Report of the IRMM Neutron Physics Unit with regard to recent neutron fluence intercomparisons and measurements

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Neutron fluence measurements at IRMM are done as a support to experimental activities, neutron measurement metrology and for environmental safety reasons. The experimental work includes reference measurements for neutron-material interactions, environmental protection and of neutron-induced reaction cross section standards. Projects are a part of the general IRMM programme on neutron data measurements in chemistry and physics, and related to fundamental material properties, with a measurement programme driven by demands from international projects and organisations (like JEF - Joint European File and the OECD) as well as policies of the European Commission. On-going projects are:

Transmutation of Nuclear Waste:

- ^{129}I and ^{237}Np total and capture cross sections,
- fission fragment properties of ^{244,248}Cm, ^{252}Cf, ^{235}U, ^{239}Pu,
- tritium production from different isotopes,
- ^{14}C production on nitrogen.

Accelerator Driven Systems:

- ^{206}Pb and ^{103}Rh total and capture cross-sections,
- Pb and ^{209}Bi inelastic scattering measurements,
- activation cross sections on Zr isotopes (n, xp) and (n, xα),
- study of tritium production cross sections,
- study of (n, αp) cross sections,
- ^{209}Bi branching ratio, thermal capture and transmission,
- fission product studies.

Thorium fuel cycle:

- ^{232}Th total and capture resonance cross-sections,
- ^{232}Th average capture cross-sections,
- fission cross section for ^{233}Pa and ^{234,236}U(n, f),
- fission fragment properties for ^{234}U(n, f),
- fission studies of ^{231}Pa and ^{233}U.

Doppler broadening:

- ^{240,242}Pu resonances.

Standard cross-sections:

- ^{10}B(ṇ,α), ^{6}Li(ṇ,α), ^{252}Cf(SF), ^{251}Cf(n, f), ^{239}Pu(n, f) prompt neutrons, ^{235}U(n, f) fission spectrum, and ^{238}U(n, f).

Theory:

- ^{235}U(n, f) prompt neutrons up to 20 MeV,
- Pa –isotopes.

Neutron data for applications:

- Fluence intercomparison,
- neutron data for astrophysics,
- neutron detector development,
- ^{26}Al (n, p) (n, α), ^{36}Cl(n, p)(n, α),
- ^{82}Kr transmission,
- ^{84}Kr capture.

Technical developments:

- Use of digitising equipment in experiments,
- Specialised detectors for neutron measurements,
- Specialised detectors for charged particle measurements,
- Neutron dosimetry using activation,
- Design studies of a new target for the GELINA accelerator.

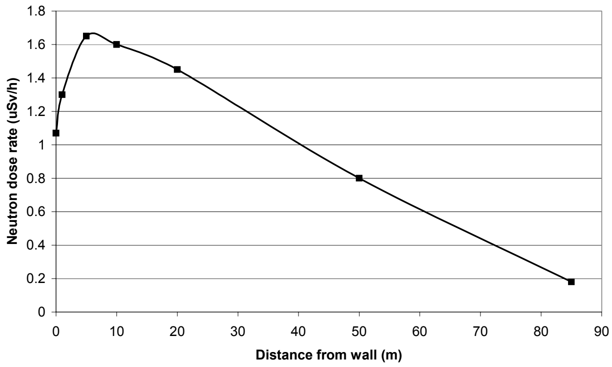
EUROMET at 15.5, 16, 17 and 19 MeV

IRMM participates in a 2004-2005 EUROMET exercise to measure neutron fluence rate for mono-energetic neutrons at 15.5, 16, 17 and 19 MeV using a recoil-proton telescope with a CsI detector. Previously, IRMM participated in a CCRI key comparison for mono-energetic neutron fields at 1.2, 5 and 14.8 MeV, with its second recoil-proton telescope equipped with a silicon detector.

Mapping of neutron doses and spectra around the IRMM Van de Graaff building

Following the erection of a new protective 0.5 m concrete wall around the VdG neutron hall, a measurement programme was initiated to study its shielding performance to neutrons. This was done by means of mapping the neutron flux around the building using various neutron monitors while the neutron energy spectrum was characterised using a Bonner sphere spectrometer. An additional investigation of the neutron field was performed by means of activation of gold discs and subsequent gamma measurements in the IRMM 240 m underground low background laboratory HADES. All measurements were carried out under typical experimental activities

The measurements showed that the actual reduction of the surrounding neutron radiation, due to the wall, was adequate. Dose rates found close to the wall were around 1 μSv/h, which is 40 to 50 times lower compared to before the wall. At 85 m distance from the wall a dose rate of 0.2 μSv/h was measured which is about 3 to 4 times lower than what was measured before the wall. The initial dominating high energy component in the neutron spectrum was also effectively removed, however a considerable thermal component remained. Another result from the measurements was the considerably contribution from neutrons escaping from the building through the thin aluminium roof and scattered back to ground outside the wall ("skyshining"). This is illustrated in the figure below where a 3.8 MeV neutron field generated in the upper experimental hall is mapped outside the wall using a standard Eberline neutron monitor. The yield at the source was here about $6.0 \cdot 10^7$ neutrons$\cdot$sr$^{-1}\cdot$s^{-1}, from a 5 μA proton beam of 4.63 MeV on a 2.0 mg/cm^2 titanium-tritium target.



The IRMM Bonner spheres

The recently installed IRMM Bonner sphere spectrometer (BSS) follows the design “PTB-C”. It consists of a ^{3}He detector and nine polyethylene spheres (3”, 4”, 5”, 6”, 7”, 8”, 9”, 12” and 18”) with fittings to mount the ^{3}He detector in their respective centres. The system was recently calibrated in the IRMM VdG neutron target hall.

The response functions of the spheres have been obtained from precise geometrical drawings from PTB and Monte Carlo calculations using MCNP. Also the volumes and the densities of the spheres have been carefully measured to be well within expected uncertainties.

Spectrum unfolding is done using either or both of the two unfolding programmes *MAXED* and *GRAVEL*, as included in the *U.M.G.* unfolding package from PTB), where *MAXED* is based on a maximum entropy mathematical procedure and *GRAVEL* is a refined version of the *SAND-II* least squares fitting algorithm.

New developed Software

IRMM has developed MS Windows software for real time calculations of accelerator settings related to ion beam parameters (ion, energy and current), neutron production (nuclear reaction and target) and neutron fluence (neutron energy spectrum and intensity). The programme, *EnergySet*, gives immediate double differential data about neutron fluence, based on kinematics, for the most commonly used nuclear reactions for neutron production using accelerators.

Also, a MS Windows programme to calculate neutron fluence fields from recoil proton telescope data has recently been developed.

Beam lines for neutron production

A new beam line aimed for time-of-flight measurements has been completed and put in operation. The beam line is extended to the centre of the IRMM VdG upper target hall to minimise neutron in-scattering from the surrounding wall construction. Time-of-flight measurements are facilitated by means of a pick-up loop located immediately before the neutron producing target. This beam-line has also been equipped with a beam deflection device for beam pulsing in the μs region.

A high intensity beam line has also been constructed in the lower level target hall. This beam line facilitates a continuous high intensity ion beam, and neutron field, for long term irradiations (week). This is a prerequisite for some low neutron cross-section measurements. Long-term stable beam currents (protons and deuterons) of more than 50 μA can be obtained routinely. With a special water-cooling device for the neutron-producing targets, operation with a beam power up to 280 W is possible.