Proposal for instruments at small and medium size neutron facilities

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Abstract. The deployment of small and medium intensity regional neutron sources facilitates the availability of neutron techniques to a wider users community. With a minimum set of instruments it is possible to cover a variety of applications. Based on the experience gained with the use of the Bariloche Electron Linear Accelerator (Argentina), we propose a few basic instruments that are suitable to be installed at a small or medium scale neutron facility.

1. Introduction
The difficulty of getting beam time at large facilities to perform ‘minor’ experiments makes the small and medium neutron facilities (SMNF) an obvious choice to test new methods or to perform less-sound (yet interesting) experiments. These neutron sources are able to accomplish a variety of goals, including the implementation of a diversity of techniques which are complementary to those available at large facilities, and play a key role in human resources training.

At the Centro Atómico Bariloche (CAB, Argentina) a 25 MeV electron linear accelerator (LINAC) has been in operation since 1969. Despite being a small scale neutron source for present day standards, the set of instruments installed there can serve as model for other planned SMNF, particularly in Spain. In fact, worldwide experience demonstrates that low intensity neutron facilities play an active role in the development of neutron techniques. Recently, coordinated projects have been launched to enhance the capabilities of SMNF for that purpose[1]. Among the SMNF in Europe, there are facilities based on charged particle accelerators that produce neutrons by interaction with suitable targets, as well as low power reactors. Their activities are coordinated through associations like EFNUDAT [2] and EUFRAT[3], providing an up-to-date list of available facilities.

2. Neutron source at CAB
The pulsed neutron source is based on an electron LINAC (Fig. 1), which produces 25 MeV electron pulses of 1 μsec width. The electrons hit a lead target refrigerated by a water circuit, where they lose their energy by bremsstrahlung. This radiation interacts with the lead nuclei, producing (γ,n) nuclear reactions. The accelerator is located inside a concrete shielded bunker, from where two neutron beams are extracted to the contiguous experimental hall. The bunker room is accessible shortly after the accelerator beam is switched off. This represents one of the
main advantages of the small facilities, since it allows to safely manipulate the target-moderator-reflector configuration once the mandatory period of time has elapsed. The moderators are slab-shaped hydrogenated materials (typically polyethylene), which produce different intensities and time responses depending on their geometric characteristics. To improve their pulse-width a new type of moderators with Cadmium grids were developed and successfully tested[4].

The Bariloche LINAC allows the operation of two simultaneous experiments. At present a detector bank to perform transmission experiments is placed on the perpendicular tube, and another one devoted to electron-volt spectroscopy experiments on the oblique tube, where alternatively a diffraction bank can also be operated. The detector banks are all composed of $^3$He tubes.

![Figure 1](image-url) Sketch of the neutron source at CAB. The accelerator and the neutron source are located in a bunker made of 1 m thick concrete walls. Neutron beams are extracted with two tubes to the contiguous experimental hall. The inset shows the detail of the neutron source.

3. Instruments at CAB
Transmission experiments, with a simple experimental setup, are relatively easy to perform (Fig. 2 (a)). A remote controlled sample-changer allows the alternate measurement of the transmitted beam, the direct beam and the background spectra. The purpose of these experiments is to determine the total cross section of the system under study. In a pulsed source with a moderator at room temperature, the white incident beam allows a measurement over a wide range of energies spanning subthermal ($\sim10^{-4}$ eV) to epithermal ($\sim10^2$ eV) neutrons. The knowledge of the total cross section can be employed to study nuclear properties of nuclei [5, 6] and structural [7] or dynamic properties [8] in condensed matter, and it is of fundamental importance for the data analysis to be carried out in large facilities.
Figure 2. (a) Sketch of a transmission experiment, with the neutron source (represented by the moderator), the sample changer system and the detector bank. (b) Sketch of the time of flight diffraction experiment, where the detector bank is arrayed on a $Qt = \text{const.}$ surface.

Figure 3. Experimental setup employed for eVs experiments. The neutron beam is scattered in the sample and is detected by an array of $^3\text{He}$ tubes at a fixed angle. A resonant moving filter is placed in the scattered beam path.

Diffraction experiments to study crystal structures can be performed employing a time-focused detector bank [9] (Fig. 2 (b)). Better resolution is achieved for back-scattering designed detector banks. It is worth mentioning that even with low intensity and resolution, this diffractometer has been useful for the study of meta-stable phase structures in inter-metallic alloys [10, 11]. As should happen with other SMNF, those works were initiated in Bariloche and then continued in large facilities [12, 13], where the intensity, resolution and environment conditions were much better.

The electron-volt spectroscopy technique (eVs) is based on the measurement of the energy transferred by the neutron to the sample. To this end, a movable resonant filter is placed in the scattering beam path, and alternate ‘filter-in’ and ‘filter-out’ measurements are performed (Fig. 3). This technique gives information on the momentum distribution of the particles conforming the sample and can only be done in pulsed sources where important epithermal neutron fluxes are available.
Finally, we can mention two other techniques that are well suited for SMNF. Small Angle Neutron Scattering is a widely spread technique in Biology and Soft Matter using mainly cold neutrons. Therefore, this technique requires a refrigerated moderator to enhance the production of long-wavelength neutrons. A good example is the instrument SANS-I [14] at Paul Scherrer Institute (PSI) in Switzerland. The Neutrography is another useful and quite simple technique well developed at PSI. These techniques have applications in Industrial and Cultural Heritage studies, being NEUTRA [15] the best example of an instrument that could easily be installed in a new facility.

4. Conclusions
We propose a series of instruments to be installed in a new SMNF. Our choice is based on the experience acquired after 40 years of operation of the Bariloche LINAC, as well as from other typical sources.

(i) Transmission, to measure total cross sections (Nuclear properties, Condensed Matter)
(ii) Electron-volt spectroscopy, to measure impulse distributions (Condensed Matter)
(iii) Powder diffraction, for crystalline structure determinations (Materials Science)
(iv) Small angle neutron scattering, for large structure determinations (Biology and Soft Matter)
(v) Neutrography, for neutron imaging (Industry and Cultural Heritage).

The enumerated techniques, serve as research instruments per se, as well as complementary techniques to those available at large facilities. The easy access to a neutron source and the possibility of performing simple experiments allow in many cases the improvement of neutron scattering techniques [16], or the methodology for data treatment [17, 18]. The main role of a small size neutron source is the human resources training at the University level, giving to the students an easy access to neutron beam time.

References
[1] “Improved production and utilization of short pulsed, cold neutrons at low-medium energy spallation neutron sources”, Report of the 2nd Research Co-ordination Meeting Kuala Lumpur, Malaysia 2 - 4 July 2009.
[2] EFNUDAT, European Facilities for Nuclear Data Measurements, http://www.efnudat.eu/
[3] EUFRAT, European Facility for Innovative Reactor and Transmutation Neutron Data, http://irmm.jrc.ec.europa.eu/html/activities/eufrat/
[4] R.E. Mayer, P.C. Florido, J.R. Granada, J. Dawidowski, V.H. Gillette, Physica B 180 & 181, 944 (1992).
[5] G. J. Cuello, J. R. Santisteban, J. R. Granada, R. E. Mayer, Nucl. Instr. Meth. Phys. Res. A 357, 519 (1995).
[6] L. A. Rodríguez Palomino, J. J. Blostein, J. Dawidowski, G. J. Cuello, J. Instr. 3 P06005 (2008).
[7] J. R. Santisteban, L. Edwards, M. E. Fitzpatrick, A. Steuwer, P. J. Withers, M. R. Daymond, M. W. Johnson, N. Rhodes, E. M. Schooneveld, Nucl. Instr. Meth. Phys. Res. A 481, 765 (2002).
[8] J. Dawidowski, J.R. Santisteban, J.R. Granada, Physica B 271, 212 (1999).
[9] F. Kropff, Nucl. Instr. Meth. Phys. Res. A 245, 125, (1986).
[10] G. J. Cuello, A. Fernández Guillermert, G. B. Grad, R. E. Mayer, J. R. Granada, J. Nucl. Mat. 218, 236 (1995).
[11] G. B. Grad, J. J. Pieres, A. Fernández Guillermert, G. J. Cuello, R. E. Mayer, J. R. Granada, Zeits. Metalllk. 86, 395 (1995).
[12] G. B. Grad, J. J. Pieres, A. Fernández Guillermert, G. J. Cuello, J. R. Granada, R. E. Mayer, Physica B 213&214, 433 (1995).
[13] G. B. Grad, A. Fernández Guillermert, G. J. Cuello, Zeits. Metalllk. 87, 721 (1996).
[14] J. Kohlbrecher, W. Wagner, J. Appl. Cryst. 33 804 (2000). See also http://kur.web.psi.ch/sans1/
[15] NEUTRA, Neutron Transmission Radiography, http://neutra.web.psi.ch/facility/
[16] G. J. Cuello, P. J. Prado, J. Dawidowski, Nucl. Instr. Meth. Phys. Res. A 325, 309 (1993).
[17] J. Dawidowski, G. J. Cuello, J. R. Granada, Nucl. Instr. Meth. Phys. Res. A 82, 459 (1993).
[18] J. Dawidowski, J. R. Granada, R. E. Mayer, G. J. Cuello, V. H. Gillette, M.-C. Bellissent-Funel, Physica B 203, 116 (1994).