SEE FLUX AND SPECTRAL HARDNESS CALIBRATION OF NEUTRON SPALLATION AND MIXED FIELD FACILITIES

Matteo Cecchetto
R. García Alía, P. Fernández-Martínez, R. Ferraro, S. Danzeca

Indico link: https://indico.cern.ch/event/760345/
Introduction

• Single Event Effect (SEE) failure rate for electronic components to be used in mixed field environments (accelerator) has to be quantified by reproducing the spectrum condition in dedicated test facilities.

• The availability of a method to compare different radiation environments is essential, because differences in neutron and High Energy Hadrons (HEH>20 MeV) spectra can play an important role.

• The approach applied for the characterization of both spallation (ChipIR) and mixed field (CHARM) facilities relies in employing SEU and SEL based detectors:

**SEU**: The memory is assumed to be equally sensitive to HEH above 20 MeV and a weighting function has to be accounted for the intermediate energy neutrons, considered from 0.2 MeV to 20 MeV, where the cross section is strongly energy dependent.

\[
\varphi_{HEHeq} = \int_{0.2 \text{MeV}}^{20 \text{MeV}} w(E) \frac{d\varphi_n(E)}{dE} dE + \int_{20 \text{MeV}}^{+\infty} \frac{d\varphi_{HEH}(E)}{dE} dE
\]

Intermediate energy neutrons start to be a major concern with scaling of technology.

**SEL**: COTS memories with a strong energy dependence on the SEL cross section are employed to correlate the spectral hardness of the facilities, supported by a FLUKA model.
ChipIr facility

- The ChipIr (Chip Irradiation) facility (UK), provides a broad neutron atmospheric like spectrum.
  - Energies from the thermal neutrons up to 800 MeV
  - Neutrons produced by colliding protons against a tungsten target.
  - The flux was measured using multi-foils activation.
- It was investigated in order to verify its capability of reproducing the SEU and SEL cross sections typically observed in mixed field environments, such as CHARM.

Figure 1: ChipIr spectrum
CHARM facility

- CHARM generates a mixed-field mainly composed by neutrons, protons and pions from the interaction of 24 GeV proton beam with a copper target.
- R10 (hard spectrum) and G0 (soft spectrum) were employed.

*SEU and SEL boards tested in R10*
ChipIR flux cross-calibration

- The flux calibration was carried out with:
  1) **ESA SEU Monitor** (0.25 μm SRAM memory)
  2) RadMon system (Toshiba 400 nm, Cypress 90 nm).
    - **Excellent HEHeq agreement within 1%** was obtained with the RadMon;
    - **Thermal neutron flux within the uncertainty** (quite high due to the very low ThN flux compared to the HEH one).

- the intermediate energy neutron response (i.e. PTB at 5, 8 and 14 MeV) is essential to derive the flux from the ESA Monitor and Cypress memories.

<table>
<thead>
<tr>
<th>HEHeq [cm$^{-2}$/s]</th>
<th>ThN [cm$^{-2}$/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ESA M. Spectrum</strong></td>
<td><strong>RadMon Spectrum</strong></td>
</tr>
<tr>
<td>2.97×10$^6$ +20%</td>
<td>3.44×10$^6$</td>
</tr>
</tbody>
</table>
SPECTRAL HARDNESS ASSESSMENT – SEL measurements

• **Samsung** (180 nm) and **Alliance** (200 nm) are SRAM memories with a strong SEL cross section energy dependence due to the presence of tungsten, deployed as detectors.

• Assessment in:
  • operational environments: JEDEC, accelerator (UJ, RR alcoves)
  • test facilities: ChipIR, CHARM (G0, R10 positions).

UJ, RR, R10 and G0 are composed by neutrons, protons, pions.

• The spectral hardness is quantified through the $H_{10\%}$ factor, representative of the energy above which 10% of the total HEH flux is still present in the spectrum, (visible in the reverse integral).

<table>
<thead>
<tr>
<th>MeV</th>
<th>UJ</th>
<th>G0</th>
<th>ChipIr</th>
<th>JEDEC</th>
<th>RR</th>
<th>R10</th>
<th>Tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>183</td>
<td>194</td>
<td>354</td>
<td>525</td>
<td>690</td>
<td>790</td>
<td>1800</td>
<td></td>
</tr>
</tbody>
</table>

$H_{10\%}$
The FLUKA model retrieves the SEL XS up to several GeV, given the spectrum, Sensitive Volume (SV) thickness and geometrical parameters of the memories.

- The SV surface is 4x20 µm² and 0.48 µm³/cell of tungsten are considered.

- Measurements and simulations are in agreement within 60% over a very broad energy and cross section range. Considering the experimental uncertainties of about 30%, the agreement is satisfactory.

Strong risk of qualifying components for SEEs in environments with a lower spectral hardness than the operational one.
SER induced by intermediate energy neutrons (1)

- SER on ESA Monitor, Toshiba, Cypress and a 65 nm FPGA* is evaluated in the 1-3 MeV, 1-10 MeV, 1-20 MeV energy intervals.
- 65nm FPGA with a G0-like spectrum:

  more than 50% of the SEUs are induced by neutrons below 20 MeV.

---

*D. Lambert et al., “Single Event Upsets Induced by a few MeV Neutrons in SRAMs and FPGAs,” in 2017 IEEE Radiation Effects Data Workshop (REDW)
SER induced by intermediate energy neutrons (2)

- **1-3 MeV**
  - negligible impact.
  - up to **12%** of SER for JEDEC, ChipIR, UJ.

- **1-10 MeV**
  - up to **36%** for CHARM G0 position.

- **1-20 MeV**
  - up to **21%** of SER for ground level, **26%** in accelerator applications and up to **54%** for G0.

<table>
<thead>
<tr>
<th>1-20 MeV</th>
<th>Spect %</th>
<th>ESA M.</th>
<th>Toshiba</th>
<th>Cypress</th>
<th>FPGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>UJ</td>
<td>39.4</td>
<td>9.6</td>
<td>12.3</td>
<td>7.1</td>
<td>18.4</td>
</tr>
<tr>
<td>G0</td>
<td>84.1</td>
<td>39.2</td>
<td>31</td>
<td>24.1</td>
<td>54.4</td>
</tr>
<tr>
<td>ChipIR</td>
<td>15.3</td>
<td>6.7</td>
<td>8.2</td>
<td>5</td>
<td>10.6</td>
</tr>
<tr>
<td>JEDEC</td>
<td>43.4</td>
<td>11.4</td>
<td>14.5</td>
<td>8.5</td>
<td>21.1</td>
</tr>
<tr>
<td>RR</td>
<td>56</td>
<td>17.8</td>
<td>13.5</td>
<td>9.9</td>
<td>26.5</td>
</tr>
<tr>
<td>R10</td>
<td>60.5</td>
<td>19.2</td>
<td>15.1</td>
<td>11.7</td>
<td>28.5</td>
</tr>
</tbody>
</table>

**SER (%) impact of different spectra**
Complementary work/Outlook

- The use of the Am-Be neutron source at CERN for SEU/SEE setup validation and evaluation of sensitivity to intermediate energy neutrons.
- The impact of thermal neutrons, for which an important sensitivity has been measured for highly integrated technologies.
Conclusions

- The procedure of cross-calibrating spallation and mixed-field facility through SEU detectors have been shown to be valid, with an excellent agreement on the HEH flux.
- The approach of determining the spectrum hardness through SEL measurements have been applied to ChipIr and CHARM. Compatible cross sections have been extracted through a FLUKA model, which therefore enables the calculations for environments in which measurements are not directly feasible, as for atmospheric and LCH areas.
- The spectral hardness of ChipIr enables for tests dedicated to some accelerator applications as shielded areas. However, tunnel and more energetic alcoves exhibit harder spectra, reproducible in CHARM.
- Considering the SEU rate of memories down to 65 nm, 1-10 MeV and 1-20 MeV ranges induce respectively up to 12% and 21% of the total SER in ground level applications, reaching up to 36% and 54% in accelerator environments.
- Intermediate energy neutrons (1-20 MeV) yield a larger SER contribution in accelerator rather than atmospheric applications.