Active neutron monitor for radiotherapy linacs

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Abstract

The neutron detection principle is based on the generation of Single Event in microelectronic devices due to neutron interactions in the integrated circuit.

Purpose / Objective

Secondary radiation dose from neutrons?

To evaluate secondary malignancies risk of CRT/IMRT treatment

Estimate peripheral organ dose due to neutrons on treatment/session

Measure neutron fluence

Possible use of **active neutron monitor** with on-line readout !?

Neutron production in high energy RT treatments !

✓High energy RT treatments lead to photo-neutron production

✓Neutron fluence distribution results from two main contributions [1,2]

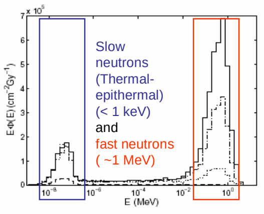
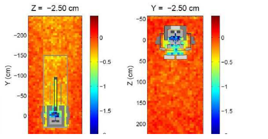


Fig. 1 Typical neutron spectra (at different locations) produced by Siemens PRIMUS 15 MV linac



Slow neutron flux seems to be rather independent of the position in the treatment room behaving as a "neutron cloud"

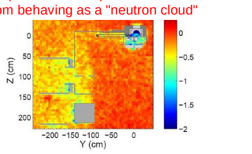


Fig. 2 Slow neutron distribution in treatment room

Measurement of neutron fluence in linac facilities?

Complex neutron detection conditions at RT linac room

- Neutron production simultaneous with pulsed photon beam
- Pulsed neutron fluence, short neutron pulses and 3 ms half-life
- High gamma background from beam and neutron activation
- Intense RF background

Possible neutron monitoring techniques?

- AAPM Report No. 19 recommends passive methods, with delayed counting. Not for treatment/session measurements
- Measurements are very difficult to perform with standard pulse detection based nuclear instrumentation [3]
- Other active detection techniques have been considered: Activation counting, Gamma spectroscopy

New technique considered:

- Neutron counting with sensitive electronic memory devices
- Some experiences in Aerospace and High energy physics

Materials / Methods

Operating principle

Detection principle is based on the **generation of soft errors in electronic memory devices due to neutron interactions** in the integrated circuit

Soft errors in memory devices:

- A soft error is a random error induced by an event corrupting data in a memory device
- SEU (single event upset): An event that induces a data error or upset in which the state of a memory cell is reversed (one to zero, or vice versa).

A known problem: neutron induced Single Event Upsets in SRAMs

- Soft errors can be caused by radiation interaction -> induced localized high ionization charge capable of upsetting internal data states.
- Thermal and epithermal **neutron interaction with 10B** is known to be a dominant source of soft-errors in submicron SRAM devices with BPSG [4]

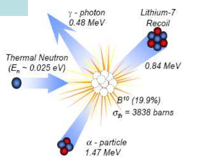


Fig. 3 Low energy neutron interaction with 10B

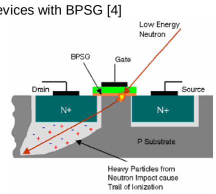


Fig. 4 Mechanism of slow neutron induced soft error by indirect interaction

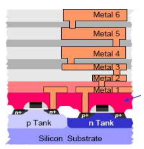


Fig. 5 Presence of Borophosphosilicate (BPSG) layer with 10B in a CMOS SRAM device

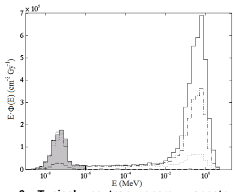


Fig. 6 Typical neutron energy spectrum produced inside a radiotherapy room. The grey filled area shows the primary or bare spectral sensitivity of a commercial SRAM with BPSG.

Active neutron monitoring

An active neutron detector based on neutron sensitive SRAM devices has been developed

- Several neutron sensitive SRAM devices have been characterized
- A high sensitive SRAM device has been chosen

Neutron monitor readout value = slow neutron counting

- Readout is proportional to slow neutron fluence at detector location
- Reference out-of-beam measurement inside the treatment room
- Related to neutron contamination and neutron fluence at isocentre/patient
- Any readout time interval can be defined

A neutron monitor prototype with electronic readout has been implemented and tested

- Readout by continuous scanning of memory device data
- Instantaneous on-line readout (seconds) to control room
- No neutron moderator
- Point-like sensitive volume (~1cm² sensitive area device)

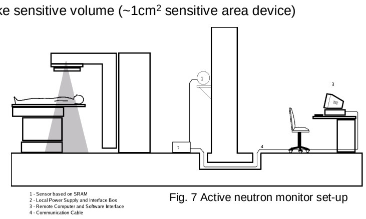


Fig. 7 Active neutron monitor set-up

Results

Neutron monitor sensitivity

✓**Use radiation sensitive memory device**

A neutron sensitive commercial SRAM device has been chosen to implement the active neutron monitor prototype

✓**Response is facility dependent**

Detector readout is proportional to neutron production at the linac, and thereby depends on beam energy, field size and linac model.

✓**Neutron monitor response characterized for a given linac facility**

- Linac:18 MV Siemens Primus (ERESA, Valencia) 10x10 field
- Monitor location: near linac (3 m from isocentre)

Average neutron monitor readout = 240 ± 11 count / 5000 MU

Neutron monitoring sensitivity is defined in terms of number of neutron-induced counts (SEUs) per photon dose in MUs.

Measurement uncertainty

- Neutron interaction is a statistical process => uncertainty improves with higher readout numbers (defined by fluence and sensitivity)
- Measurements with ~5% uncertainty for neutron fluence estimation
- But ~ 20% uncertainty for 500 MU high energy RT session

➢**Scalable sensitivity**

- Increased sensitivity can be easily obtained by scaling the number of sensitive devices to be used
- A neutron monitor system has been developed based on 32 neutron sensitive SRAM devices.

Active neutron monitor system operation

Several tests have been performed to asses reliable performance of the neutron monitor prototype

✓**No sensitivity to gammas**

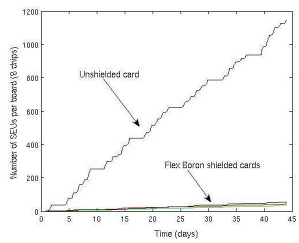
Detector readout is only sensitive to neutron production of the linac. The neutron detector showed no sensitivity to gammas when exposed to peripheral radiation during linac operation at 6 MV.

✓**Linear detector readout**

Detector readout results from counting neutron interactions and is proportional to slow neutron fluence in a wide dynamic range

✓**Reliable long term operation**

The system has been tested for continuous (24 h) operation along several weeks, installed near a Siemens Primus linac at CHUS, Santiago de Compostela (6 MV and 15 MV)



➢**Future activities**

- Test with increased sensitivity neutron monitor prototypes (sensibility, linearity, reproducibility and directionality)
- Relation of neutron monitor readout and neutron dose will be studied carefully

Conclusions

➔An active neutron detector based on neutron sensitive SRAM devices has been developed and proof of principle has been demonstrated.
➔Neutron monitor sensitivity has been characterized.
➔Extensive tests showed reliable operation of neutron monitor prototype.
➔Further studies have to be performed to relate monitor readout to neutron dose.

References

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