Investigation of 14 MeV Neutron capabilities for SEE Hardness Evaluation

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**Stakes**
Great interest to get tools complementary to accelerators for quick & cost efficient radiation assessment

- **Existing tools**:
  - Laser, Cf232, prediction tools

- **Promising tools**
  - 14MeV neutron generator ⇔ numerous papers in the last years

**Aim**

- Assessment of the representativeness of 14MeV neutrons ⇔ higher neutron energies
  - Based on nuclear database analysis
  - Experiments

- Capability to use 14MeV results for extrapolation to higher neutron and proton energies


F. Irom *et al.,* “The results of recent 14 MeV neutron single event effects measurements conducted by jet propulsion laboratory,” in Proc. IEEE Radiation Effects Data Workshop, 2007

E. Normand and L. Dominik, “Cross comparison guide for results of neutron SEE testing of microelectronics applicable to avionics,” in Proc. IEEE Radiation Effects Data Workshop, 2010


S. Jahinuzzaman *et al.,* “Correlating low energy neutron SER with broad beam neutron and 200 MeV proton SER for 22nm CMOS tri-gate devices,” IRPS 2013

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Increasing interest in 14 MeV neutron tests over the years
For advanced technologies 14MeV cross sections seems to be within a factor of 2 of WNR or high proton/neutron energies cross sections.
**Advantages**
- Tabletop irradiation configuration
- Isotropic experiments can be put all around
- No need of device opening
- Not as expensive as usual accelerator tests

**Drawbacks**
- Isotropic Flux/cm² has to be carefully calibrated
- Isotropic neutron flux ↔ Shielding of the test boards

**BUT**
**Only 14MeV ↔ what are the limits?**
Test results on a 90 nm SRAM

Facilities

- 14MeV neutron test performed at SODERN
- Proton tests performed at UCL

- 14MeV cross section close to saturated part (within a factor of 2), but MCU rate lower (as well as MCU multiplicity)

Reason ? & What to expect with technology scaling?

<table>
<thead>
<tr>
<th>Facility</th>
<th>MCU rate</th>
<th>Max MCU multiplicity</th>
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<tbody>
<tr>
<td>14MeV neutrons</td>
<td>4%</td>
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<td>63MeV protons</td>
<td>24%</td>
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Representativeness of 14MeV

Nuclear Physic

- Various probable reactions ↔ characteristics of secondary ions (number of secondary particles, nature, energy, direction)
- Database of the characteristics of the secondary ions generated with MCRED 1.2 & validated with experiments and EXFOR experimental database

Nuclear databases

Compilation

Sorting of the secondary ions characteristics for different neutron energies

Elastic

Non-elastic

1MeV
3MeV
5MeV
150MeV
Probabilities

Energies
Comparison of the secondary ions characteristics generated for 14MeV, 50 MeV and 150MeV neutrons

**LET**

- Distribution of the LET of the secondary ions (both elastic & non elastic reactions)

14MeV : LET < 9MeV.cm²/mg

- Higher neutron energies generate higher secondary ion LETs but
- For advanced technologies, not far from the HI saturated cross section
  ⇔ should not be an issue for the representativeness
Comparison of the secondary ions characteristics generated for 14MeV, 50 MeV and 150MeV neutrons

Range
- Distribution of the range of the secondary ions (both elastic & non elastic reactions)
- Truncated X scale (light ions have much longer range)

Range limited to few µm:
- Not fully representative of probability of MCUs

Experimental tests on a 90nm SRAM

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**Range**
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With technology scaling
- May become representative of probability of MCUs
- But may not be fully representative of the multiplicity of MCUs which would occur at higher energies (↔ higher ranges).
**Characteristic of the secondary ions at 14MeV compared to higher energies**
- Representativity in terms of LET is ok
- Representativity in terms of MCU rate should be ok with scaling
- Limits in terms of MCU multiplicity

But distributions are different. How to explain that 14MeV results tend to be within a factor of 2 compared to higher energies?
Possibility to estimate neutron & proton cross sections from 14MeV results

**Assumptions**
- LET criteria $\Leftrightarrow$ an event if secondary ion
  - LET is $> \text{LET}_{\text{threshold}}$
- Simplified heavy ion curve shape with a saturation and a threshold

The neutron cross section for a given neutron energy ($E_n$) is:

$$\sigma_{E_n} = \sigma_{\text{nuclear},E_n} \sum_{\text{LET} > \text{LET}_{th}} A_{E_n,\text{LET}} \cdot \sigma_{\text{ion}}$$
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\[
\sigma_{150\text{MeV}} = \sum_{\text{LET} > \text{LET}_{\text{th}}} \cdot x 
\]

\[
\sigma_{14\text{MeV}} = \sum_{\text{LET} > \text{LET}_{\text{th}}} \cdot x 
\]

Possibility to estimate neutron & proton cross sections from 14MeV results
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\[
\sigma_{150\text{MeV}} = \sum_{\text{LET} > \text{LET}_{\text{th}}} \times \sigma_{14\text{MeV}}
\]

Possibility to extrapolate \(\sigma_{n,14\text{MeV}}\) to other energies & particles (neutron/proton)

Only 1 unknown remaining : the heavy ion threshold LET.
Possibility to estimate neutron & proton cross sections from 14MeV results

SRAM
14MeV Neutron tests performed at SODERN on a 90nm commercial SRAM.

Strong variability in the total nuclear cross section ⇔ no prediction in this area
SRAM
Proton tests performed at UCL on a 90nm commercial SRAM.

- Possibility to estimate neutron & proton cross sections from 14MeV results
- Let threshold = 5MeV.cm²/mg
- Let threshold = 0.1MeV.cm²/mg
- Capability to extrapolate 14MeV neutron results to other neutron/proton energies validated on a 90nm SRAM.
Conclusions & Perspectives

**14MeV neutron generator**

- Flexible and cost efficient radiation tool
- Analysis of nuclear databases showed that 14MeV neutrons produce ions with characteristics able to trigger events
- Potential issue for representativeness of MCUs (especially multiplicity) due to the limited range of secondary ions.
- Capability to extrapolate from
  - Experimental 14MeV neutron test (high confidence to neutron or protons within a x2 margin whatever the considered heavy ion LET for a non hardened technology (LET<5MeV.cm²/mg)
- 14MeV test services are starting (Sodern/Nuclétudes)

**Perspectives**

- Pursue validation on more advanced technologies
- Capability of extrapolation for power technologies/other devices