WP9-TA1: Neutron, muon and mixed-field spallation facilities and irradiation

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Anna Ferrari
RADNEXT Kick Off Meeting – 19-21 May 2021
https://indico.cern.ch/event/983095/
https://indico.cern.ch/event/1029314/
WP9: big variety of facilities

**Type of particle**
- Neutrons - 15
- Mixed fields - 1
- Muons - 1

**Production mechanism**
- Spallation source (high energy accelerator) - 5
- Fusion (DT or DD) - 4
- Other nuclear reactions - 3
- Fission - 1
- Be converter - 3
- Photoproduction - 1

**Energy**
- Atmospheric (hundreds of MeV) - 3
- Monoenergetic (up to 20 MeV) - 5
- Quasimonoenergetic (up to 30 MeV) - 3
- Thermal - 2
- Low and intermediate energy white beam - 4
## Neutron Facilities

<table>
<thead>
<tr>
<th>Neutron Facilities</th>
<th>Energy range</th>
<th>Flux ($s^{-1} cm^{-2}$)</th>
<th>Yield ($s^{-1}$)</th>
<th>Neutron production</th>
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<tbody>
<tr>
<td>ChipIr (UKRI)</td>
<td>Atmospheric</td>
<td>$6 \cdot 10^6$</td>
<td>-</td>
<td>Spallation (up to 800 MeV)</td>
<td>UK</td>
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<tr>
<td>TRIUMF</td>
<td>Atmospheric</td>
<td>$5 \cdot 10^5 - 3 \cdot 10^6$</td>
<td>-</td>
<td>Spallation (up to 500 MeV)</td>
<td>CA</td>
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<tr>
<td>FNG (ENEA)</td>
<td>$14$ MeV (or $2.5$ MeV)</td>
<td>$\text{Up to } 5 \cdot 10^9$</td>
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<td>EMMA (UKRI)</td>
<td>Thermal</td>
<td>$2 \cdot 10^6$</td>
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Atmospheric neutrons – High energy

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Spallation sources produce spectrums that go up to the proton energy (500MeV/800MeV); a much broader, high energy spectrum than can be obtained from fission reactors sources.
Neutron Source Requirements Driven by Standards

Standards for SEE testing by JEDEC and IEC committees

JEDEC: JESD89A: Measurement and Reporting of Alpha Particle and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices


IEC TR 62396 - Process management for avionics
Atmospheric radiation effects

IEC: TR 62396-1: Atmospheric radiation (2016)
IEC: TR 62396-6: Extreme space weather (2017)
IEC: TR 62396-8: Protons, electron, pion, muon fluxes (due 2019)
Major areas of current commercial research:

- Systems for autonomous ‘driverless’ cars
- Device and system level for internet and communication infrastructures
- High power devices for renewable energy applications and automotive
- Aerospace applications
# Monoenergetic sources

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Based on nuclear reactions.
Low scattering facilities

Many other different applications:
- Nuclear Fusion R&D
- Metrology, spectrometry and dosimetry of neutron radiation
- Nuclear data for energy production
- Nuclear data for astrophysics
- etc.
**Monoenergetic sources and electronics**

- **Measurement of cross sections as a function of energy**
- **Comparative studies**
- **Application of electronics for nuclear technology**
  - because they are more representative of **fusion (or fission) reactors environment**.
- **Preparation and test of setups and methods** (more availability than spallation sources).
- **Characterisation of dosimeters as a function of energy**.
- **They are NOT fully representative of the atmospheric spectrum, but they can be used in a complementary way.**

Source: Cecchetto et al. 2021
Thermals

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- Fast neutrons slow down in a moderator
- Thermal equilibrium -> Maxwell-Boltzmann distribution, most probable energy KT = 25meV
- Use of thermal neutrons for neutron scattering.
- EMMA and ILL, complementary flux. Continuous vs. pulsed.
Testing electronics with thermal neutrons

- Thermal neutrons are known to induce **SEE in the electronics when Boron is present**.
- Enrichment of $^{11}\text{B}$ is a too expensive solutions, in particular for commercial electronics.
- **Recent studies** have found probabilities of SEE induced by thermal neutrons to be of the same order as fast neutrons, for **commercial devices (COTS)** to be used for safety-critical applications.
# White beams (low and intermediate energy)

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High Fluxes!

- Electron beam on Target: $^{nat}$Ta 3.52 cm

- Measured continuous energetic spectra with thick Be converter and proton and deuteron beam

Source: GANIL

Source: nELBE
Applications

Other applications:
- Nuclear data (fast neutrons)
- Nuclear technology (eg. transmutation of actinides)
- Etc.

- Electronics testing:
  - High fluxes useful for displacement damage studies
  - Comparative testing, method development
  - Nuclear environments
  - Time of Flight can be interesting for detector testing
Mixed Field (CHARM)

- CHARM’s spallation mixed field (mainly neutrons, protons and pions)
- Main interest from radiation effects community: representative radiation environment at System Level, thanks to very large radiation field available (homogeneous, highly penetrating)
- Strong interest from space community: lifetime effects – TID, displacement damage – and SEEs
- Testing electronics for accelerator environment.

CHARM comparison with the atmospheric neutron spectrum
Muons

- Muons are the **largest component** of the atmospheric flux on the ground.
- Muons **cross sections are much smaller** than neutrons. At the moment they are not a problem for industry, but more an academic interest.
- Facilities need to be ready if the problem increases with **scaling down of microelectronics**.

**Source:** Manabe et al. 2019
WP9: Relationships with Joint Research Activities (non-TA) WPs

WP5
- Radiation monitors, dosimeters and beam characterization
  - Neutron fields are very different (meV to GeV), need a variety of techniques and methods.
  - Importance of cross-calibration between facilities (at least of the same kind).
  - Need of innovative monitors that can be reference for users.

WP6
- Standardization of system level radiation qualification methodology
  - Neutrons are very attractive for system level testing (high penetration, large volumes)
  - Need standardization for use (e.g. Using neutron for space as proxy for protons).

WP7
- Cumulative radiation effects on electronics
  - Facilities with high fluxes for TID and displacement damage.
  - Decoupling SEE and cumulative effects

WP8
- Complementary modelling tools
  - Need Measurements to benchmark simulation tools
  - Simulations can be used to compare results obtained with different radiation fields.
Transnational Access

Please see NA2 presentation later in the morning

Description of work

• Users will be given access to RADNEXT through TA. The access to the facilities and information of various facilities are made more readily available to all.

• Help will be provided for the selection of suitable facility and proper beams for user’s research needs.

• An ad-hoc User Selection Panel (USP) will be established at the beginning of the project. The USP will thoroughly evaluate the proposals according to its scientific excellence, impact on the radiation effects community, and implementation description and feasibility.
Thanks for your attention!