Neutron Dosimetry and Spectroscopy at LASA-Segré

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INTRODUCTION

- This presentation is an overview of the irradiation facility and of the instrumentation for neutron dosimetry and spectrometry of Gruppo V – INFN at LASA-Segrate (MI):
  - a facility for calibrating neutron detectors and dosimeters is available;
  - moreover, neutron monitors and spectrometers have been developed during the last decades, in collaboration with national and international institutions.

This presentation is an overview of the irradiation facility and of the instrumentation for neutron dosimetry and spectrometry of Gruppo V – INFN at LASA-Segrate (MI).

In particular it is available a facility for calibrating neutron detectors and dosimeters.

Moreover, neutron monitors and spectrometers have been developed during the last decades, in collaboration with national and international institutions.
At LASA the experimental area that at 1980s was occupied by the Superconductive Cyclotron, nowadays running in Catania at LNS, is now divided in areas where different experiments related to the superconductivity, the development of accelerators or to the construction and the Quality Assurance photocathodes realization are carried out.

The part indicated with the red circle is reserved to neutrons measurements and/or to calibration radioprotection detectors.
The calibration facility is equipped:

- in order to host the calibration sources at about 3 m from the ground and from the wall in order to minimize the neutron scattering component;
- a device for positioning the detector to be irradiated, that can be moved along the x direction by a step by step screw computer controlled system;
- a shadow “cone” for assessing the influence of neutron scattering on the irradiated detector.

Starting from the Superconductive Cyclotron project, the studies and the settings of different kind of rem (sievert) counters and spectrometers for the neutron dosimetry in thermal up to GeV neutron energy range were carried out.

The developed, tested and calibrated instrumentation is utilized as at high energy accelerators as at accelerators used in medicine and for neutron dosimetry measurements related to the exposition of the crew to cosmic rays in commercial flights.

All the tests and the calibration of this instrumentation are made at LASA where are available two Am-Be sources of 37 and 3.7 GBq respectively and this calibration facility, completely home-made, that is equipped:

- in order to host the calibration sources at about 3 m from the ground and from the wall to minimize the neutron scattering component;
- a device for positioning the detector to be irradiated, that can be moved along the x direction by a step by step screw computer controlled system;
- a shadow “cone” for assessing the influence of neutron scattering on the irradiated detector.
In this figure is shown the exposure set up from a different point of view in order to give the complete image and the idea of the real dimension of the facility. The two photos are related to the calibration procedure, realized at LASA with our system of N-DOSYS dosimeters, an integrated personal neutron dosimeter system based upon the well-known PADC/CR-39 track-etch technology, manufactured by Radosys Ltd.
• The source can also be inserted in a moderating cylindrical column of 50 cm of diameter and 50 cm of height
• provided with inserts for irradiating samples with thermalized (slowed-down) neutrons:
  ✓ for activation;
  ✓ for measuring the detector sensitivity to thermal neutrons.

The source can also be inserted in this activation home-made facility, realized with a moderating cylindrical column of 50 cm of diameter and 50 cm of height, provided with inserts for irradiating samples with thermalized (slowed-down) neutrons:

*for activation;
*for measuring the detector sensitivity to thermal neutrons.
At LASA, Bonner Spheres Spectrometers – BBS – consisting in a set of moderating spheres of different diameter housing a thermal neutron detector at their centre are realized both in conventional and in the extended to high energy range set up.

In particular:

• a conventional BSS constituted by only polyethylene spheres housing a $^3\text{He}$ proportional counter as thermal neutron detector for assessing neutron spectra from thermal energies up to about 20 MeV;

• a BSS with extended response to high energy neutrons (up to a few GeV). In this case an attenuator shell of high mass number is coupling to the moderator. This high-A shell can be inserted into the moderator or placed around it. A high-energy neutron, inducing an inelastic interaction in the attenuator, generates secondary neutrons: these evaporation neutrons are in the MeV energy range and therefore can be more effectively slowed down by polyethylene, acquiring a higher probability of being captured by the thermal neutron detector. The high-energy peak of neutrons from direct nuclear interactions can be observed at 100 MeV, while the evaporation peak is clearly visible at a few MeV. It is evident the fundamental role for improving the response to high energy neutrons, played by evaporation neutrons.
INSTRUMENTS: BSS

- A BSS configuration allowing to expose all the spheres jointly is also available.
- The electronic signals are sent to a common acquisition system which registers the counts of each sphere.
- This system is intended to reduce the measurement time. Alternatively each sphere has to be exposed separately.
- Of course it should be used where the neutron field is uniform over a wide area.

The conventional BBS is composed by seven Bonner Spheres of different diameter one of which is covered with a Cd shell.

With this configuration all the spheres can be exposed at the same time; the electronic signals are sent to a common acquisition system which registers the counts of each sphere.

A software code, written in LabView, allows to reconstruct the spectrum energy of the neutron field.

This system is intended to reduce the measurement time. Alternatively each sphere has to be exposed separately.

Of course it can be used where the neutron field is uniform over a wide area, like to measure the neutron field in proximity of a medical cyclotron, as was done at Policlinico Hospital of Milano.
A second set of Bonner Spheres is installed at CERN.

In this case we have five polyethylene spheres (81, 108, 133, 178 and 233 mm in diameter) and two additional extended range spheres Stanlio and Ollio.

In this figure are shown the spheres with their respectively aluminum supports, the filler pieces that can be inserted instead of detector, the preamplifier and the electronics that have been realized at the electronic laboratory of LASA. The thermal neutron detector placed at their centre is a Centronics $^3$He proportional counter (type SP9) of a spherical shape.
In this slide are shown the details of the two extended range CERN–BSS, realized with inserts of cadmium and lead.

Are also reported the absolute neutron fluence response functions of all CERN–BSS. In this case each sphere has been exposed separately.

Knowing the response functions of all spheres, the fluence of the neutron field can be reconstructed by unfolding the experimental data.
INSTRUMENTS: BSS

- The fluence can be reconstructed by unfolding the experimental data. This procedure is based on the following system of integral equations:

\[ C_i = \int_{E_{\min}}^{E_{\max}} f_{i,E} \Phi E dE + \varepsilon_i \quad i=1,\ldots,m \]

- It should be underlined that, generally, the unfolding techniques calculate a spectral fluence which maximizes the probability of giving the measured set of count rates \( C_i \).

This procedure is based on the system of integral equations reported in the slide, where:

\( C_i \) is the measured count rate of the thermal neutron detector (or the saturation activity of the activation foil, etc.), \( f_{i,E} \) are the response functions of the spheres, \( \Phi E \) is the unknown spectral fluence, \( \varepsilon_i \) are the experimental uncertainties and ‘m’ is the number of spheres constituting the BSS.

Since the response can only be calculated/measured in discrete values, the system of equations can be rewritten in a discrete form.

There is fairly wide literature on the unfolding of experimental data.

It should be underlined that, generally, the unfolding techniques calculate a spectral fluence which maximizes the probability of giving the measured set of count rates \( C_i \).
When there is the necessity to measure high-energy neutron fields like the ones generated at CERN, it is fundamental to know the BBS response not only to neutrons but also to charged hadrons that should be accounted for when measuring the neutron spectral fluence in the proximity of a target bombarded by a high energy beam. These measurements are intended, for example, for evaluating radiation effects on the electronic instrumentation inside an experimental hall or for shielding studies.

In our case the BSS response to charged hadrons was also calculated with FLUKA simulations.

The CERN-INFN BSS was used for measuring the spectra of secondary neutrons generated by 40 GeV/c positive hadrons striking targets of various materials.

In this case, the secondary particles other than neutrons (mainly protons and pions), which are produced in the target, have sufficient energy to generate further neutrons inside the BSS materials. The high-A shells, which are inserted in the moderator to extend the response to high-energy neutrons, give the main contribution to this additional neutron field, as shown in the slide 7.

The reported figure shows the calculated spectral fluence of the secondary neutrons, protons and pions generated at 30° by a 40-GeV/c beam of positive pions striking a 50-mm thick silver target.

Secondary charged hadrons show a peak above 100 MeV. These high-energy particles are responsible for the additional generation of neutrons in the BSS, which, if not accounted for, give an overestimate of the measured neutron spectral fluence.

In other words, the BSS measures an additional number of neutrons, without knowing that this contribution is generated by particles other than neutrons.
In these figures are reported calculated, with FLUKA simulations, response functions of all the CERN-BSS to charged hadrons (protons, positive and negative pions) and to neutrons, that are used to reconstruct the neutron field.
INSTRUMENTS: AN EXAMPLE OF NEUTRON SPECTROMETRY WITH BSS

- The high-energy peak of the neutron spectral fluence resulted to be overestimated without correcting for the charged hadron contribution (blue curve).
- The agreement with the simulated spectrum (red curve) is satisfactory (black curve) after applying the correction procedure.

In this slide is reported the neutron spectral fluence calculated with FLUKA at 30° from a 50-mm thick silver target bombarded by a 40-GeV/c beam of mixed positive hadrons (80% pions + 20% protons).

The neutron spectral fluence measured without any correction for the additional contribution is shown in the same figure.

The high-energy peak of this uncorrected spectrum results to be overestimated with respect to the simulated one.

The simulated spectrum was used as pre-information in the unfolding procedure.

The agreement is satisfactory when the BSS response to charged hadrons is considered and its contribution to the measured count rate is subtracted.
The measurements at different angles of different series of targets, put on the beam line, by a corresponding neutron detectors with different shielding are possible thanks to a semiautomatic system realized at LASA. The system had to guarantee the movement of the targets on the beam line and of the corresponding detectors on the three axis with a good precision.

The structure is composed by:

- a frame “A” of suitable dimension and shape in order to be positioned on a support previously realized in the measurement bunker of SPS Laboratory at CERN of Ginevra made with aluminum section bars Bosh 45x45 mm;
- an aluminum fan-shaped structure “B”, suitable excavated, in order to reduce the weight but to preserve the maximum strength. The calculated weight of this structure, obtained from a sheet 10 mm thick is of about 8 kg. This structure, suitable constrained to the “A” system, can be moved forward and backward;
- a long staff “C” that at the end becomes wide to support the neutron detector. It is constrained at the centre of circular sector of structure “B” and can rotate up to 120° by 15° step by step in the two directions;
- the structure “D”, hinged in the same potion of “C” in respect of “B”, that can hold the targets and move them up and down, in order to bring them in front of the beam line.
All the system is driven by this control panel, from where it is possible to command the position of the targets and of the detectors and to read and register the information of all the parameters.

The X axis position is obtained by a position linear transducer of very high precision, putted up inside the Bosh bar of the frame “A” and constrained to the rectangular nut of the lead screw.

The reading of the Z axis position is obtained by a multiturn potentiometer with a linear response, whose shaft is keyed by a 4:1 reducer to an electric motor that moves the lead screw and moves the bogie.

The angular position of the detectors (“C”) is showed by a series of leds that light up in sequence with regard to the reached position.
The LASA research group proposed at the end of eighties an extended-range rem counter LINUS for improving the response to high-energy neutrons. This instrument was obtained by modifying the Anderson–Braun (A-R) rem meter.

A 1 cm thick lead layer was inserted between the boron attenuator and the outer polyethylene moderator. So the high-energy neutrons, interacting with the lead layer, generate evaporation neutrons (in the MeV range), which are slowed down by the inner moderator, placed between the boron attenuator and the detector. These slowed-down neutrons can be captured by the thermal neutron detector, improving the rem meter response to high energies.

In the 1990s, a spherical version of the LINUS was constructed, housing a spherical ³He (Centronics SP-9) proportional counter at its centre.

In this slide it is shown the response of the spherical LINUS together with the fluence-to-H*(10) conversion coefficients against neutron energy.

Other extended-range rem meters were constructed following the original LINUS design and a number of models are now commercially available.

It should be underlined that the response of a rem counter to charged hadrons should be taken into account, if measurements are performed close to a target, struck by a high-energy beam, as presented for the BSS.
The research group, with INFN experiments SID, MICROSI, studied and tested, as neutron spectrometer, a monolithic silicon telescope coupled with a polyethylene converter.

The device consists of a $\Delta E$ and an $E$ stage detector (about 2 $\mu$m and 500 $\mu$m in thickness, respectively) fabricated on a single silicon wafer and separated by a p+ common electrode.

The telescope allows the discrimination among the different secondary particles generated by neutrons on the converter (recoil-protons) and secondary electrons from the associated photon field.
The previous described facilities are present at LASA together with some other laboratories.

In particular a Physics Measurements Laboratory where are installed: eight HPGe gamma spectrometers, two alpha spectrometers with a Si surface barrier detector and two different liquid scintillation counting systems - Beckman LD5000 system and the high-resolution α-liquid scintillation with α/β pulse shape analysis (PSA) discrimination - TRIATHLER “multilabel tester”.

The HPGe detectors are filled with a LN$_2$ automatic system based on the reading of the weight of the detectors: the start and stop of filling is driven by the thresholds of maximum and minimum values set on the balances inserted under each dewar. A second alarm is controlled by strain gauges inserted in each cryostats. All the system can be monitored remotely also via internet.
These is the radiometric equipment installed in the Physics Measurements and Radiochemistry laboratories.
The Radiochemistry Laboratory is a Laboratory ISO Class II and UNICEN 7815 classified Controlled (Restricted) Area for the Radioprotection Italian Law. In it, Non Sealed sources of medium activities containing radionuclides of short and medium half life can be manipulated.

Are present:

• aspiration, depression and filtering plant, that is independent from the main building one. In particular the laboratory is divided in two areas with different negative pressure levels (5 + 5 mm of water) with a growing depression from the incoming door to the radiochemistry hoods, which constitute the hot area of the laboratory. A ventilator located on the building roof guarantee a minimum of 10 room changes per hour; the laboratory air system works 24 hour per day all over the year. To control the potential spread of radioactive contamination the air is extracted through the three hoods installed in a single collector and filtered with prefilters and absolute filters. The prefiltered air is completely expelled. The air conditioning and filtering plant is controlled by the central computer of the LASA.

• hydraulic and liquid disposal plant: two different liquid discharge pipelines, a "cold pipeline" and a "suspect pipeline" are available. A washing machine, fed with mineralized water, and an emergency shower are also connected to the same pipeline. The suspect waters are conveyed to a tank pit located outside the laboratory. These effluents can be discharged in the pipeline of the main building after radioactive monitoring.

• Security and monitoring systems: in order to entry the laboratory it is necessary to pass trough an armored door. Outside the laboratory are available the personnel dosimeters, two emergency masks with compressed air. The decontamination area is equipped with an hands and fits monitor, elbow sink and decontamination shower.
Any radioactive sample manipulation is authorized by the Qualified Expert of LASA.

The walls with rounded edges are coated up to a 180 cm height with PVC and the remain parts and the ceilings are painted by decontaminable paint.

Benches and hoods are coated with AISI 316L to facilitate the decontamination.

The radiochemistry hoods (ASEM) are coated with sealed PP, their working planes are shielded with 10 mm Pb and have a removable stainless steel basin.

One hood is equipped with a 100 mm Pb shield and a 30 mm Pb equivalent sliding glass. The hoods are connected together with SAS system and equipped with porthole in order to be used as glove boxes. The glasses of the hoods are coated with anti-explosion film.

Large activity can be monitored under the hoods with a well type ionization chamber and NaI detector.

In the hoods area a radioactivity environmental monitor is installed other than a portable station for air sampling.
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