LEMRAP Laboratory

2019 Annual report

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ANET experiment (2019 - 2021) - CSN 5

ANET is a CSN 5 experiment including LNF, Torino (nat. resp.), Trieste and Pavia units and has the objective of prototyping an innovative design of compact collimator for slow neutrons.

Neutrons are widely used in non-destructive investigations, such as neutron radiography and tomography (neutron imaging), and materials science studies based on scattering.
Imaging with slow neutrons (thermal and cold) is in principle similar to X-ray imaging, but, due to the different interaction mechanisms, it is used to reveal different materials. Differently than X-rays, neutrons are very sensitive to some light elements like H, Li, B. Also, neutrons easily penetrate thick layers of heavy metals. Neutrons can distinguish between isotopes (e.g. ^{1}H and ^{2}H, ^{6}Li and ^{7}Li, ^{10}B and ^{11}B), which is not the case for X-rays. These characteristics made neutron imaging very useful for non-destructive inspections in basic research, cultural heritage and industry. All mentioned applications ideally use broad parallel neutron beams, thus neutron collimators play a fundamental role. Neutron collimators are in principle composed by pipes, selecting only neutrons travelling in the desired direction. The collimator walls are ideally fabricated from a neutron absorbing material, such as Boron or Lithium.
Collimating apertures should meet the criteria:

- Collimation ratio: The collimation ratio (L/D) is simply the ratio of the collimator length L to the diameter D of the aperture. For neutron imaging, this ratio directly determines the relationship between sample thickness (t) and image sharpness (penumbra) $p = t / (L/D)$. The geometrical blurring is also related to L/D with the relation $d = l / (L/D)$, where d is the spatial resolution and l the sample-to-detector distance.
- Beam divergence: The half angle of beam divergence is an important measure of the usefulness of the beam near its periphery. If the neutron beam diverges very rapidly to a large size then the outer portion of the images produced will suffer significant distortion.

Collimators should be either evacuated or filled with non-interacting pure ^{4}He gas, as every meter of air reduce the intensity of thermal neutron by 5%.
To achieve good geometric conditions (high L/D, small penumbra, blurring and divergence) over reasonably large irradiation fields (ten - few tens of cm), practical collimators are always very long (ten meters or more).
This requires:

- Large facilities
- Very intense primary neutron beams.
- Need for ^{4}He filling or operation under vacuum.

The main objective of ANET is designing and testing an innovative compact collimator, able to reach the mentioned desired geometrical beam properties in one meter or less.

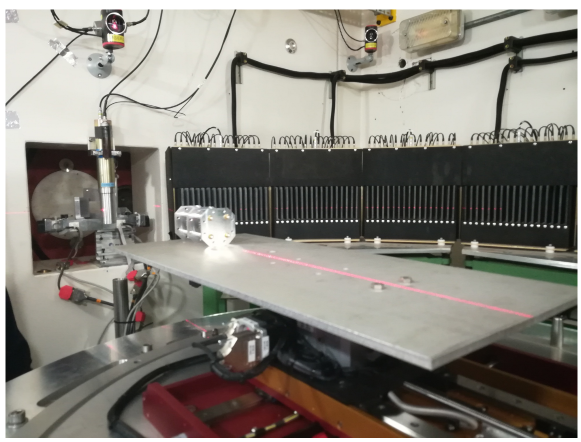
Neutron science will greatly benefit from such a device, as neutron imaging or scattering experiments will be feasible in small-medium scale labs, using neutron source much weaker than a reactor. In addition, shorter collimating structures would not require ^{4}He filling or operation under vacuum.

ANET compact collimator was designed as a complex, micro-structured body, built in neutron absorbing material. The design was submitted as an INFN patent.

In 2019 the ANET group at LNF developed the following activities, aimed at experimentally demonstrating, in small scale, the feasibility of such a design of compact collimator.

- Achieving an executive design for a small-scale collimator (10 cm length, field of view 2 cm x 2 cm).
- Choosing the neutron-absorbing building material
- Choosing and optimizing the fabrication technique
- Building the small-scale compact collimator
- Testing the small-scale compact collimator in the neutron beam of the INES beamline at ISIS spallation neutron source (UK), See Figure 1.

Figure 1. Testing the prototypal small-scale compact collimator for slow neutrons.



One of the phases of the experiment included the use of a finely collimated thermal neutron detector, developed and calibrated at LNF. See Fig. 2. The neutron sensor is a one square-mm windowless Silicon diode covered with 30 mm of ^{6}LiF. The cylindrical collimating aperture has diameter 1 mm and length 8 mm. The detector shield was made in borated plastic.
The detector was tested in the LNF-ENEA HOTNES thermal neutron facility [1,2], taking the direction distribution of the thermal field [3] into consideration, See Figg. 3 and 4.

Figure 2. Collimated thermal neutron detector built for tests at INES beam-line. The sensitive capsule has diameter 15 mm and length 35 mm. The internal thermal neutron sensor has 1 mm^2 area and the collimating channel has diameter 1 mm x length 8 mm.

Figure 3. Direction distribution of the thermal neutron field at the reference point (+50 cm) in the HOTNES facility. In X axis, the cosine of the polar angle, see also Fig. 3. Cosine = 1 indicates bottom-top directed neutrons.

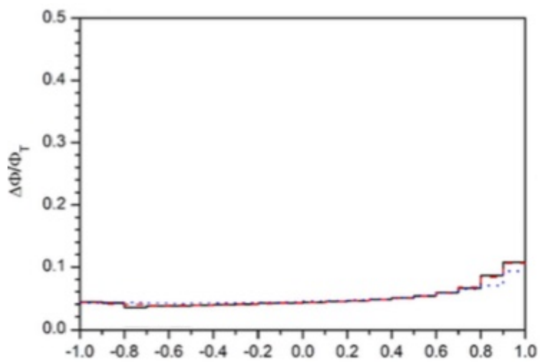


Figure 4. Position of the detector in HOTNES test point (+50 cm from the facility bottom).

The collimating aperture of the Silicon detector has 7.85E-3 cm^2 cross sectional area and identifies a cosine bin from 0.992 to 1.00, comprising about 1.5% of the HOTNES cosine distribution. The detector has thermal neutron efficiency 2% (unc. 5%). The thermal neutron fluence rate in HONTES test position is 760 $cm^{-2}s^{-1}$ (unc. 3%). Thus the expected count rate is 1.79E-3 (unc. 3%) cps, which agrees with the experimental value 1.65E-3 (unc. 8%) cps.

Conclusions

A prototypal small-scale (10 cm length, field of view 2 cm x 2 cm) compact collimator for slow neutrons was designed and built. A complex testing experiment was undertaken in the INES beam-line - ISIS spallation neutron source (UK).
One of the phases of the experiment included the use of a finely collimated (collimating channel has diameter 1 mm x length 8 mm) thermal neutron detector, developed and calibrated at LNF.
As the overall result of the INES experiment, the basic concept behind the new compact collimator for slow neutrons was successfully proved.
The objective of next year (2020) is achieving a working prototype of compact collimator exhibiting:

- State-of-art collimating ratio (> 100)
- State-of-art field of view (5 cm x 5 cm)
- The unprecedented length of about 50 cm only.

Publications

[1] R. Bedogni, A. Sperduti, A. Pietropaolo, M. Pillon, A. Pola, J.M. Gómez-Ros. Experimental characterization of HOTNES: A new thermal neutron facility with large homogeneity area. NIM A 843 (2017) 18–21.

[2] A. Sperduti, M. Angelone, R. Bedogni, G. Claps, E. Diociaiuti, C. Domingo, R. Donghia, S. Giovannella, J.M. Gomez-Ros, L. Irazola-Rosales, S. Loreti, V. Monti, S. Miscetti, F. Murtas, G. Pagano, M. Pillon, R. Pilotti, A. Pola, M. Romero-Expósito, F. Sánchez-Doblado, O. Sans-Planell, A. Scherillo, E. Soldani, M. Treccani, A. Pietropaolo. Results of the first on the Homogeneous Thermal Neutron Source HOTNES (ENEA/INFN). JINST, 2017 **12** P12029.

[3] R. Bedogni, A. Pietropaolo, J.M. Gomez-Ros. The thermal neutron facility HOTNES: theoretical design. Applied Radiat. Isotopes 127 (2017) 68-72.