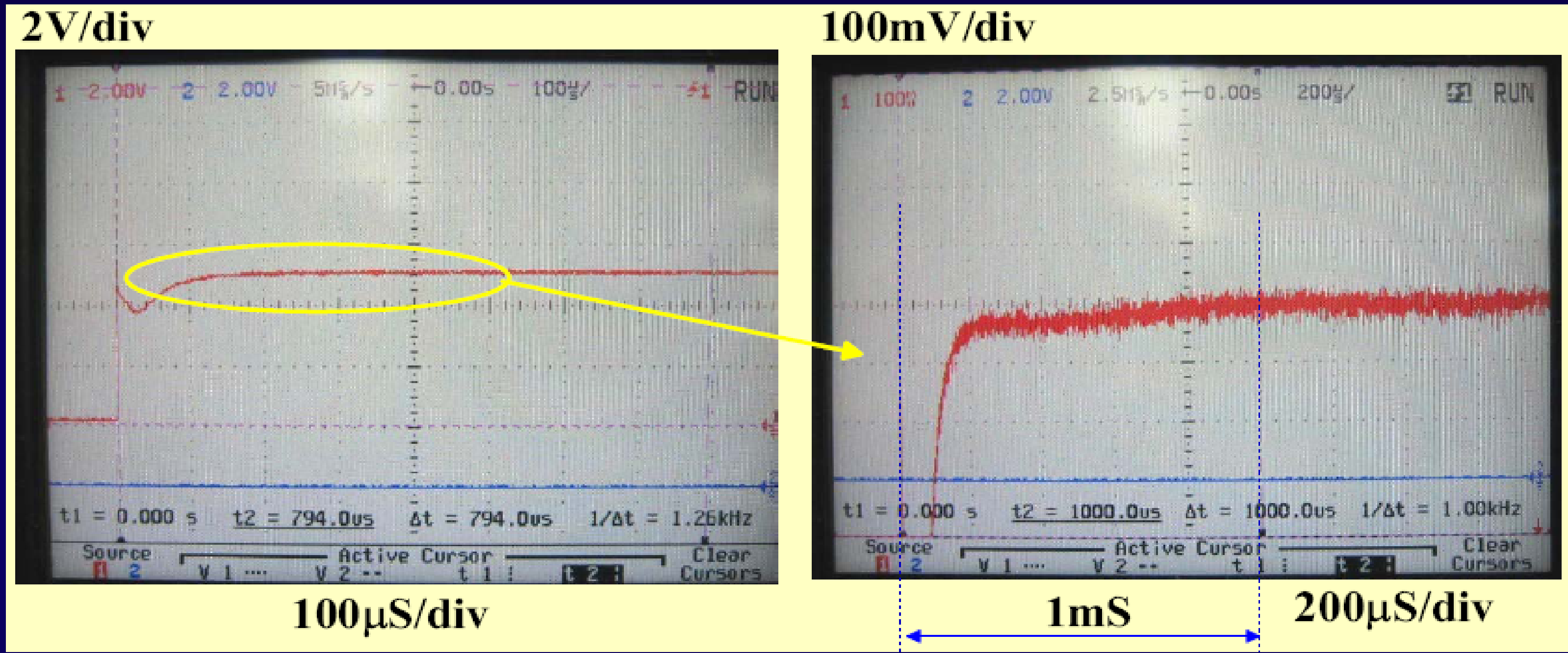
Co-60

RADMON - Thermo compensation in practice

NMRC RADFET 1000 nm (non irradiated device)

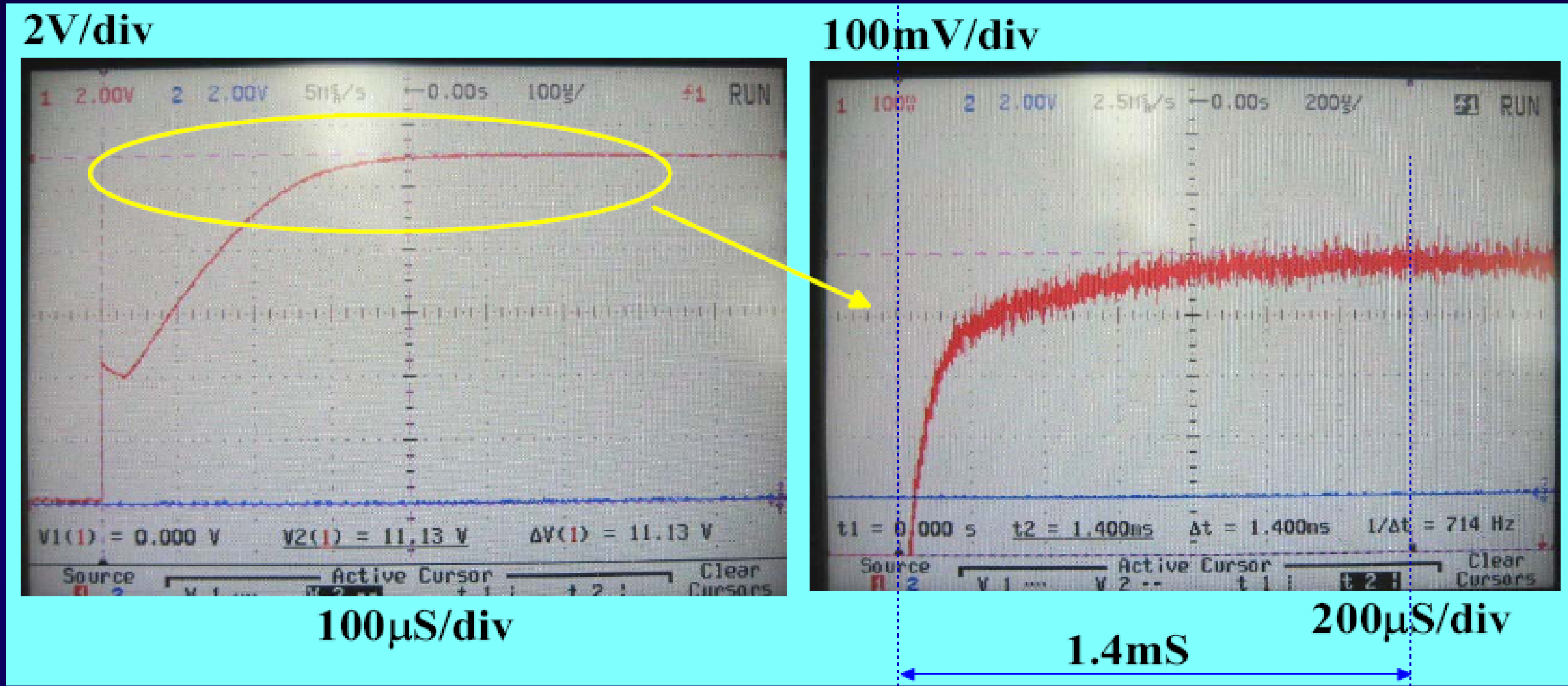


NMRC Radfets - Voltage Rise time at 0 Gy



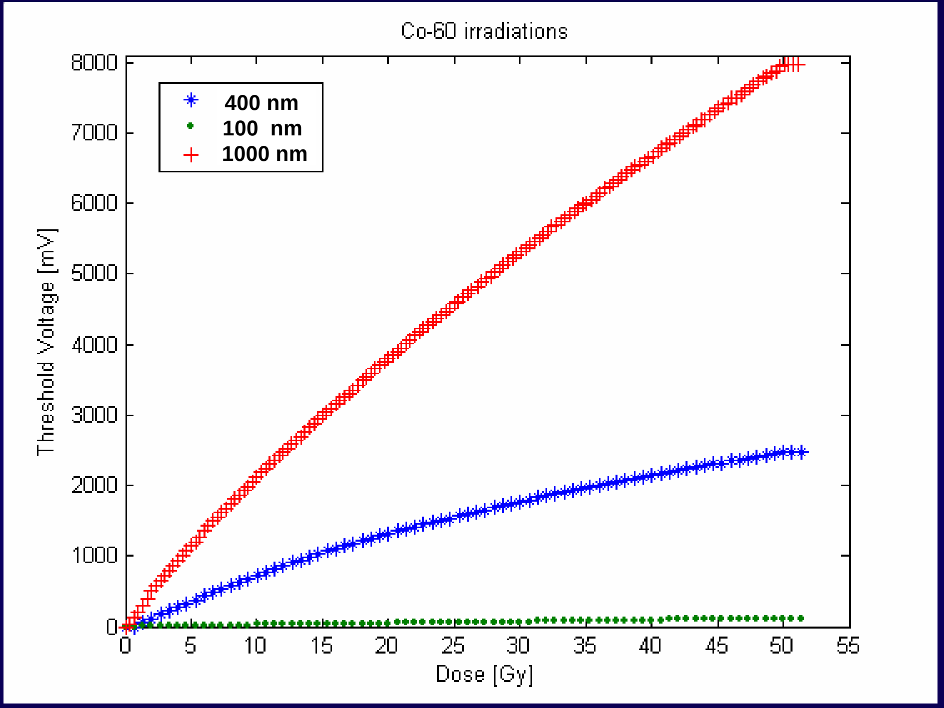
- NMRC Radfet 1000 nm
- Readout current 8.7 μA
- Short circuit : CMOS analog switch (TC4S66F Toshiba)

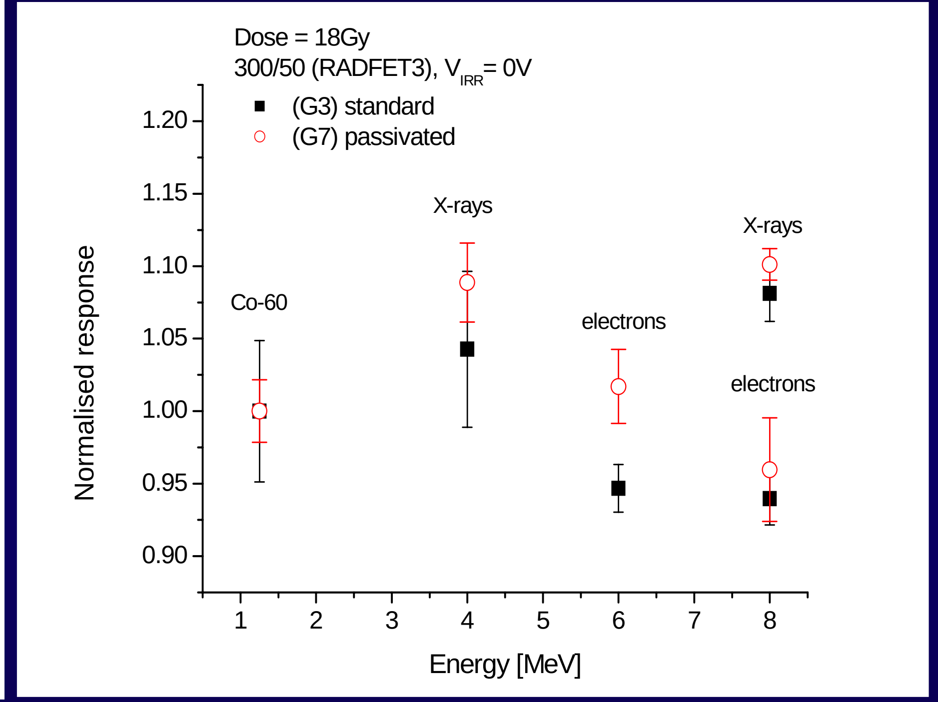
NMRC Radfets - Voltage Rise time at 50 Gy



- NMRC Radfet 1000 nm
- Readout current 8.7 µA
- Short circuit : CMOS analog switch (TC4S66F Toshiba)

NMRC Radfets : energy response for photons



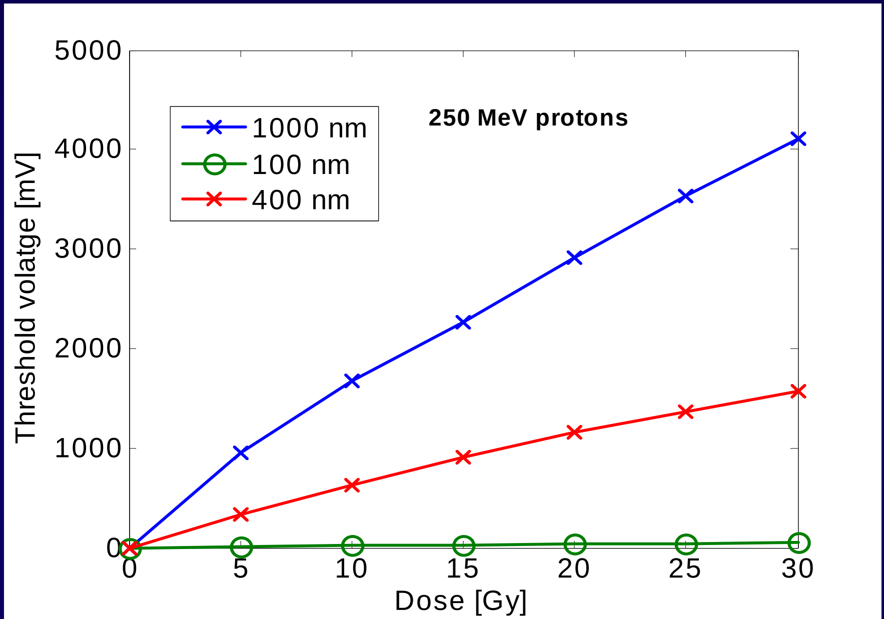


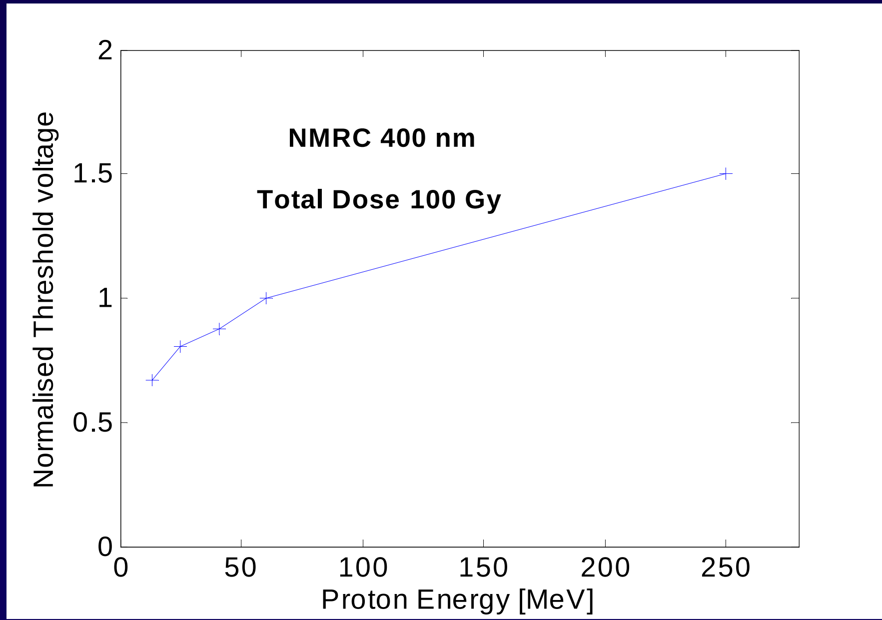
- Co-60 <E> = 1.25 MeV
- Dose rate 50 Gy/hr
- ZTC readout

- NMRC Radfet 400 nm

Courtesey A. Jaksic (Tyndall)

NMRC Radfets : energy response for protons (1)

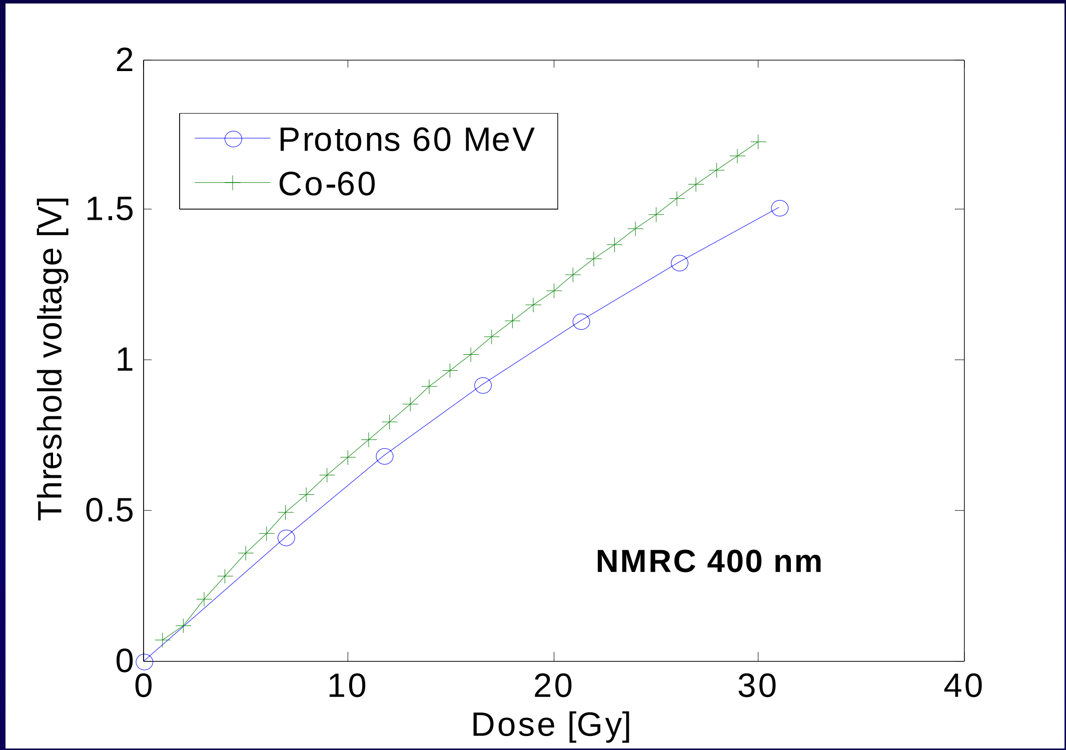




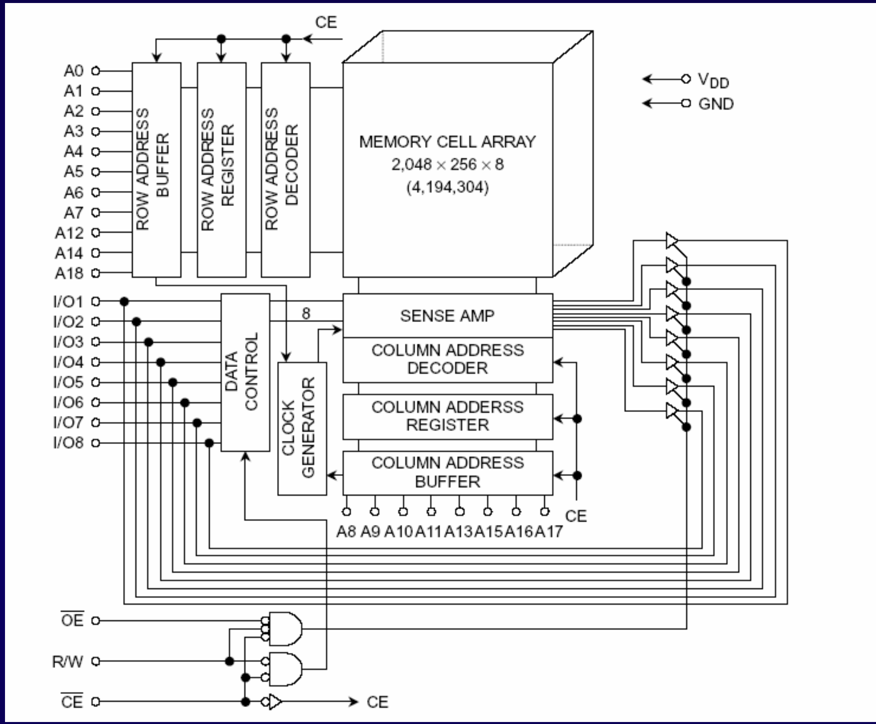
- Proton flux : 7 10^7 cm^{-2}
- Thermo compensated (ZTC) readout

- Normalisation : 60 MeV protons

NMRC Radfets : energy response for protons (2)



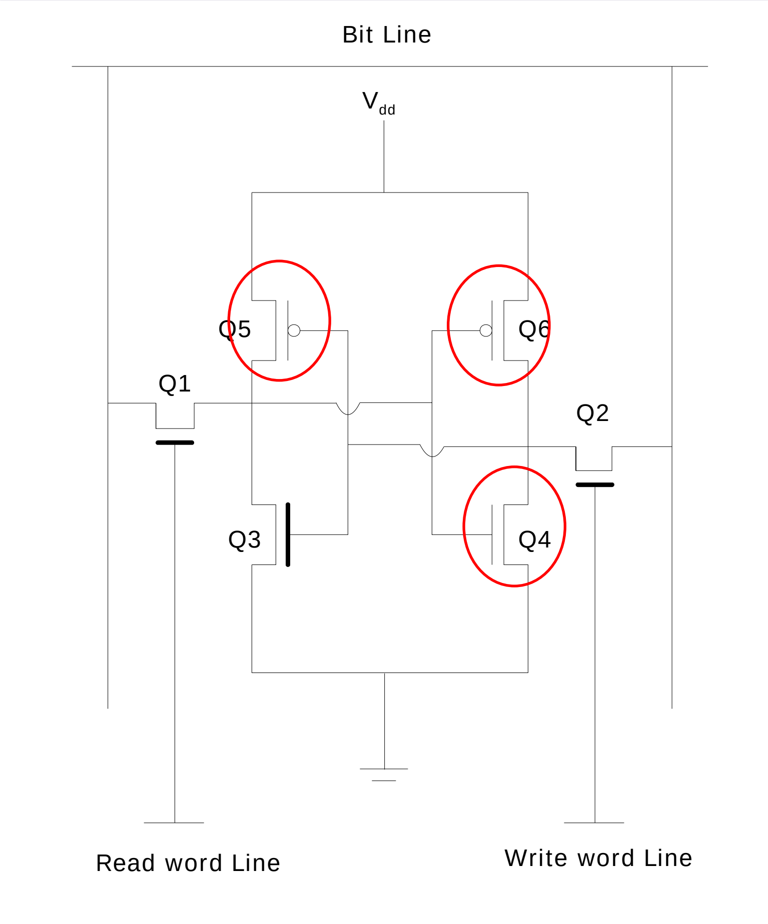
SEU counter – SRAM cell layout



Toshiba TC554001AF-70L

- 0.4 µm technology
- 3 – 5 V operation
- 4 Mbit (524288 words x 8 bits)
- grid arrangement 8192 x 512
- min cycle time 70 ns

SEU counter - 6 T SRAM cell 0.4 μm



Toshiba TC554001AF-70L

- Asymmetric SRAM cell
- V_{dd} = 3 or 5 V operation
- 3 TFTs, 3 bulk transistors
- Read at 3 V if :
  $\beta(Q3)/\beta(Q1) > 3.0$
- Write at 3 V if :
  $\beta(Q4)/\beta(Q2) < 0.1$

SEU counter – Radiation effects

$Q_{crit} = C_{node}V_{dd} + I_{restore}/f$

SEU if $Q > Q_{crit}$

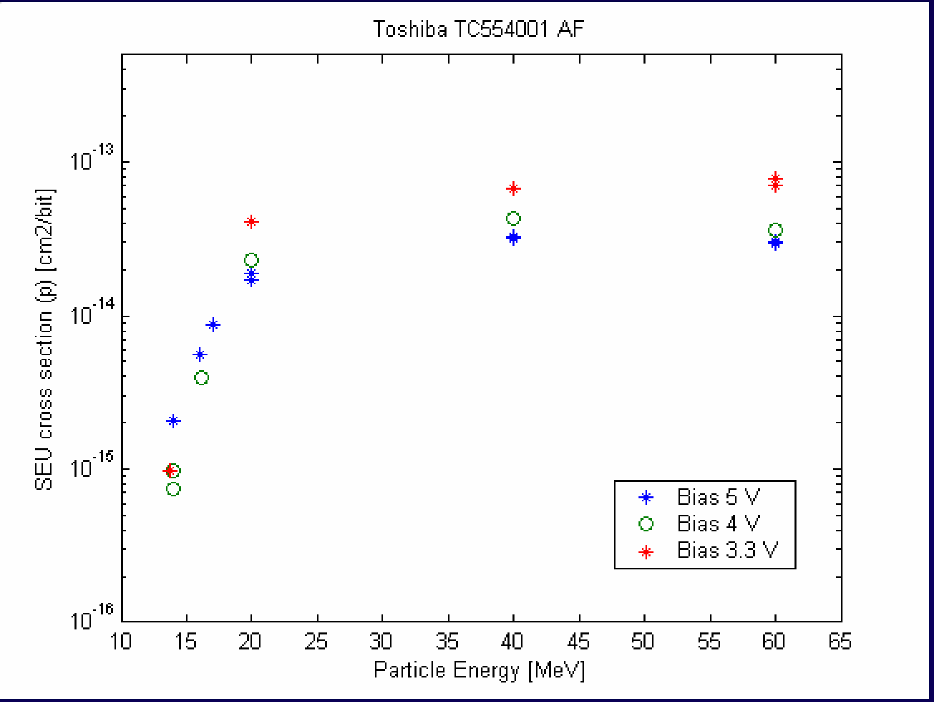
Q = radiation induced charge
C_{node} = capacity of the node
$I_{restore}$ = current restoring transistor
f = frequency of event

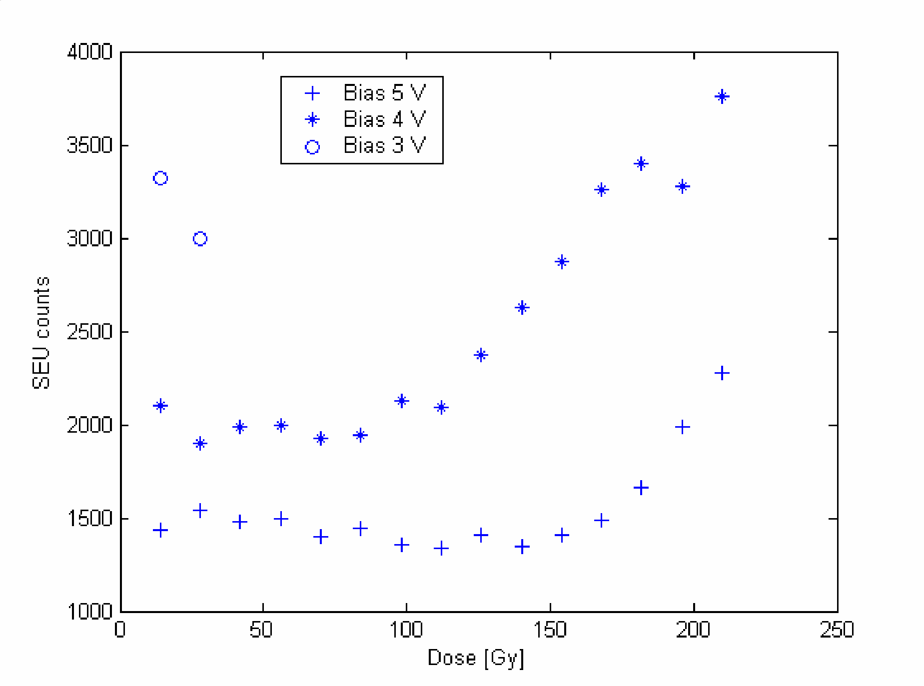
Effect of lowering the bias V_{dd} :

- SEU sensitivity increased
- TID tolerance is decreased

(writing more difficult because β(Q4)/β(Q2) increased)

SEU counter – Proton irradiation



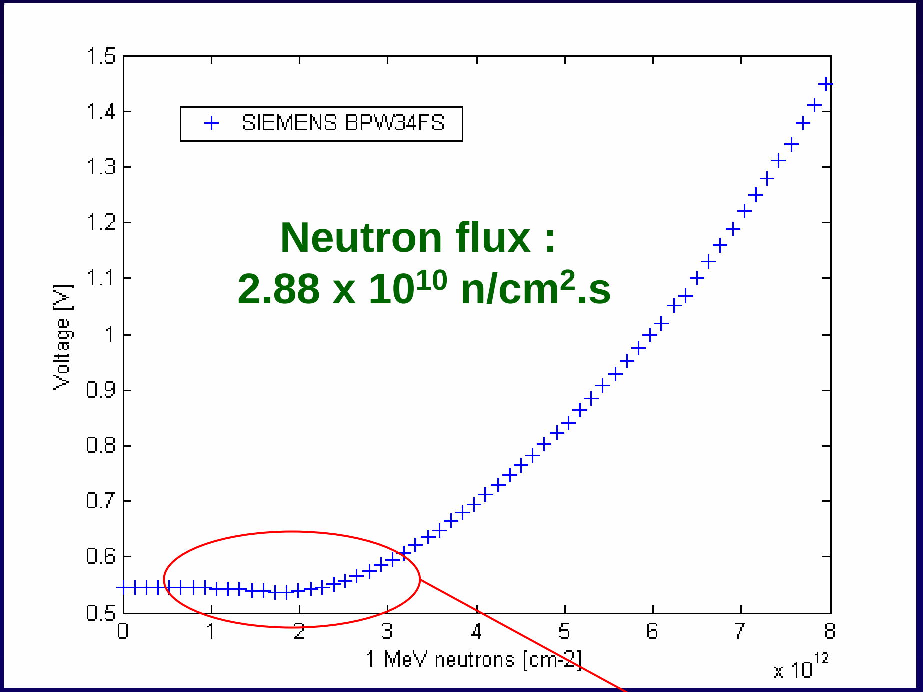


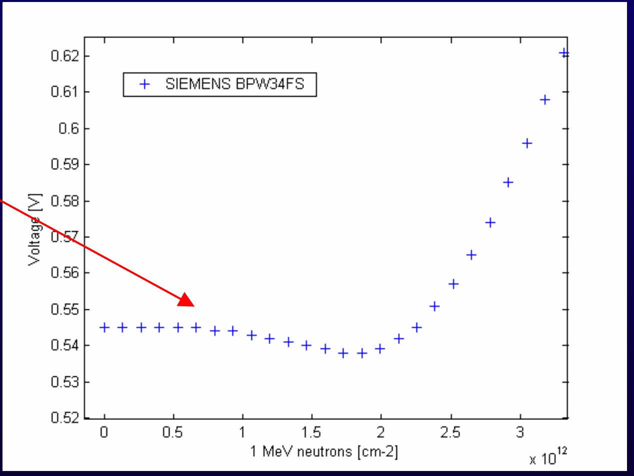
60 MeV protons

Pin Diode - BPW34FS key characteristics

- **Temperature coefficient :**
  - **2.4 mV/ºC vs 2.5 mV/ºC (after 5 10^{12} n/cm^2)**
- **Linear dependence to 1 MeV neutron fluence**
  - **fluence > 4 10^{12} n/cm^2**
- **Annealing at room temperature very small**

PIN diode – 1 MeV neutron response

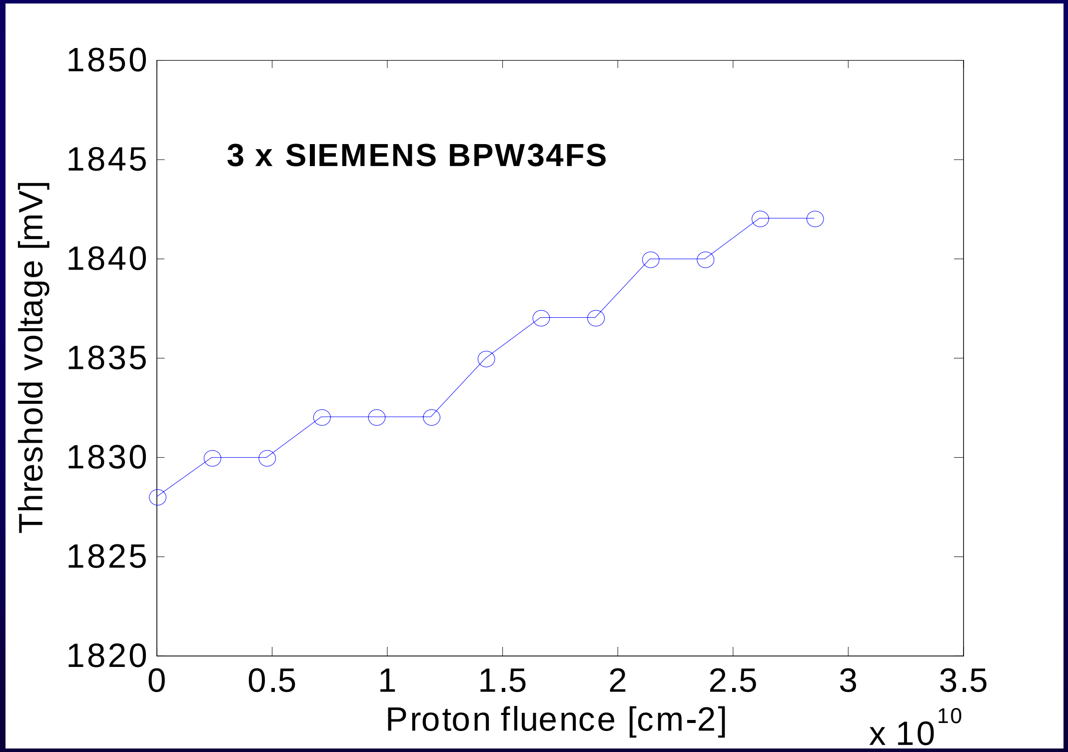




Irradiation of a single diode

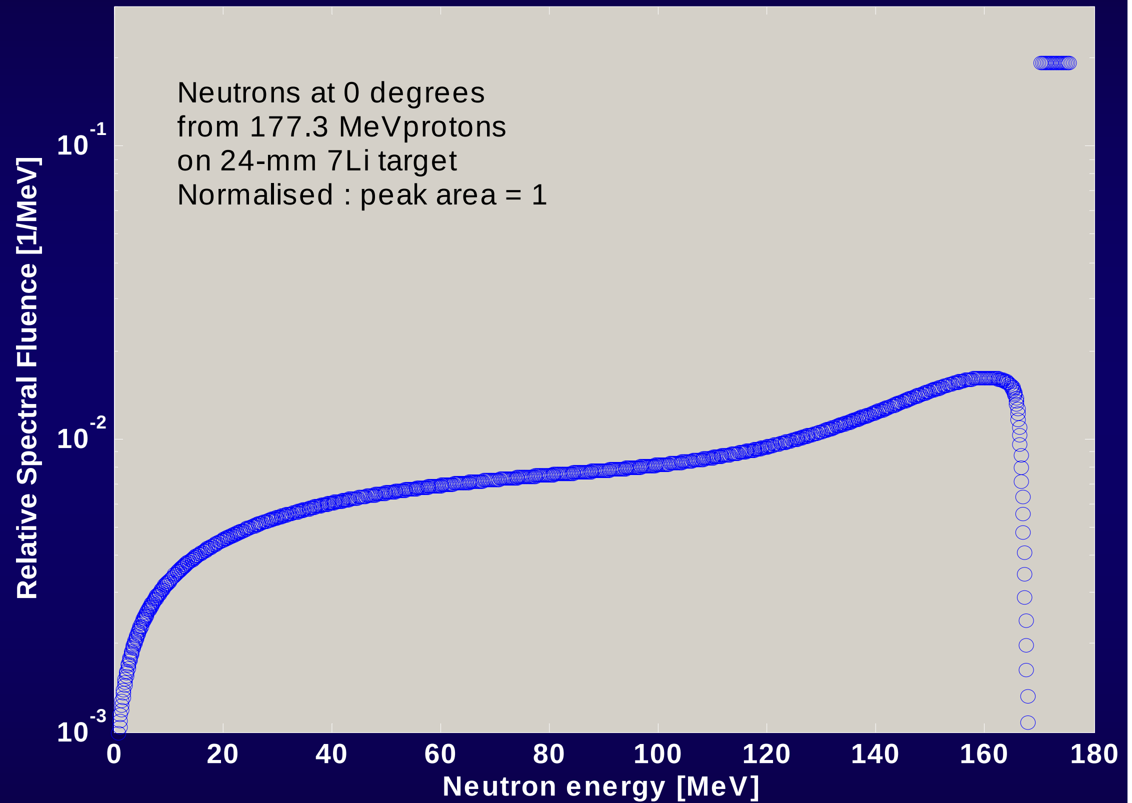
Pin Diode - response to 250 MeV protons

- **Improved resolution for *RADMON* monitors**
  - **pre-irradiation with 4×10^{12} n/cm^2 at 1 MeV**
  - **3 diodes in series – thermo compensated**



RADMON radiation tests – 173 MeV neutrons

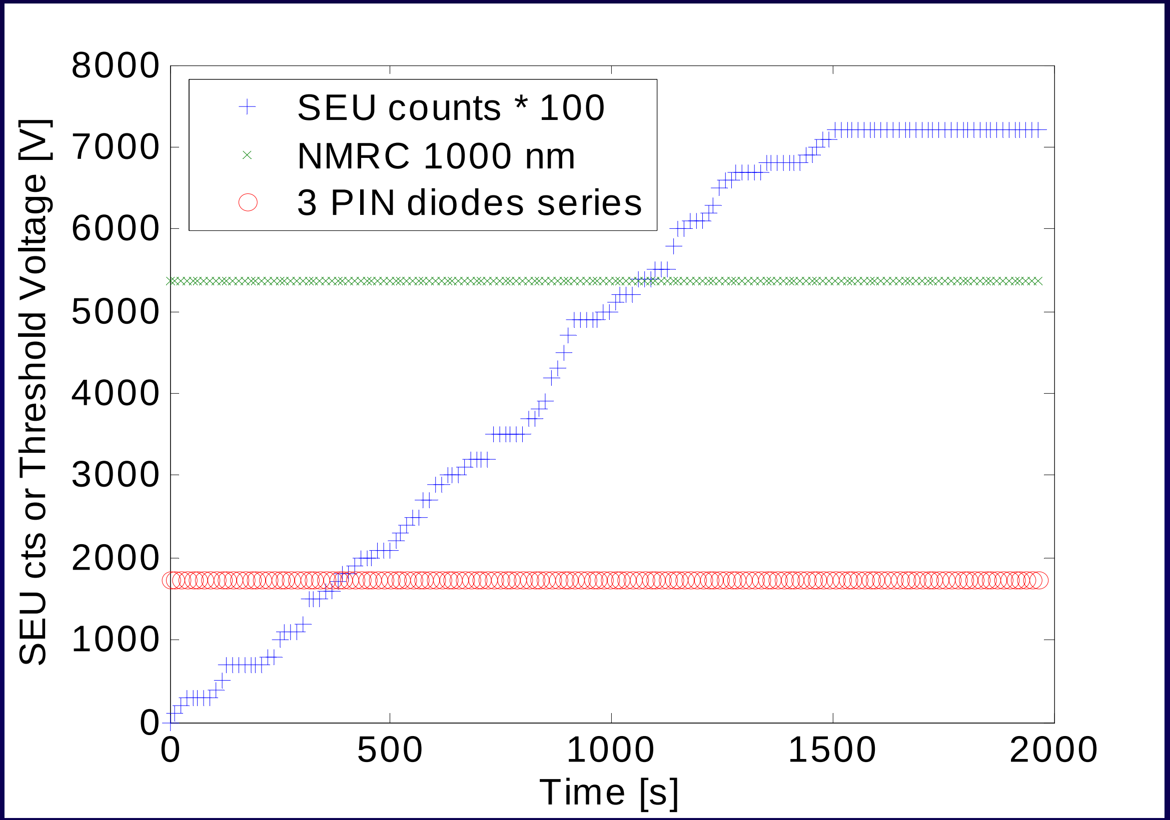
TSL Uppsala, Sweden



A.V. Prokofiev, M.B. Chadwick, S.G. Mashnik, N. Olsson, and L.S. Waters.
Journal of Nuclear Science and Technology, Supplement 2, pp.112-115 (2002)

Acknowledgements : A. Prokofiev

RADMON - response to 173 MeV neutrons



- **Fluence : 1.5 x 10^{8} cm^{-2}**
- **Flux : 1 x 10^{5} cm^{-2} s^{-1}**

Summary

- **NMRC Radfets**
  - *Radiation response sufficiently well understood*
  - *3 types (gate oxide thickness) allows for flexibility*
  - *2 radfets in // to improve range <u>and</u> resolution*
- **SEU counters**
  - *Time resolution to radiation monitoring*
  - *3 V : high resolution, increased uncertainty*
  - *5 V : reduced resolution, high precision*
  - *Total Dose effects visible below 200 Gy*
- **PIN diodes**
  - *Linear response to 1 MeV neutrons after ~3 x 10^{12} neutrons*
  - *Low fading at room temperature*
  - *Very small variation of Temperature coefficient with n fluence*
  - *Use of 3 pre irradiated diodes in // to provide :*
    - *improved resolution*
    - *remove initial threshold*