Neutron SEE irradiation facilities and irradiation tests at TSL (The Svedberg Laboratory)

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Acknowledgements

The Svedberg LABORATORY

SEEDER
Sowing Reliability by Design

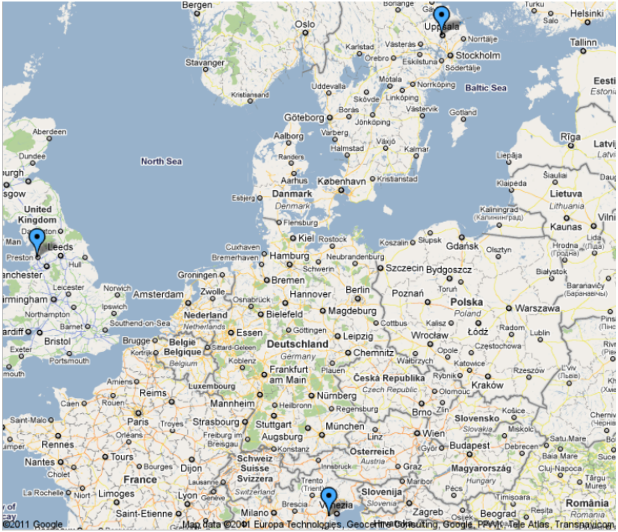
BAE SYSTEMS

QinetiQ

SAAB

Outline

Uppsala, Sweden



The Svedberg Laboratory

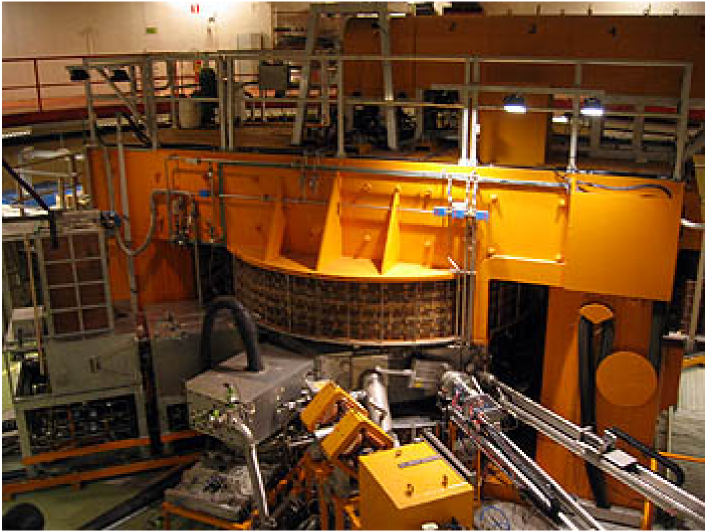
www.tsl.uu.se

The Svedberg

nobelprize.org

- Professor of Physical Chemistry, University of Uppsala, 1912–1949
- Nobel Laureate in Chemistry 1926
- Founder of the Gustaf Werner Institute for Nuclear Chemistry
- The Gustaf Werner Institute was re-founded as the The Svedberg Laboratory in 1986

Gustaf Werner cyclotron



www.tsl.uu.se

Activity at the The Svedberg Laboratory

Proton therapy

- Primary activity

Nuclear science

Radiation effects testing

- Quasi-monoenergetic and atmospheric-like neutrons
- Protons
- Heavy ions (in development)

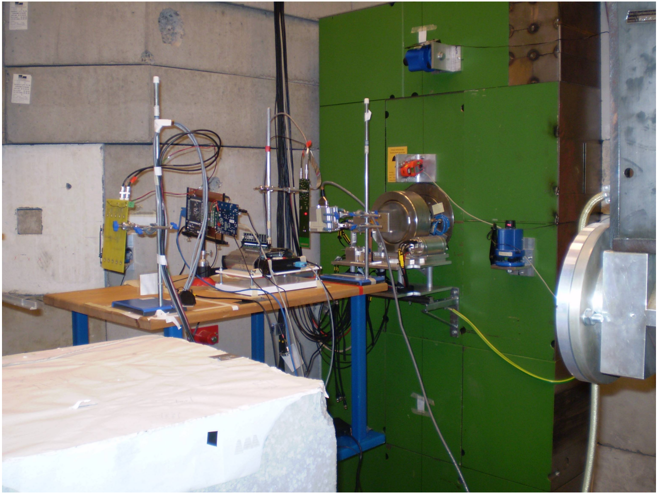
The TSL neutron beams

- Blue Hall
- Neutron beams and their spectra
  - ANITA
  - Quasi-monoenergetic neutrons (QMN)
- Time structure
- Beam monitoring
- Neutron fluence rate
- Collimation
- Accuracy of cross-section measurements & FIT predictions
- Beam contaminants and background radiation
- Communications with counting rooms
- Beam benchmarking
- Collocated beams
  - Protons
  - Current developments

The TSL neutron beams

The Blue Hall

Experiments in the neutron beam line ('D' line)



The Blue Hall

The proton beam line ('B' line)

The TSL neutron beams

The TSL neutron beams

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ANITA

Atmospheric-like **N**eutrons from a th**I**ck **TA**rget

History

- First use in 2007
- First report at RADECS 2008 [Prokofiev et al. (2008)]
- Canonical reference from 2009 IEEE Radiation Effects Data Workshop [Prokofiev et al. (2009)]

Spallation source

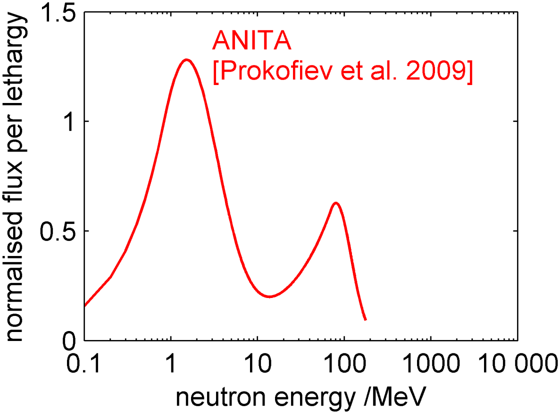
A 180 MeV proton beam is stopped in a tungsten target.

Neutrons are generated through spallation processes and emerge into the user area.

Spallation mimics the natural interactions between primary cosmic rays and atmospheric atoms leading to "cascade" and "evaporation" peaks in the neutron spectrum (c. 100 MeV and c. 1 MeV, respectively).

ANITA spectrum

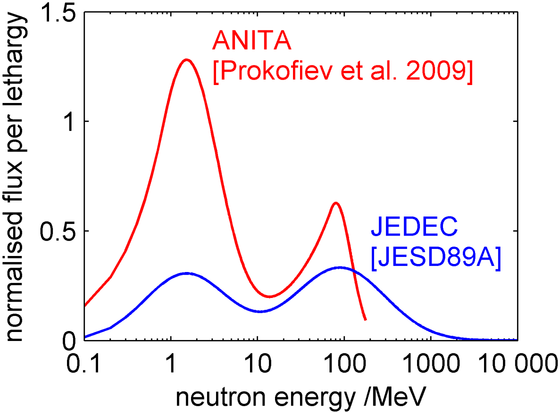
normalised to the integral fluence above 10 MeV



[Prokofiev et al. (2009)]

ANITA spectrum

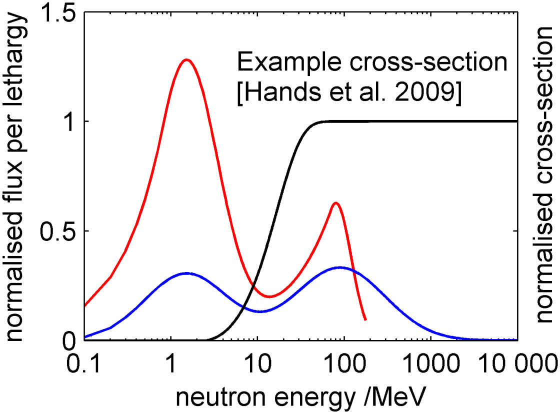
compared to the natural atmospheric radiation field



[JESD89A]

ANITA spectrum

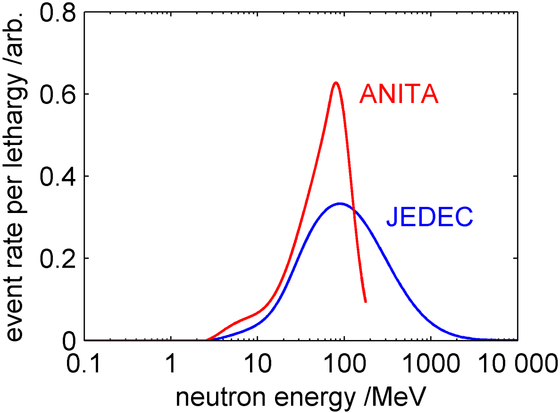
compared to a typical neutron SEU cross-section function



[Hands et al. (2009)]

ANITA spectrum

folded with a a typical neutron SEU cross-section function



[Platt et al. (2010)]

Estimating SEE cross-section and SEE rates in service

from measurements in the ANITA beam

Measured integral cross-section

$$\overline{\sigma} = \frac{N}{\Phi}$$

N: observed no. of events; Φ: monitored fluence above 10 MeV

Predicted SEE rate

$$\mathrm{SER} = \overline{\sigma}\dot{\Phi}$$

$\dot{\Phi}$: predicted fluence rate in service (above 10 MeV)

Failures in time

$$\mathrm{FIT} = \mathrm{SER} \times 10^9 \mathrm{h}$$

[JESD89A]

The TSL neutron beams

QMN

Quasi-**M**onoenergetic **N**eutrons

History

- First installed at TSL in 1980s, rebuilt 2003/4, upgraded 2007
- Described in several references [Österlund et al. (2005), Prokofiev et al. (2006), Prokofiev et al. (2007)]

Quasi-monoenergetic source

A proton beam is incident on thin a ^{7}Li target.

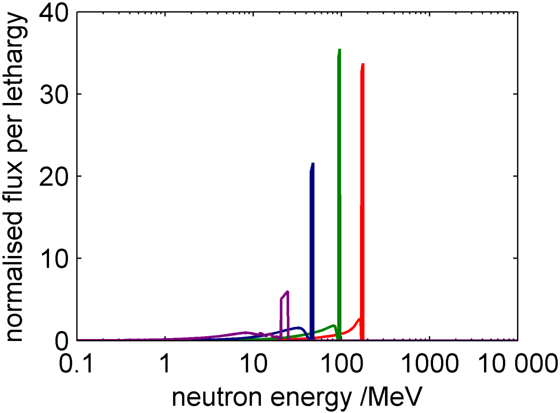
Neutrons are generated through the ^{7}Li(p,n)^{7}Be reaction and neutrons pass through into the user area:

- $\sim$40% of the resulting neutrons have energies just below the proton energy (the nominal neutron energy).
- the remainder form a broad tail at lower energies.

Residual protons are removed magnetically.

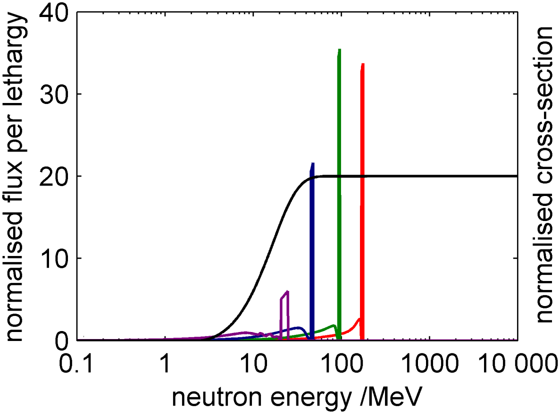
Quasi-monoenergetic neutron beam spectra

normalised to the integral fluence at the nominal energy



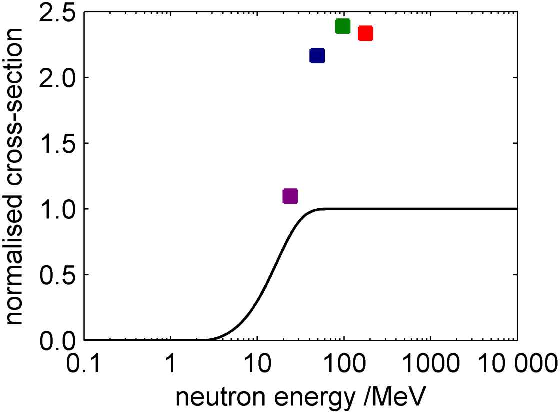
Quasi-monoenergetic neutron beam spectra

compared to a typical neutron SEU cross-section function



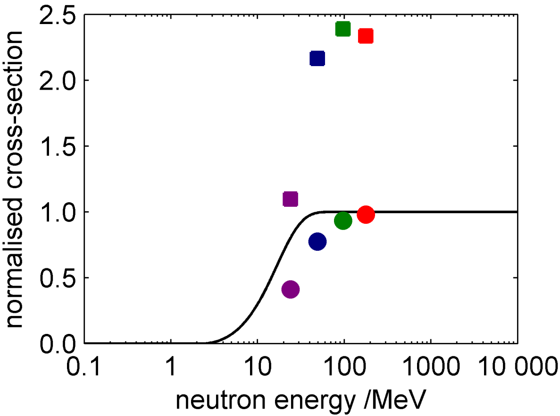
Quasi-monoenergetic neutron beam spectra

Measurements using the fluence at the nominal energy tend to overestimate cross-sections



Quasi-monoenergetic neutron beam spectra

Measurements using the total fluence tend to underestimate cross-sections



[Dyer et al. (2004), Dyer et al. (2006)]

Estimating SEE cross-section and SEE rates in service

from measurements in QMN beams

Upper and lower bounds

[Dyer et al. (2004), Dyer et al. (2006)]

Upper and lower bounds to cross-sections can be estimated assuming interactions with the QMN peak only or the whole spectrum, respectively.

Cross-sections can be folded with atmospheric spectra [JESD89A].

Results are consistent with measurements in spallation beams.

Unfolding

[Granlund et al. (2004), Olmos et al. (2005)]

Unfolding techniques can be used to estimate the influence of the low-energy field, and provide improved estimates of $\sigma(E)$.

Results are consistent with measurements in spallation beams. [Granlund et al. (2004)]

The TSL neutron beams

Neutron beam time structure

Neutron beam time structure is determined by the cyclotron operating mode:

- 25 MeV – 100 MeV (QMN): continuous
- 100 MeV – 180 MeV (QMN & ANITA): pulsed
  - $\sim$0.5 ms macropulses at up to 150 Hz (variable by the user)

Beam microstructure is not normally significant for SEE testing.

Beam sharing with proton therapy

The primary use of the cyclotron is for proton therapy.

- 180 MeV pulsed operation is most often scheduled. ANITA and $\sim$180 MeV QMN beams are most often available.
- Proton beam is liable to be diverted to therapy several times during daytime shifts.

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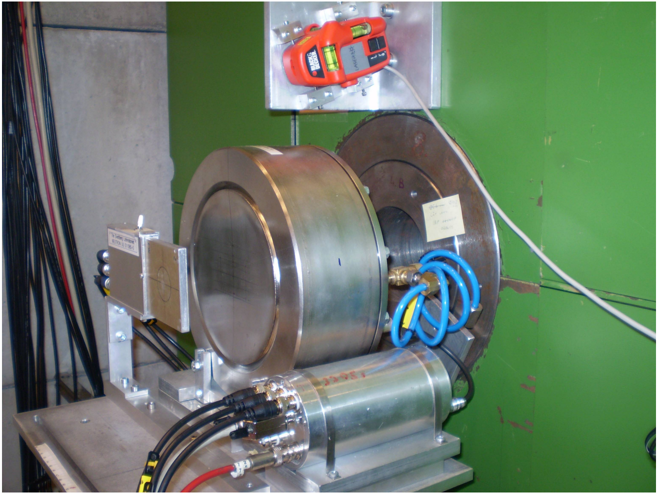
Neutron beam monitoring

Ionisation chamber monitor and thin-film breakdown counter



Neutron beam monitoring

Three independent beam monitors are in routine use:

- Ionisation Chamber Monitor (ICM)
- Thin-Film Breakdown Counter (TFBC)
- proton beam dump (Faraday cup)

Beam monitor counts are available to users

- using manual scalars
- as time-stamped online data
- as logic pulses

Calibration factors provide fluence per count at the Standard User Position (SUP):

- fluence above 10 MeV for ANITA
- fluence at the nominal energy for QMN

Calibration is typically accurate to 10%

Fluence rate downstream of the SUP varies according to a R^{-2} law

The TSL neutron beams

Neutron fluence rate

at the Standard User Position (upstream)

ANITA

- Maximum (@$\sim$200 nA proton current) is $\sim 1 \times 10^6\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ above 10 MeV, $\sim 3 \times 10^8 \times$ [JESD89A].
  - Easy reduction available (up to $\times 1/150$) by reducing repetition rate.
- Minimum (through cyclotron adjustment) $\sim 200\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ above 10 MeV, $\sim 6 \times 10^4 \times$ [JESD89A]

QMN

Achievable fluence rate is typically between $\times \frac{1}{10}$ and $\times \frac{1}{2}$ ANITA, depending on nominal energy.

[Prokofiev et al. (2007), Prokofiev et al. (2009)]

The TSL neutron beams

Collimation

the maximum neutron beam aperture is 30 cm

Collimation

a wide range of collimator inserts is available

Collimation is available between 1 cm×1 cm and 30 cm⌀. Collimation changes take less than an hour.

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Sources of error in cross-section measurements & FIT predictions

Beam monitoring uncertainty is quoted as 10%

Poisson counting statistics often limit accuracy.

- Treatment is standard. [Gehrels (1986), JESD89A]
- It is not normally worth observing more than 100 errors under any one condition.

Extrapolation to in-service conditions may be difficult:

- Limited upper energy (ANITA)
- Unfolding (QMN)
- Service conditions might not be well understood.

Upstream experiments degrade the beam for downstream experiments.

- Standard methods for estimating degradation effects are available. [JESD89-3A]
- Simulation is possible. [Truscott et al. (2006)]
- In-situ beam monitoring using minimally-invasive diode detectors may be preferred. [Platt & Török (2007)]

Do you need to measure absolute cross-section?

Cross-section measurements are not the only aspect of SEE testing:

- Device screening – stress tests
- Assessing mitigation techniques (fault injection)
- Investigating threshold energies (QMN)

In these applications *absolute* fluence measurements might not be needed.

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Unwanted radiation components

Protons

Proton contamination is small, e.g. $\sim$10 ppm (95 MeV QMN), $\ll$1% (ANITA). Observable effects due to proton contamination are unlikely.

Gamma rays

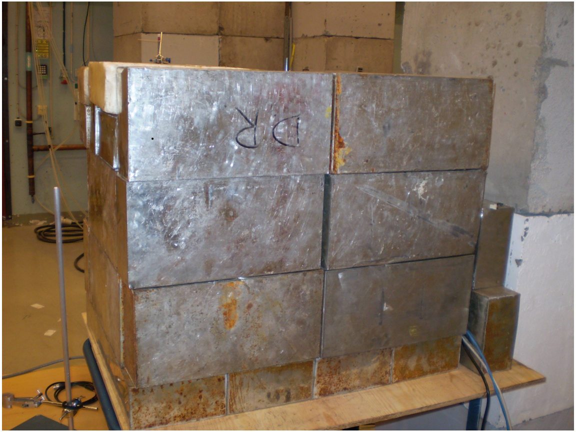
Dose rate $\sim 10\,\mathrm{mGy\,h^{-1}}$ (ANITA), $\sim 1\,\mathrm{mGy\,h^{-1}}$ (QMN).

Thermal neutrons

Thermal neutron components can be more significant. A modest ($<$2%) thermal neutron component is present in the beam and as a background in the Blue Hall. This can be increased by the presence of scatterers in the beam line. DUTs are not normally shielded against thermal neutrons, but support electronics in the hall should be.

[Prokofiev et al. (2007), Prokofiev et al. (2009)]

Thermal neutron background

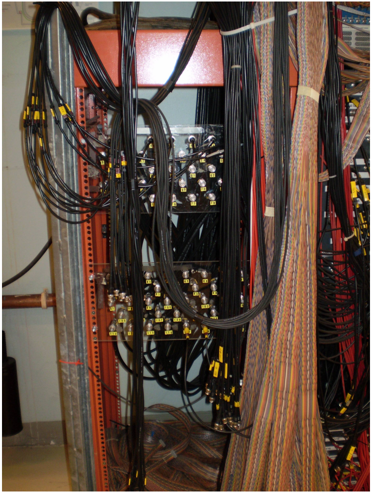


Borated wax shielding is available to protect support equipment. Borated rubber is also useful.

The TSL neutron beams

Communications with counting rooms

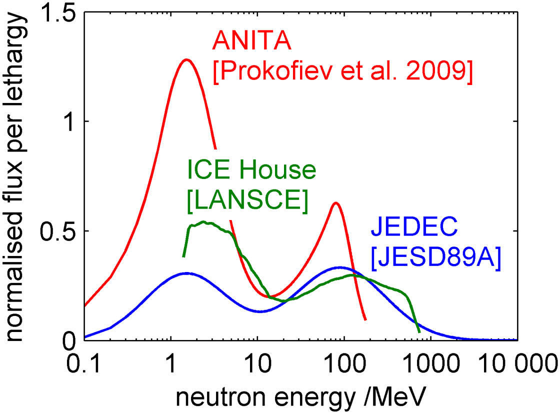
Ethernet and 50 Ω coaxial patch connections to counting rooms are available.



The TSL neutron beams

ANITA v. LANSCE ICE House

Normalised spectra



[Prokofiev et al. (2009), JESD89A, LANSCE]

ANITA v. LANSCE ICE House

	ANITA	ICE House
spectrum	good	excellent
thermal neutrons	present	absent
fluence rate	$1 \times 10^6\,\mathrm{n\,cm^{-2}\,s^{-1}}$	$5 \times 10^5\,\mathrm{n\,cm^{-2}\,s^{-1}}$
fluence rate range	wide	limited
macropulse repetition	1 Hz–150 Hz	40 Hz
collimation	flexible	limited
divergence	broad	narrow
availability	good	limited
collocated beams	QMN neutrons, protons	

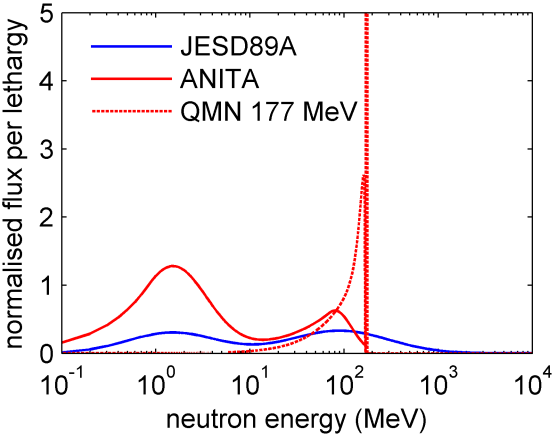
LANSCE ICE House provides the best direct simulation of the atmospheric neutron spectrum currently available.

ANITA provides a useful alternative with greater flexibility. [Patel & Puchner (2009), Platt et al. (2010)]

QMN neutrons provide a mechanism for adjusting for the shortfall of cascade-peak neutrons at ANITA. [Platt et al. (2010)]

QMN adjustment

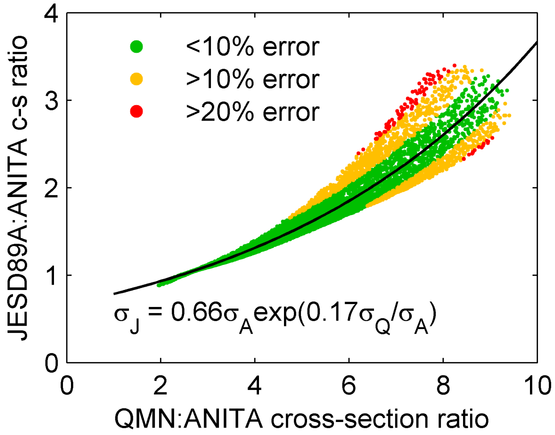
Beam spectra



[Platt et al. (2010)]

QMN adjustment

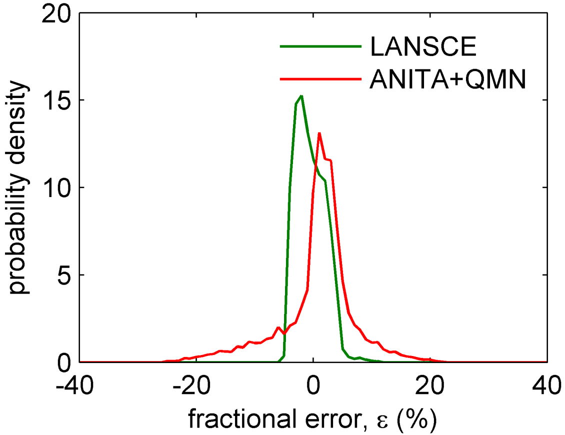
Adjustment procedure



[Platt et al. (2010)]

QMN adjustment

Component of error due to spectral infidelity



[Platt et al. (2010)]

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The TSL neutron beams

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Collocated proton beams

Protons are available in the Blue Hall on beamline ‘B’

- Protons can provide a truly monoenergetic proxy for neutrons at higher energies.
- Direct ionisation from protons can cause SEE in more recent device technologies

Key characteristics of the proton beam:

- 20 MeV – 175 MeV
- Peak fluence rate:
  - direct beam: $1 \times 10^{11}\,\mathrm{cm^{-2}\,s^{-1}}$ – $1 \times 10^{12}\,\mathrm{cm^{-2}\,s^{-1}}$
  - scattered beam: $5 \times 10^{7}\,\mathrm{cm^{-2}\,s^{-1}}$ – $5 \times 10^{9}\,\mathrm{cm^{-2}\,s^{-1}}$
- 4 mm–20 cm $\varnothing$
  - nonuniformity $< 10\%$

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Ion beam developments

Proton f**A**cility in **U**ppsa**LA**

PAULA will provide greater flexibility

- energy degraders
- collimation
- flux

No publications yet

Heavy ions

A heavy ion test facility is in development adjacent to the Blue Hall. The first SEE test campaign is scheduled for June 2011.

Support and Logistics

User facilities

On-site support

Logistics

Visiting Uppsala

Support and Logistics

User facilities

On-site support

Logistics

Visiting Uppsala

User facilities

Counting rooms

- Two counting rooms
- Manual scalars for beam monitor counts
- Computer-controlled user interface provides limited user control (interlocks etc.)

Home comforts

- Kitchen
- Common room
- Rest room
- Shower
- Wired and wireless internet access

Support and Logistics

User facilities

On-site support

Logistics

Visiting Uppsala

Technical support

User support

- Overnight running possible
- Radiation team: on site or on call
- Cellphone for users
- Cyclotron operator on hand

Radiation safety

- Radiation safety preparation online
- Onsite briefing on site
- Survey meters (γ, β)
- Electronic dosimetry
- Typical interlock/clearing system

Support and Logistics

Logistics

Scheduling

- Quarterly scheduling cycle: Jan, April, June, September

Charging

- Beam pricing policy online at www.tsl.uu.se/radiation_testing

Shipping

- Surface shipping convenient from Europe
- No customs requirements from EU

Release of irradiated samples

- Cool down time typically a few days (for neutron irradiations)

Support and Logistics

User facilities

On-site support

Logistics

Visiting Uppsala

Visiting Uppsala

Getting there

- Easy access by rail or taxi from Stockholm Arlanda Airport

Staying there

- Many hotels within easy walking distance
  - e.g. Akademihotellet www.akademihotellet.se
- Many places to eat in Uppsala city centre
- Many parks, museums, sites of historical interest
- English very widely spoken

Summary

TSL provides particle beams for irradiation including SEE testing

- Atmospheric-like neutrons (ANITA)
- Quasi-monoenergetic neutrons (QMN)
- Protons (PAULA)

A heavy ion irradiation facility is in development.

Recent users from industry including avionic systems, electronic systems, electronic devices, and academia include

- Aero Engine Controls
- BAE Systems
- Cisco
- Cypress
- University of Delft
- MBDA

Appendix

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Appendix

Contacts

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