NEURAPID

NEutron RAPId Diagnostics

2015 Activity Report

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See website **https://sites.google.com/site/csn5neurapid/** for more details

1. *Project introduction*

NEURAPID has the objective of developing instruments to measure neutron spectra in “emerging” fields, i.e. those fields where the neutron detection is made especially difficult due to the following aspects

- **Very low fluence fields**: fields with very low fluence rate such as the neutron component of the cosmic rays at ground level. Cosmic ray field at ground level is characterized by:
  - a continuous spectrum ranging from thermal up to GeV neutrons (12 orders of magnitude in energy)
  - a very low fluence rate, in the order of 10^{-2} cm^{-2} s^{-1} (integrated on the whole energy interval). This constraint opens serious problems of detector efficiency, especially when a complete spectrum measurement is expected to be performed in minutes. This is the case of the GLE (Ground Level Enhancement) detection. Real-time detection of GLE with ground-based instruments has substantial impact on aircrew radiation protection and prevention of failures in electronic equipments of aircrafts.

- **SPF (Single Pulse Fields):** fields with “extreme” pulsed structure, such a single pulses with femtosecond duration. Examples are the neutron fields produced by bombarding suitable gaseous or solid targets with ultra-intense (TW-PW) / ultrashort (fs) lasers

  SPF environments present:
  - more than 10 order of magnitudes in neutron energy.
  - An expected spectrum-integrated fluence per pulse in the order of 10^2-10^5 cm^{-2}/shot. In this case a major measurement problem is the very shot pulse duration (fs), likely to cause serious pile-up problems in any combination of active detector + analog electronics.

Major scientific challenges of NERAPID are:

Challenge 1.

Measuring a neutron spectrum over more than ten order of magnitudes in energy (from thermal up to GeV). This problem is in common to cosmic ray and SPF environments, and a validated solution consists in thespectrometer geometries CYSP and SP^2 developed and tested already in the NESCOFI@BTF project (2011-2013).

Challenge 2.

Measure thermal neutrons with the highest possible efficiency. This is needed to
- speed up measurements in very low intensity fields

- collect the maximum possible amout of information about a "single pulse" of neutrons With respect to the one-cm^2 thermal neutron detectors established within NESCOFI, a major technology challenge is to increase the thermal neutron efficiency, of more than a factor of ten.

Challenge 3.

Developing efficient thermal neutron counting system for pulses of 10^2-10^5 cm^{-2}/shot, which would cause serious pile-up problems in any combination of active detector + analog electronics. After thermalization in the polyethylene, an ultra-short pulse of neutrons will be spread over tens of microseconds (dye-away time). However, even if the detector pulses are shaped to fractions of microsecond, there is still a serious risk of pile-up for the stated values of fluence per pulse. A solution was proposed including the use of **large-area semiconductors** covered with ^{6}Li compounds, connected to a fast electronics: the NEURAPID group has experience in designing multi-detector analog boards for nuclear spectroscopy, including for every detector (one channel) a bias regulator, a charge pre-amplifier chosen according to the electric characteristics of the detector, and Gaussian-shaper amplifier. Dedicated multi-detector boards will be developed using short shaping times (250 ns or lower), and the analog signal will be digitally filtered and sampled with high-speed digitizers (50 MS/s or more).

A thermal neutron field with uniform flux profile over a large area (as large as several tens of cm^2) is needed for testing and calibration purposes.

Being the efficiency of the large area thermal neutron detector a key-issue, this should be measured as accurately as possible. Therefore this thermal neutron field should have metrological quality.

With this philosophy, the development of large-area and highly uniform thermal neutron fields was included among project's activities. Three thermal neutron facilities base don this design were designed and set up is three different collaborating Institutes: **ETHERNES** (Extended THERmal NEutron Source) at INFN-LNF, **HOTNES** (HOmogeneous Thermal NEutron Source) at ENEA-Frascati, and **ESTHER** (Extended Source of THERmal neutrons) at Politecnico di Milano.

2. Prototypes to be developed

a. Large area thermal neutron detectors (LATND)
b. Large-area and highly uniform thermal neutron fields
c. CYSP-C (Cosmic) (*)
d. CYSP-P (Pulse) (*)
e. SPEEDY

(*) CYSP means a cylindrical moderating structure embedding up to ten thermal neutron detectors and showing spectrometric capability along a specific direction, identified by a collimator. A CYSP prototype equipped with one-cm^2 Silicon diodes covered with ^{6}LiF was successfully tested during NESCOFI).

For cosmic rays application:

CYSP-C will be able to accumulate sufficient information to compute a whole neutron spectrum (eV-to-GeV) in approx. one hour of acquisition at flux in the order of 0.01 cm-2 s-1.

For single-pulse neutron fields (such as lasers):
CYSP-P will perfom neutron spectrometry in specific direction of interest
SPEEDY will perform area monitor measurements with isotropic response. It will be a spherical device and will contain one or more thermal neutron detectors.

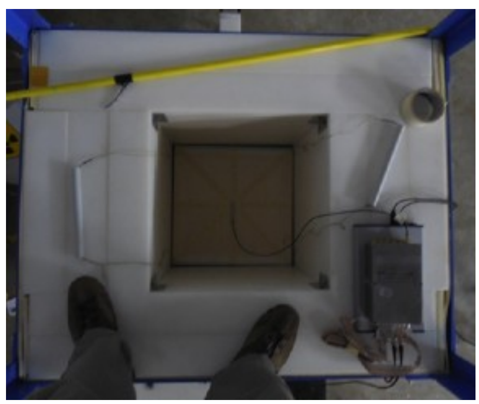
CYSP-C, CYSP-P and SPEEDY will take advantage of well-established single-moderator multiple-detector geometries developed in NESCOFI and applied to the CYSP and SP^2 instruments. However, for the three new devices, new thermal neutron detectors with large area (LATND) need to be developed in the framework of NEURAPID.

3 2015 Activities

3.1 Setting up large area thermal neutron calibration facilities

3.1.1 ETHERNES @ INFN-LNF

Lateral view of ETHERNES.



ETHERNES irradiation cavity (45 x 45 x h=63 cm^3), from top.

See 2014 annual report for design and relative thermal neutron measurements, performed using the TNPD type detectors from NESCOFI@BTF project [1].

Absolute thermal flux measurements were performed with the gold-foils technique, including a metrology inter comparison about gold activity measurements with the NPL (National Metrology Institute of UK) in the framework of a collaborative research on thermal neutron standards.

Activated gold foils with different sizes (diameter 1 cm x 10 micron thickness, diameter 1.128 cm x 50

micron thickness) were measured both at INFN / ENEA Frascati (with Hp-Ge detector) and at NPL, always obtaining differences lower than 1%.
On this basis, the thermal fluence rate at the reference plane of ETHERNES (15 cm from lead bottom) was determined as follows.

The exposure was performed without the polyethylene ceiling to produce an almost parallel beam.

Foil parameters and exposure details

	Bare foil	Cd covered foil
Mass	35.01 mg	36.04 mg
Radius	7.5 mm	7.5 mm
Mass per unit area	19.81 mg.cm-2	20.39 mg.cm-2
Start of 1st irradiation	12:02 9/1/15	12:02 9/1/15
End of 1st irradiation	13:33 12/1/15	09:25 14/1/15

The counting was performed in a HGPe spectrometer in contact geometry, with measured efficiency 0.0678 (unc. 1%, k=1). The efficiency in contact was determined on the basis of the efficiency measured at 6 cm with a point ^{152}Eu source (411 keV line).
A formalism similar to NPL report DQL RN008 was adopted to determine $F_w(th)$ and is reported below.

$F_w(th)$ = sub-cadmium cut off fluence rate in the Westcott convention
= conventional thermal fluence rate

$$F_w(th) = F_c\,(As_{bare} - As_{Cd}\,F_b/F_a) / (N\,\sigma_{Au}\,g)$$

As_{bare} = specific saturated activity in the bare foil
As_{Cd} = specific saturated activity in the Cd-covered foil
N = atoms per gram (Navogadro / AW)
AW = Atomic weight Au
g = Westcott factor

Parameters derived using a fully detailed Monte Carlo simulation (MCNPX) of the facility

F_a = corrects for the incomplete thermal neutron attenuation in Cd cover =
= $1+ (rr)_{ipo,Au,Cd} / (rr)_{epi,Au,Cd}$
= 1.003 (unc. 0.02% k=1)
(rr = reaction rate)

F_b	= corrects for the epithermal neutron attenuation in Cd cover
	$= (rr)_{epi,Au,Cd} / (rr)_{epi,Au,Cd}$
	= 1.014 (unc. 0.6% k=1)
F_c	= corrects for self absorption of thermal neutrons in Au foil
	$= (rr)_{ipo,VAC,bare} / (rr)_{ipo,Au,bare}$
	= 1.015 (unc. 0.2% k=1)
T	= effective maxwellian temperature (K)
	= 313±2

Physical constants values

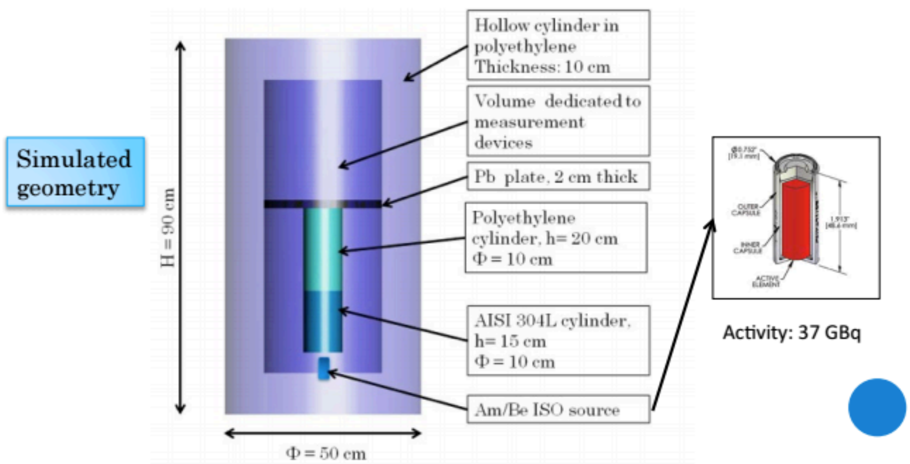
σ_{Au}	98.69 barns
AW, Atomic weight Au	196.97
Westcott g	1.0046
Avogadro number	6.02214E+23 mol^{-1}

Specific saturated activities and fluence rates

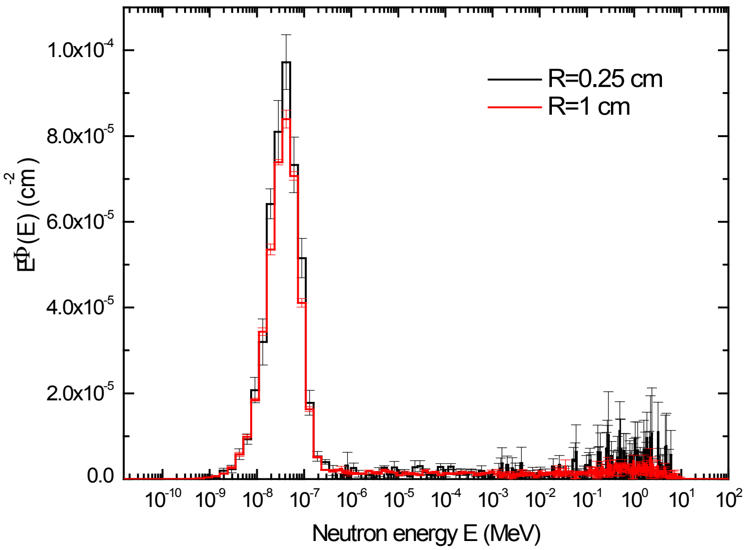
As_{bare}	187.85 (unc. 1.4% k=1) Bq/g
As_{Cd}	25.84 (unc. 3.7% k=1) Bq/g
$F_w(th)$	541 (unc. 1.8% k=1) cm-2 s-1

3.1.2 ESTHER (Extended Source of THERmal neutrons) @ Politecnico di Milano

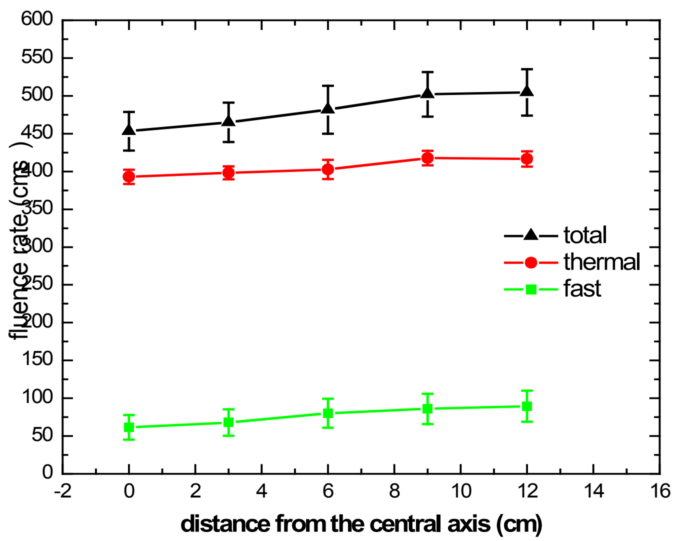
The ESTHER facility has cylindrical geometry, as described in Figure, and uses a 1 Ci Am-Be source. Achievable thermal fluence rates are in the order of 400 $cm^{-2}s^{-1}$ (according to chosen irradiation plane) in a homogeneity area of 30 cm in diameter.



Details of the Monte Carlo simulation (FLUKA) and practical facility.



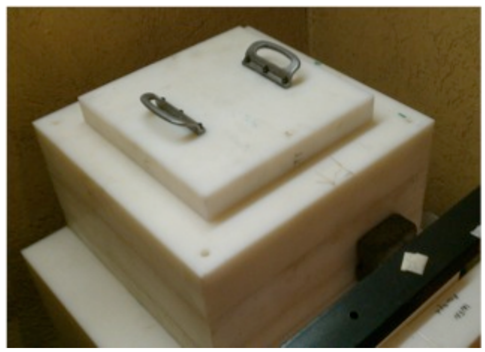
Neutron Spectrum in ESTHER at 5 cm from the lead bottom.



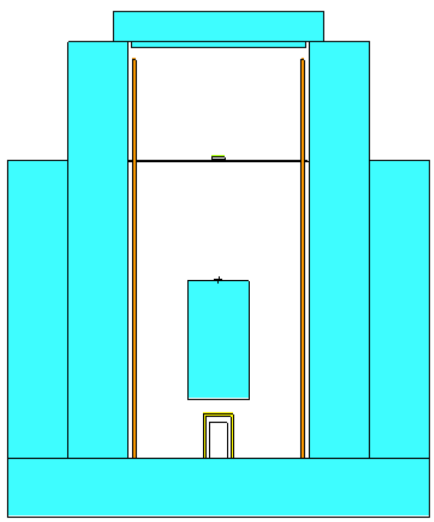
Thermal fluence rate in ESTHER, at 5 cm from the lead bottom, as a function of the radial position.

3.1.3 HOTNES (HOmogeneous Thermal NEutron Source) @ ENEA Frascati

The joint INFN-LNF / ENEA Frascati thermal neutron facility, called HOTNES, has cylindrical irradiation cavity. Irradiation planes, where the thermal flux is uniform within 1% or less, are defined as disks parallel to the cavity bottom. As shown in Figure, a cylindrical (20 cm height x 10 cm diameter) shadow object prevent neutrons directly emitted by the source to reach the irradiation planes. The irradiation cavity has 30 cm diameter and 40 cm height. A polyethylene ceiling is used to produce an almost isotropic field. By removing the ceiling, a nearly parallel beam is achieved. The facility includes a 10 Ci Am-B source surrounded by a 5 mm thick lead photon shield.



Picture of the HOTNES facility.



Longitudinal cross cut of HOTNES

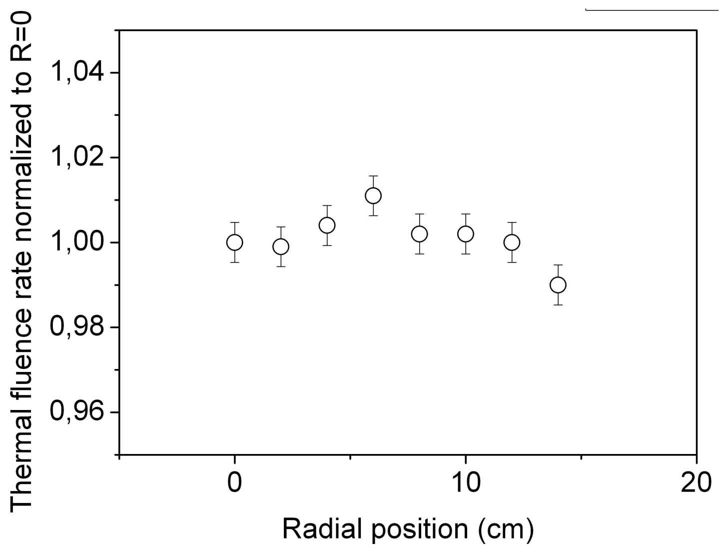
Absolute thermal flux measurements were performed with the gold-foils technique, by both INFN and NPL (National Metrology Institute of UK), using the formalism described in 3.1.1. The reference plane to which these measurements refer is +50 cm from facility bottom (about 20 cm above the shadow cylinder). Here a resume of the measurements:

HOTNES, plane +50 cm. Fluence rates (F_w(th)) obtained by INFN and NPL for different foil sizes. Uncertainties are in the order of 2%.

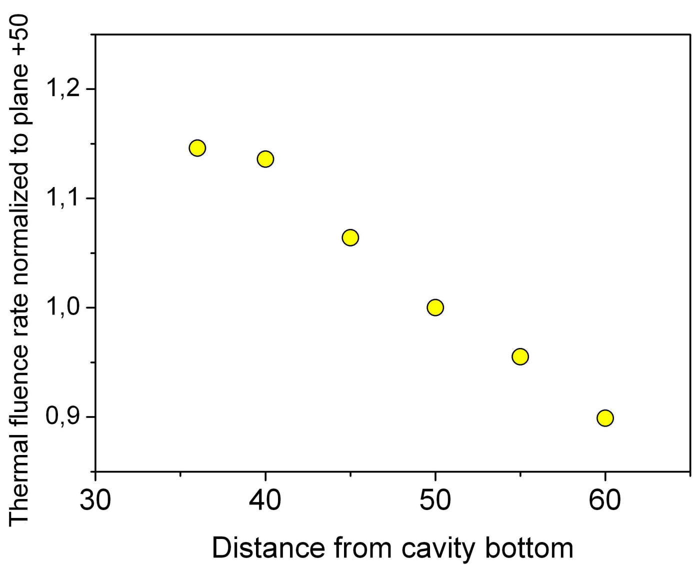
INFN	10 micron thickness x 1.5 cm diam	758 cm^{-2} s^{-1}
	50 micron thickness x 1.128 cm diam	768 cm^{-2} s^{-1}
NPL	50 micron thickness x 1.128 cm diam	770 cm^{-2} s^{-1}

In following Figures:

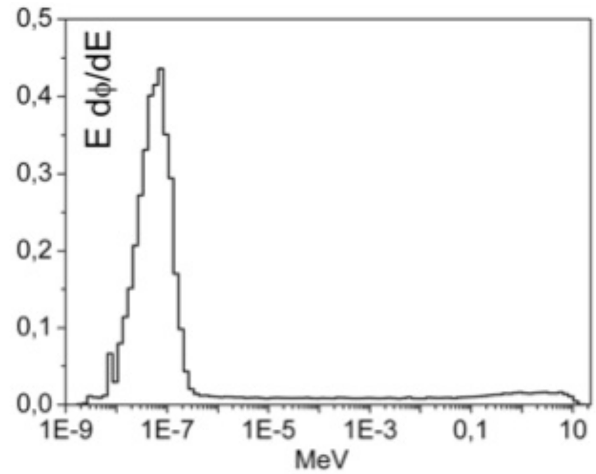
- the measured homogeneity plot for plane +50. The thermal fluence rate is homogeneous within 1%.
- measured vertical thermal flux profile in HOTNES. In the linear region, the flux change is about -1% cm^{-1}
- the simulated neutron spectrum at the centre of plane +50 cm.



Measured homogeneity plot for plane +50



Vertical thermal flux profile in HOTNES. In the linear region, the flux change is about -1% cm^{-1}.



Simulated neutron spectrum at the centre of plane +50 cm. The thermal fraction is 90% ore higher, depending on the irradiation plane.

The photon component of the field in the HOTNES cavity was measured by means of a compensated Geiger counter (GM-2 from Far West Technology), having flat response in air kerma from 70 keV to 2 MeV. To achieve the insensitivity to neutrons, the counter was covered with a 6LiF shield.
The instrument was calibrated using reference ^{137}Cs and ^{60}Co fields from collimated point sources.
The calibration factors are:

Calibration Factor to ^{137}Cs N(Cs) = 183 counts / μGy

Calibration Factor to ^{60}Co N(Co) = 207 counts / μGy

Uncertainties on calibration factors are 5%, corresponding to the uncertainty on the reference air kerma from the collimated fields.
By applying the ^{60}Co calibration factor, the photon air kerma rate in HOTNES cavity ranges from 9 μGy/h (plane +40 cm) to 4 μGy/h (plane +60 cm).

3.2 Fabricating the LATND Large Area Thermal Neutron Detectors

The LATNDs were developed by depositing with 30 micron of ^{6}LiF (optimal thickness) a 2.8 cm x 2.8 cm p-i-n silicon diode. The sensitive covered area is about 7.84 cm^2. The sensitivity of this configuration can be doubled by coupling two diodes to the same deposit, thus achieving a sensitive covered area of 15.6 cm^2.
In Figure: a single LATND after deposition and assembled pairs of LATNDs.

Single LATND after deposition and assembled pairs of LATNDs.

As low as possible bias voltage was chosen to achieve a good photon-to-neutron discrimination capability but, at the same time, to preserve the maximum efficiency. Signal processing was performed using specially manufactured boards, including for every detector a bias regulator, a charge pre-amplifier and a Gaussian-shaper amplifier (2 μs time constant). The data were acquired on a PC through a commercial 2 MS/s digitizer. Calibrations were done at the reference position in ETHERNES (centre of irradiation plane at reference height 15 cm from cavity bottom).

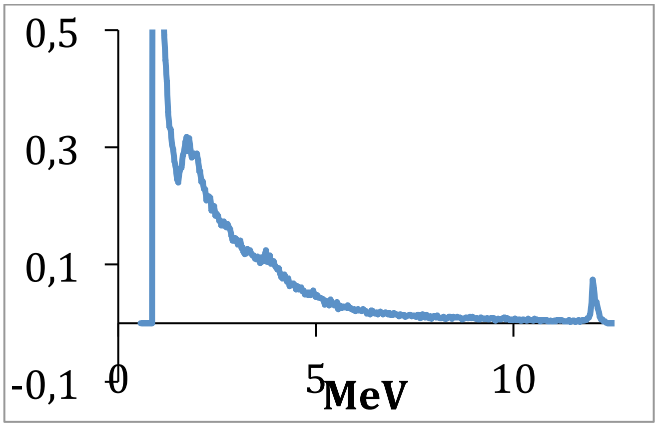
The thermal neutron response (counts per unit thermal fluence) of one cm^2 is 3%, thus a LATND of 7.84 cm^2 has 23% response and a double-diode with 15.6 cm^2 area has 46% response.

3.3 Radiation Tolerance test at 14.8 MeV (ENEA-FNG)

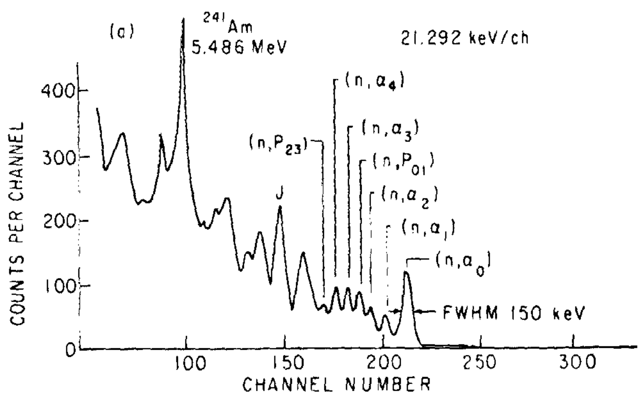
On July 7th 2015 a radiation tolerance test with 14.8 MeV neutrons was performed on one of the thermal neutron detectors achieved by depositing 30 microns of 6LiF on a p-i-n silicon diode. It is known that thermal neutrons are less effective than fast neutrons in radiation damage, but fast neutrons are always present in fields where the instruments CYSP and SPEEDY will operate. Thus a fast neutron tolerance level may be very useful to estimate the expected life of an instrument in a given operational workplace, especially for those instruments that will work in accelerator or laser environments.

The chosen facility was the Fast Neutron Generator on ENEA Frascati, where 14.8 MeV neutron are emitted in the forward direction from the target. The detector was placed at 2 cm from the target in this direction and a 5 min spectrum of (fast-n,alpha) in silicon, obtained at low accelerating current, was registered every 20 minutes of "hard" irradiation at maximum current. The total 14.8 MeV fluence delivered to the detector was 2E+12 cm^{-2}, which degraded the detector response. The intermediate spectra allow appreciating how the radiation response changes along the irradiation.

The spectrum from the virgin detector exposed to 14.8 MeV neutrons shows, at low Energy (about 2 MeV), the peaks corresponding to the maximum ^{28}Si recoil energies from elastic (2 MeV) and first excited state inelastic (1.7 MeV). At higher energy the (n,alpha0) level (12.1 MeV) is observed between 11 and 12 MeV.



Pulse height distribution of 14.8 MeV neutrons in Silicon detector, 1 cm x 1 cm, +12 V bias. Data obtained for a virgin detector, non deposited.



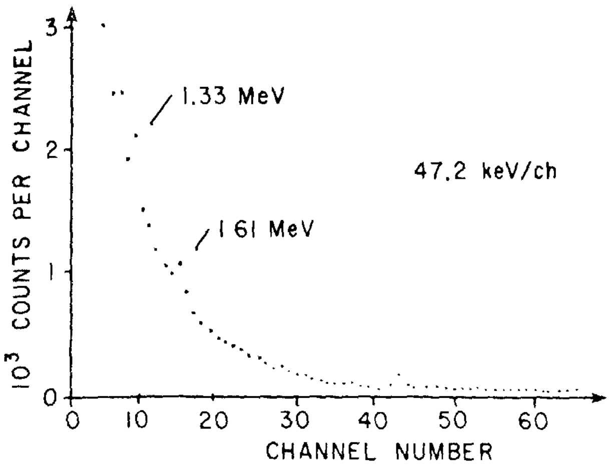
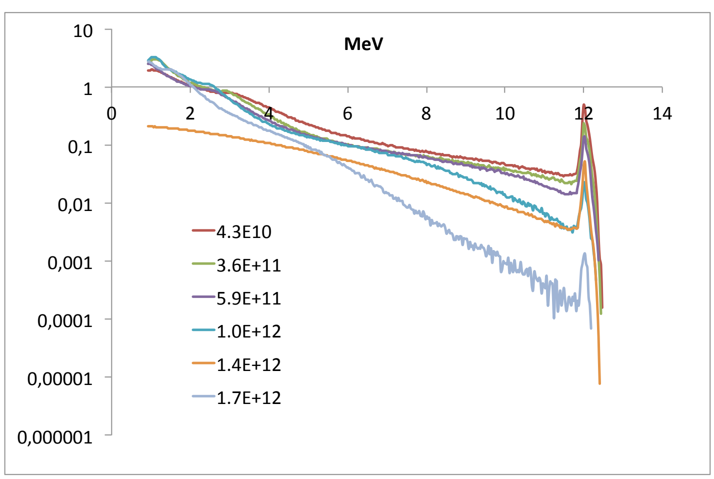


FIG. 2. Low pulse-height region of a Si-detector spectrum, showing steep increases in count rate at low energies due to elastic and inelastic scattering, gamma rays, and low-energy neutrons. The energies of the indicated peaks correspond to the cutoffs produced by the elastic and inelastic scattering of neutrons from the ^{28}Si ground and first excited states[4] for 14.0-MeV incident neutrons.

Literature spectrum of 14 MeV neutrons on Silicon detector. Elevant, T. et al., Rev. Sci. Instr. 57 (1986) 1763.

Increasing the accumulated 14.8 MeV neutron fluence produce degradation in the spectrum as shown in Figure. As shown in literature, a fluence of 1E+12 cm^{-2} certainly damage the detector, but its response start damaging at few E+11 cm^{-2}.

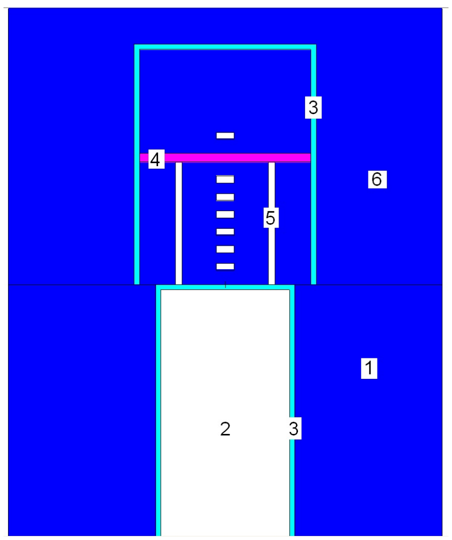


Spectrum degradation as a function of the accumulated 14.8 MeV neutron fluence. Silicon detector, 1 cm x 1 cm. Data obtained for a virgin non deposited detector.

3.4 Fabricating CYSP-P and CYSP-C

The design of the cylindrical spectrometer CYSP was adapted to allocate large area thermal neutron detectors LATNDs. On the basis of the current status of the studies to define the final structure of the LATND, we assumed a 3 cm x 3 cm silicon-based sensitive area covered with a prompt (6LiF) radiator, corresponding to the largest format for commercially available windowless p-i-n diodes. The final objective is to arrange two 3x3 Silicon detectors in a sandwich structure, with the radiator in the middle.

To date, there are no reasons to differentiate the structure of the CYSP-C from that of CYSP-P, because in both cases one or two 3x3 Silicon detectors will be used to register the particles from a radiator.

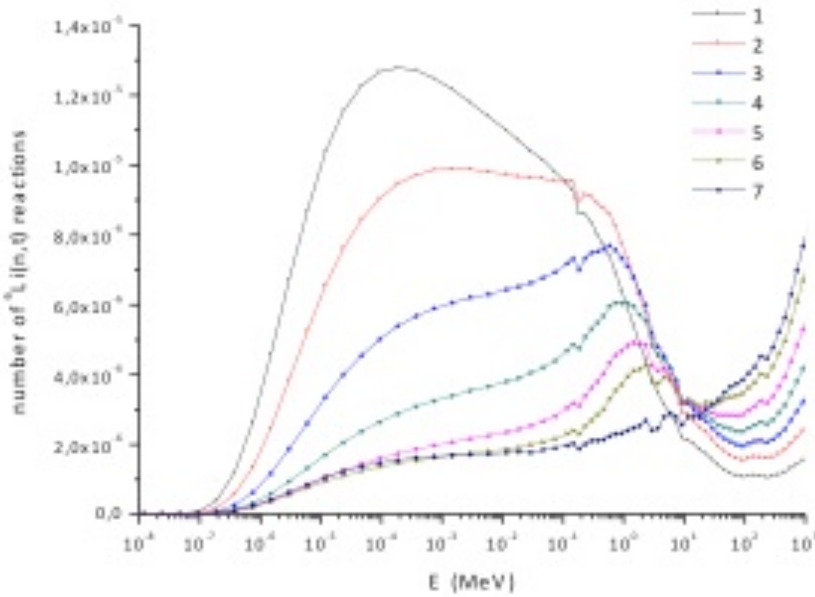


CYSP general design.

CYSP is a HDPE cylinder with overall diameter 50 cm and total length 65 cm. The dimensions of the cylinder as well as the location of detectors have been chosen to maximize the "spectrometric capability" of the device, i.e. the degree of differentiation between the response functions associated to different detector positions. The collimator (label 1) is 30 cm in length and its collimating hole (label 2), 16 cm in diameter, is covered by 5 mm of borated plastic. The seven thermal neutron detectors, located along the cylindrical axis, are contained in a HDPE capsule (20 cm in diameter, 30 cm in length). An external shield made of 5 mm of SWX-238 (label 3) plus 15 cm of HDPE (label 6) protects the sensitive capsule from lateral contributions over a broad energy range. A one cm thick, 20 cm in diameter, lead disk (label 4), has been inserted between 6^{th} and 7^{th} positions to increase the response to high-energy neutrons. The distance between two adjacent detector cavities is 2 cm (centre to centre). The seven detectors are located at depths 4, 6, 8, 10, 12, 14 and 21 cm from the end of the collimator. The latter is located under the one-cm lead filter.

Label 5 symbolizes eight cylindrical air cavities, one cm in diameter, designed to enhance neutron streaming towards the deeper detectors.

The HDPE capsule was dimensioned to allocate LATNDs made of a 2.8 cm x 2.8 cm silicon diode coupled with a thermal neutron radiator.



Response matrix of the CYSP-C / -P with 2.8 x 2.8cm^2 silicon diodes covered with 30 microns of 6LiF, expressed in number of n,t reactions per unit fluence.

<u>3.5 Fabricating the SPEEDY detector</u>

The SPEEDY detector is a 22 cm diameter spherical device with an internal cavity (4 cm height x 4 cm diameter) to allocate a double LATND, see Figure. For detector testing, see 3.6.

The SPEEDY detector, made of a 22 cm diameter sphere, and the detector cylindrical insert (detector cavity: 4 cm height x 4 cm diameter).

3.6 Measurements in pulsed neutron fields

Testing the LATND in a sharply pulsed thermal neutron field mimics the situation that a complete CYSP-C / -P or SPEEDY instrument will experience when exposed to pulsed fast neutron fields. This simplified configuration will help to understanding the limits of the elementary thermal neutron sensor. A large variety of pulsed thermal fields with different **fluence per pulse, pulse duration and repetition rate** are desirable to perform this test, but unfortunately it is quite difficult to find workplace fields where these three parameters are known. Two workplace fields were identified:

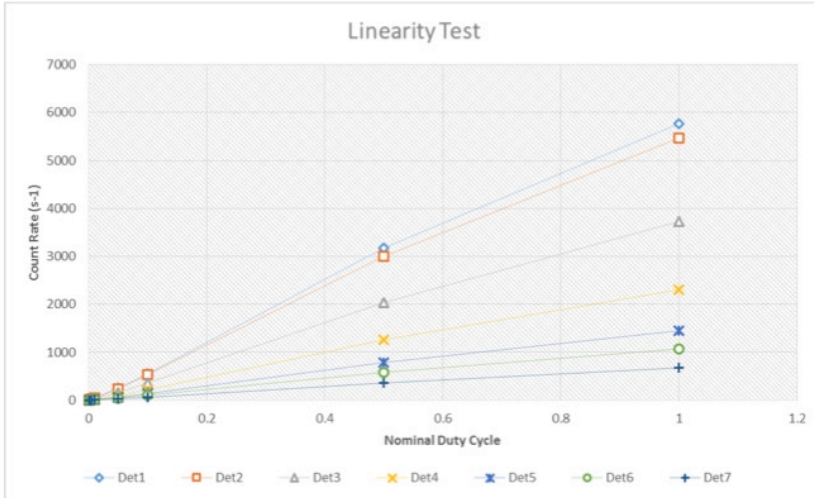
(1) Epithermal neutron field at SARAF facility (SOREQ Nuclear Centre, Israel)

In the framework of the ABNP2014 workshop (Legnaro, 2014), NEURAPID received an endorsement from the SOREQ Nuclear centre, Israel, where intense neutron fields from hundreds keV up to 2.5 MeV (maximum energy) are achieved by bombarding thin (solid) or thick (liquid) Lithium targets with protons from 2.1 MeV to 4 MeV. The proton current can be varied, according to the target type, from few hundred nA up to 2 mA. The beam time structure can be varied from continuous CW beam up to few Hz. Undertaking a test with the CYSP spectrometer in a fixed set-up (3 MeV protons on Liquid Lithium target), but varying the time structure, will greatly help in understanding the limits of the acquisition system.

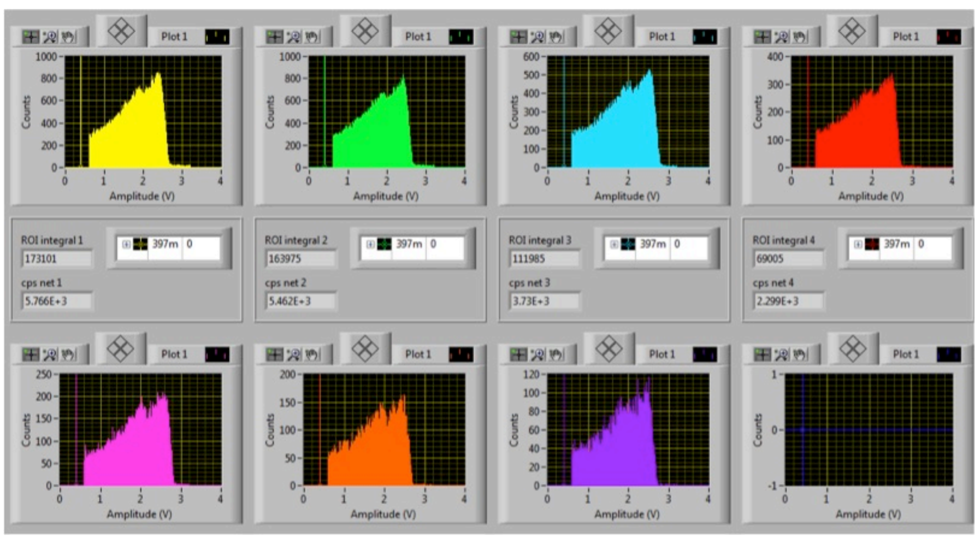
A measurement campaign with the CYSP instrument took place in September 2015. The instrument was placed at about 160 cm from the beam port, at 0° from a Liquid Lithium target receiving 1920 keV protons. The following combinations of pulse duration and repetition rate were set up, to achieve duty cycles from 0.001 (0.1 ms at 10 Hz) up to 1 (CW):

500 microA, 0.1 ms, 10-50-100-500 Hz
500 microA, 1 ms, 10-50-100-500 Hz
500 microA, 10 ms, 10-50-100 Hz
500 microA, 0.01 ms, 500 Hz
500 microA, CW

The nominal neutron fluence rate at the point of test was in the order of 6E+3 $cm^{-2}s^{-1}$ (500 microA, CW). The count rate in the detector at different positions within the CYSP structure are reported in Figure, as a function of the beam duty cycle.
The instrument response is fully linear as a function of the duty cycle.



Count rate in the detectors at different positions within the CYSP structure, as a function of the beam duty cycle. Pulses are processed using CREMAT CR-110 charge preamplifiers and CR200 (2 microsec) amplifiers.

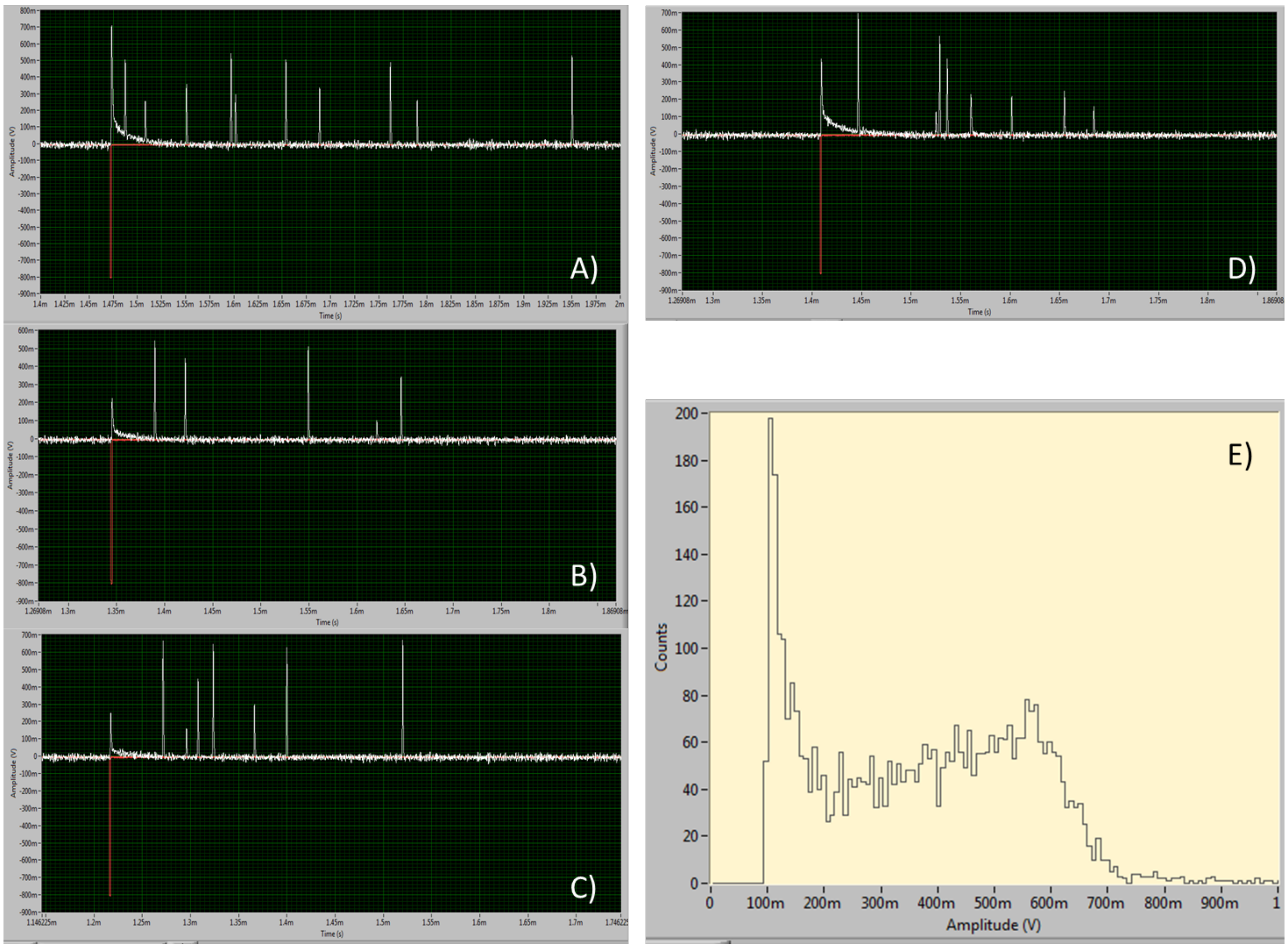


Pulse height distributions in the detectors located at different depths in the CYSP structure. The spectrum shape is the same as observed in continuous fields from calibration sources.

<u>(2) n@BTF neutron facility at INFN-LNF</u>

The detector SPEEDY, equipped with a pair of LATNDs, was irradiated in the n@BTF pulsed fast neutron beam at 130 cm from the neutron emitting target, in the 90° direction from the incident 510 MeV electron beam [2]. Beam time structure was 10 ns pulse duration, 2 Hz, about 2E+8 electrons/pulse. The detector was exposed to a neutron fluence of about 130 cm^{-2} per pulse. The LATND pair was acquired with a CREMAT CR-111 charge preamplifier followed by a 250 ns CR-110 amplifier.

See results in Figure. Evidently, the instrument is able to correctly see the pulses with no pile-up. Moderation process promotes time spreading of events in the central detector.



In A-D: Typical time distribution of pulses in the SPEEDY central detector for single BTF pulses (10 ns duration, in red). In E, pulse height distribution of the measured pulses. The spectrum does not differ from spectra obtained with continuous beams.

3.7 Spectrum measurements at ROMA3 SVIRCO cosmic neutrons observatory

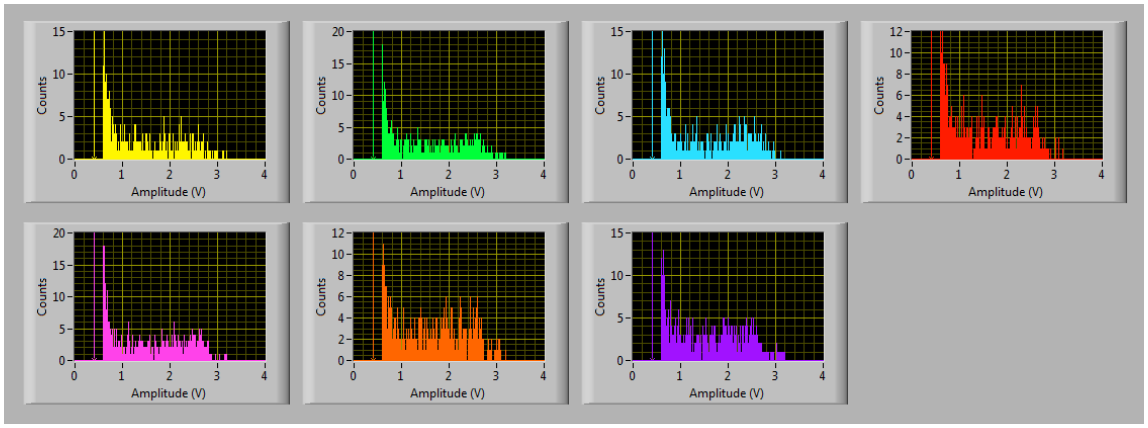
To better understanding the problems connected with long-term acquisitions, as will be the case of cosmic neutron measurements with CYSP-C, a test was performed with the current CYSP (equipped with 1 cm^2 LiF covered single diodes) exposed at the SVIRCO cosmic-ray measurement station of Roma 3 University, see Figure below.

The CYSP exposed to the vertical component of the cosmic-ray-induced neutron field at SVIRCO, Roma 3.

The acquisition finally took place from 5th December 2014 to 28th May 2015 for a total number of 2716 acquired hours. The following safety aspects were established to guarantee a stable long-term acquisition together with a minimum number of interventions required.

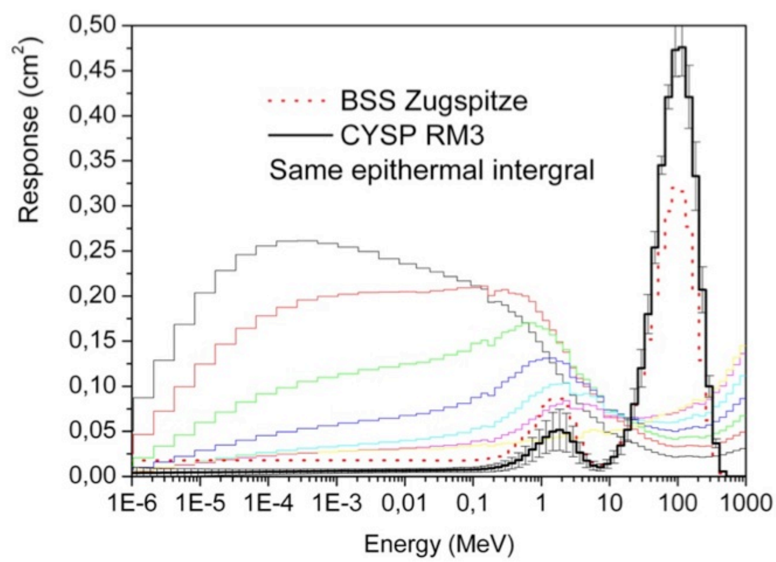
- very stable DC supply for electronics, achieved through additional energy supplies (UPS).
- remote control of equipments, vis TeamViever

The following are pulse height distributions of TNDs of type TNPD located in the seven positions of the traditional CYSP geometry. TNPD is the 1st generation of thermal neutron pulse detector, i.e. one cm^2 windowless silicon p-i-n diode covered with optimal thickness of 6LiF (30 μm). Position 1 (yellow) is the shallowest position, whilst position 7 (purple) the deepest one. See Para. 3.5 for details on CYSP structure and detector positions. The counting threshold is fixed at 0.6 V and corresponds to the valley between the secondary electron tail (initial portion of the spectrum) and the alpha and triton peaks (broad peak ending at 3 V).



Position 1 – Total counts above threshold 514
Position 2 – 630
Position 3 – 610
Position 4 – 671
Position 5 – 725
Position 6 – 710
Position 7 – 801

See in following Figure the unfolded neutron spectrum, using the FRUIT code [3,4]. Spectrum-integrated quantities are reported below.



In black: Unfolded neutron spectrum at the Roma 3 SVIRCO station (in lethargy representation and normalized to fit scale). In red: guess spectrum (from literature). In colour: CYSP response matrix

Fluence rate 0.0058 ± 0.0002 cm-2s-1

H*(10) rate 6.6 nSv/h

Mean energy 90 MeV

3.8. Collaborations

- CIEMAT Madrid: 35,000 equiv-hours CPU time on EULER cluster for response matrix calculations
- Roma3 University, support for CYSP cosmic measurement test.
- Politecnico di Milano: support for electronics design and testing. Use of ESTHER thermal neutron facility.
- LNF support: 2 man*month at mechanical workshop.
- Universidad de Sevilla (Spain): irradiation tests in medical linacs to study parasitic photon response of neutron detectors based on Silicon diodes covered by 6LiF radiators.
- ENEA FRASCATI: support to build HOTNES thermal neutron facility.

3.9 *Meetings, workshops and conferences*

(See website for downloading agendas, posters and presentations)

Project meetings

INFN-LNF, 13 March 2015

INFN-LNF, 28-29 September 2015

Workshops

17 February, 2015: Mini workshop acceleratori CSN 5 LNL-INFN. Poster "Monitoring accelerator-based neutron sources with spectrometric devices operating from thermal to GeV"

12-15 May 2015. INFN Laboratori Nazionali di Legnaro. 5th International Meeting of Union for Compact Accelerator-Driven Neutron Sources (UCANS). Poster "Innovative solutions for neutron beam monitoring"

Conferences and seminars

20-24 April, Bruges, Belgium. International Conference for Individual monitoring of Ionising Radiation. ORAL PRESENTATION: "A single-exposure, multi-detector neutron spectrometer for workplace monitoring". R Bedogni, D Bortot, B Buonomo, A Esposito, J M Gómez-Ros, M V Introini, G Mazzitelli, M Moraleda, A Pola and A M Romero. **BEST PRESENTATION AWARD**

23-26 June. 4° Congreso Conjunto 20SEFM/15SEPR (sociededes espanolas de Fisica Medica y de Proteccion Radiologica), Valencia. Poster Contribution DMR-31: "Desarrollo de dos nuevos espectrometros de neutrones basados en multiples detectores activos".

8-12 June. Budva, Montenegro. Third Conference on radiation and applications in various fields of research (RAD2015) with two oral presentations:

- CYSP and SP^2: novel instruments for continuous spectrometric monitoring of neutron producing facilities.
- New devices to determine field and dosimetric quantities in radiotherapy.

10 September 2015, SOREQ Nuclear Research Centre (Israel). Invited Seminar: R. Bedogni, A. Pola, J.M. Gomez-Ros, D. Bortot, M.V. Introini, A. Gentile, M. Costa, V. Monti. Neutron spectrometry with single-moderator instruments.

20 October, NPL (Teddington, UK). NPL Neutron Users Club meeting. Invited talk "Novel neutron spectrometers based on a single moderator".

8 October, Roma 3 University (Rome). Invited Seminar "Neutron spectrum measurements at SVIRCO observatory using the CYlindrical SPectrometer CYSP".

12 October, Frascati (Rome). Participation to the workshop RAIN15 (Radiazione per l'Innovazione, 12-13 October 2015). Talk: "The ETHERNES neutron facility: innovative way to produce thermal fields".

December 5-6, 2015, 11th International Workshop on Ionizing Radiaiton Monitoring, OARAI, Japan. Invited Talk "Development of active single moderator instrumentsfor neutron monitoring" (J.M. Gomez-Ros).

3.10 *Web-site*

https://sites.google.com/site/csn5neurapid/

3.11 *2015 Publications*

1. Bedogni, R.; Gomez-Ros, J. M.; Pola, A.; Bortot, D.; Gentile, A.; Introini, M. V.; Buonomo, B.; Lorenzoli, M.; Mazzitelli, M.; Sacco, D. Experimental test of a newly developed single-moderator, multi-detector, directional neutron spectrometer in reference monochromatic fields from 144 keV to 16.5 MeV. NIM A 782 (2015) 35-39.

2. Bedogni, R.; Bortot, D.; Pola, A.; Introini, M. V.; Lorenzoli, M.; Gomez-Ros, J. M.; Sacco, D.; Esposito, A.; Gentile, A.; Buonomo, B.; Palomba, M.; Grossi, A. Experimental characterization of semiconductor-based thermal neutron detectors. NIM A 780 (2015) 51-54.

3. Bedogni, R.; Gomez-Ros, J. M.; Bortot, D.; et al. Neutron spectrometry from thermal energies to GeV with single-moderator instruments. EPJ PLUS 130 (2) Article Number: 24 .

4. J.M. Gómez-Ros, R. Bedogni, D. Bortot, B. Buonomo, A. Esposito, A. Gentile, M. Lorenzoli, M.V. Introini, G. Mazitelli, M. Moraleda, A. Pola, D. Sacco. CYSP: A new cylindrical directional neutron spectrometer. Conceptual design. Radiat. Meas. 82, 47-51(2015).

5. R. Bedogni; D. Bortot; B. Buonomo; A. Esposito; J. M. Gomez-Ros; M. V. Introini; G. Mazzitelli; M. Moraleda; A. Pola; A. M. Romero. A single-exposure, multi-detector neutron spectrometer for workplace monitoring. Radiation Protection Dosimetry 2015;doi: 10.1093/rpd/ncv380.

6. R. D. Sacco, R. Bedogni, D. Bortot, M. Palomba, A. Pola, M.V. Introini, M. Lorenzoli, A. Gentile, L. Strigari, C. Pressello, A. Soriani, J.M. Gómez-Ros. Thermal neutron Imaging through XRQA2 GAFCHROMIC films coupled with a Cadmium radiator. Nucl. Inst. Meth. A 798, 70-73 (2015).

7. L. Irazola, L. Brualla, J. Rosello, J.A. Terron, B. Sanchez-Nieto, R. Bedogni, F. Sanchez-Doblado. Proceed. 57th Annual Meeting and Exhibition of the American-Association-of-Physicists-in-Medicine (AAPM) Anaheim, CA Date: JUL 12-16, 2015. MEDICAL PHYSICS. Volume: 42 Issue: 6 Pages: 3376-3376 Published: JUN 2015.

8. L Irazola, C. Domingo, M. Romero-Exposito, M. Garcia-Fuste, J. Terron, B. Sanchez-Nieto, R. Bedogni, F. Sanchez-Doblado. Proceed. 57th Annual Meeting and Exhibition of the American-Association-of-Physicists-in-Medicine (AAPM) Anaheim, CA Date: JUL 12-16, 2015. MEDICAL PHYSICS. Volume: 42 Issue: 6 Pages: 3417-3417 Published: JUN 2015.

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[1] R. Bedogni, D. Bortot, A. Pola, M.V. Introini, M. Lorenzoli, J.M. Gómez-Ros, D. Sacco, A. Esposito, A. Gentile, B. Buonomo, M. Palomba, A. Grossi. Experimental characterization of semiconductor-based thermal neutron detectors. Nucl. Instr. Meth. A 780 (2015) 51.

[2] Bedogni, R.; Quintieri, L.; Buonomo, B.; Esposito, A.; Mazzitelli, G.; Foggetta, L.; Gomez-Ros, J. M. Experimental and numerical characterization of the neutron field produced in the n@BTF Frascati photo-neutron source. NIM A, 659 (2011) 373-377.

[3] Bedogni, R., Domingo, C., Esposito, A., Fernandez, F., 2007. FRUIT: an operational tool for multisphere neutron spectrometry in workplaces. Nucl. Instr. Meth. A 580, 1301 1309.

[4] Bedogni, R., Pelliccioni, M., Esposito, A., 2010. A parametric model to describe neutron spectra around high-energy electron accelerators and its application in neutron spectrometry with Bonner Spheres. Nucl. Instr. Meth. A 615, 78-82.