NESCOFI@BTF

2011 - 2013

2013 Launch meeting

INFN-LNF, 29 January 2013

C

10:00 – 10:30	***Short report of 2012 activity*** (R. Bedogni)
10:45 – 11:15	***Experiments performed in 2012*** *Charaterization of the active detectors* *In-house fabrication and reproducibility* *Dedicated acquisition boards: lesson learnt* *2013 boards production* (A. Pola, D. Bortot)
11:15 – 11:40	**B r e a k**
11:40 – 12:10	***State of art of computational activity*** *Experiment Vs simulation: how good? Need to improve?* *From activation foils to active detectors: calculation aspects* *Final design of CYSP* (J.M. Gomez-Ros)
12:10 – 12:40	***Budget for 2013 and strategy proposal - Discussion*** *50% budget cut….One or two instruments?* *Final calibration campaigns* *Need for a detector processing facility* *Strategic collaborations and co-funding partners*
13:00	***L u n c h***
14:00 – 15:00	***Discussion – cont'd***
15:00 – 15:30	***What's next?*** *"Marketing" our products in industry, medicine and research* *Future activity: An R&D in portable neutron sources? Neutron beam-lines in the Frascati area?*

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NESCOFI@**BTF**

NEutron Spectrometry in COmplex FIelds

Esperimento TRIENNALE **(2011-2013)** per lo sviluppo di tecniche sperimentali per la caratterizzazione di fasci neutronici pulsati ed ad alta intensità.

Roberto Bedogni (resp. LNF e nazionale)
B. Buonomo, A. Esposito, G. Mazzitelli, A. Gentile (30%), M. Chiti
INFN-LNF

M.V. Introini (50%), A. Pola (30%), D. Bortot (10^{12} %)
INFN-Milano e Dip. di Energia Politecnico di Milano

J.M. Gomez-Ros (50%)
CIEMAT, Madrid

Motivation

Developing innovative neutron sensitive instruments for the spectrometric and dosimetric characterization of neutron fields, intentionally produced or present as parasitic effects, in particle accelerators used in **industry, research and medical fields**.

These neutron fields:

- range in energy from thermal (1E-8 MeV) to tens or hundreds MeV;
- range in fluce rate from few tens up to 10^5 cm^{-2} s^{-1}
- are accompanied by other particles (photons, high-E hadrons)
- Have pulsed structure

(1) Fast neutron irradiation

TRIUMF, LANSCE, TSL (ANITA), ISIS: dedicate neutron lines for material science, chip irradiation (electronics, avoinics, aerospace) and radiation damage.

Spectra are generally known by simulation. Measurements performed only in limited energy regions only. A large interest exists for on-line spectrometry that would allow

- *estimating field pertutbation due to irradiated objects,*
- *evaluate the importance of room-return for different user positions;*
- *prevent beam alterations due to change in energy or space characteristics of primary beam.*

(2) Medical field

Modern radiotherapy techniques (including hadron-therapy) dramatically improved lifespan and life quality of patients. In parallel the interest for secondary cancers is increasing.

Neutrons contribute to that:

(1) large w_R and (2) irradiate the whole patient

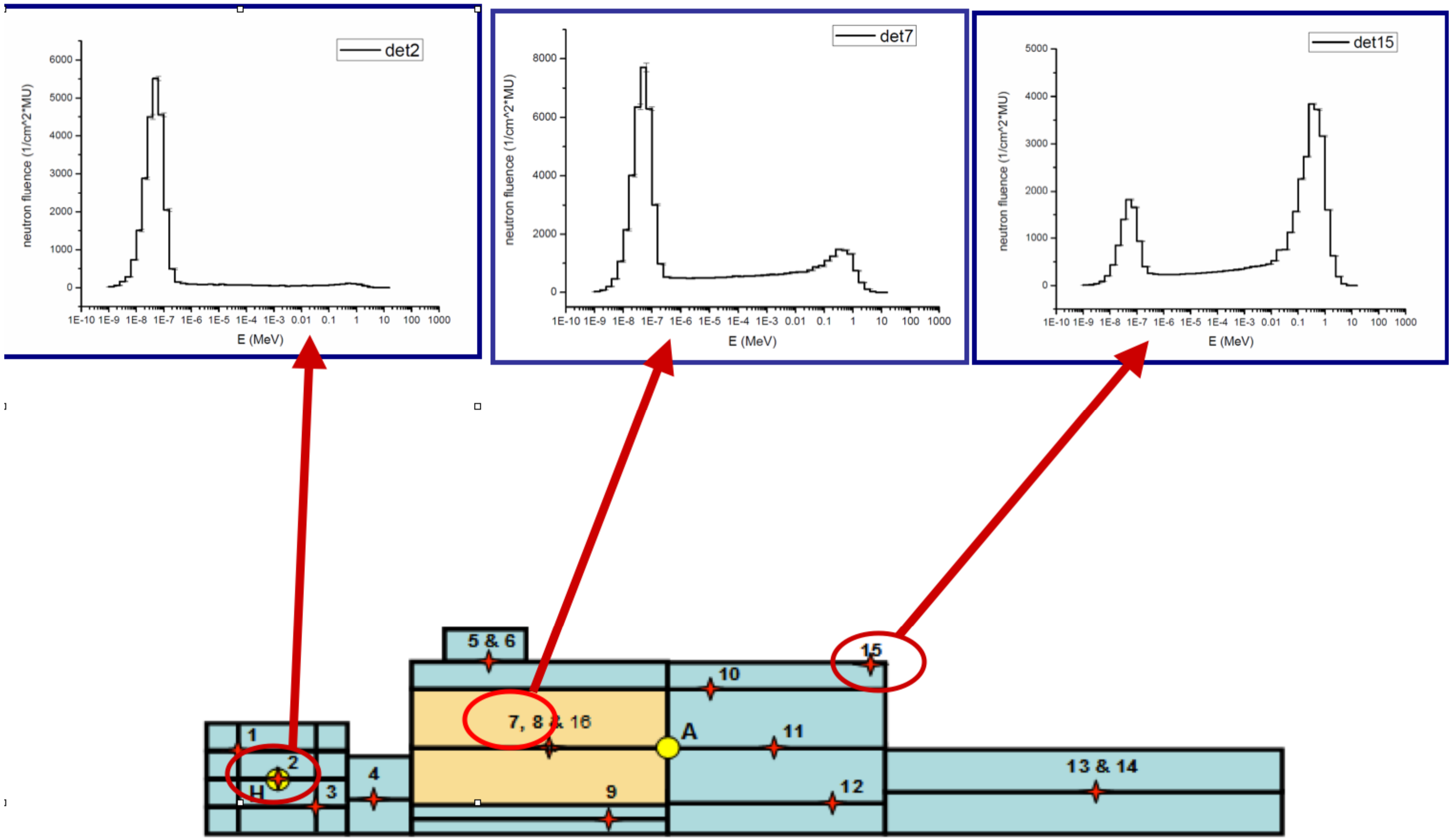
The medical physics community is seeking on-line instruments to provide neutron-related field and dosimetric quantities.

These should be able to reliably measure in a broad range of neutron fluence (from 10^2 to 10^6 cm^{-2} Gy^{-1})

(Spain) *NEUTOR and its continuation*. Possibility to derive neutron quantities on the basis of the measurement of the thermal room-return and the room surface.

(2) Medical field

The products of NESCOFI (in this case the new ATNDs), are of interest for the medical physics community involved in in-phantom (or in vivo…) neutron verifications (Neutor & cont.)



To date, the multi-sphere spectrometer (or Bonner Sphere spectrometer) is the only existing device having the capability to simultaneously determine all energy components. Disadvantage: need to sequentially expose the spheres.

NESCOFI goal is to provide real-time spectrometers to simultaneously provide all energy components (and their variation with time) in a single irradiation.

These could be employed for:
(1) Monitoring the neutron fields in terms of energy-integrated neutron flux and spectral neutron flux in energy intervals of interest.

(2) Active real-time control of possible deviations from nominal field properties and of possible modifications induced by materials introduced in the radiation field (samples, materials to be irradiated, patients to be treated).

The final users of the NESCOFI products will be a variety of facilities interested to monitor not only the intensity of a neutron beam, but also –and simultaneously- its energy and/or direction distribution

Idea: two types of spectrometers for different field geometries:

(SP)² **SPherical-Spectrometer:** determine the total spectrum it the point of test **independently from direction distribution**

Design problems:

- *finding the way to "hysotropize" the response*
- *external / internal thermal n separatation*

CYSP **CY**lindrical-**SP**ectrometer: collimated beam OR determine the spectrum from a WELL DEFINED direction (typ. from target. Allows eliminating room return)

Design problems:

- *optimize the lateral "protection" layer for all energies*

For each geometry: Identify suitable Active Thermal Neutron Detectors (ATND) to equip a low-rate & a high-rate version.

NESCOFI would ideally yield FOUR products:
Hi-rate SP^2, Lo-rate SP^2, Hi-rate CYSP, Lo-rate CYSP

2011 MC Design of the geometries and test with passive detectors (Dy-foils)
2012 Identify suitable ATND
2013 Build and calibrate final spectrometers

2011 Activities

- Study and optimization of the geometry of the prototype spectrometers
- Testing the experimental prototype spectrometers in neutron reference fields

Due to budget cut (-50%), especially in travels and money for mono-E beam-time, only the SP^2 was built and tested with passive detectors at mono-enegetic neutrons of low-E (147 to 14.8 MeV at PTB) and high-E (50 to 180 MeV at TSL).

For CYSP it was decided to go through an **hybrid prototypal stage** (non extended range geometry equipped with ATNDs) to be carried out in 2012.

Referees agreed

2011 Milestones	completed 100%
Manpower 2011	0.40 % of the CSN 5 total FTE
Budget 2011	2.30 % of the CSN 5 total budget
Total FTE:	2.40
Total Researchers:	5.00
Publications in peer rev jour	7
Talks at conferences	2

Completed thesis: none in 2011 - 1 planned for 2012

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Remaining 2011 work still un-published (or publication in progress)

Validation of SP^2 with Dy-foils at low-E	(submitted)
Validation of SP^2 with Dy-foils at High-E	(ms under elaboration)

INFN Istituto Nazionale di Fisica Nucleare

Testing a newly developed single-sphere neutron spectrometer in reference monochromatic fields from 147 keV to 14.8 MeV

R. Bedogni[1], J.M. Gómez-Ros[1,2], A. Pola[3], M.V. Introini[3], D. Bortot[1,3], A. Gentile[1], A. Esposito[1], G. Mazzitelli[1], B. Buonomo[1], L. Quintieri[1], L. Foggetta[1]

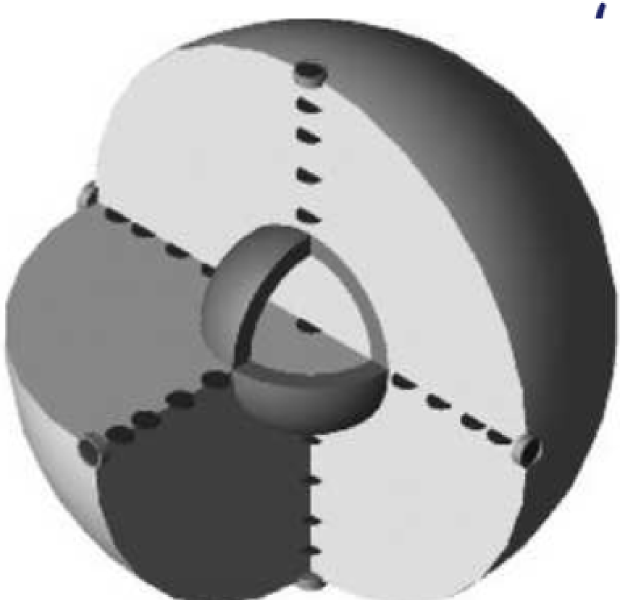
[1] INFN – LNF Laboratori Nazionali di Frascati, Via E. Fermi n. 40, 00044 Frascati, Italy

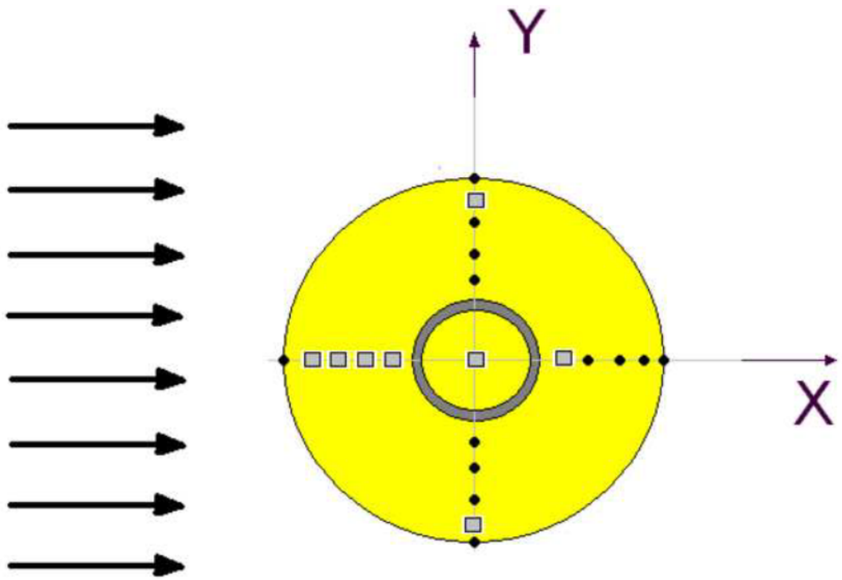
[2] CIEMAT, Av. Complutense 40, 28040 Madrid, Spain

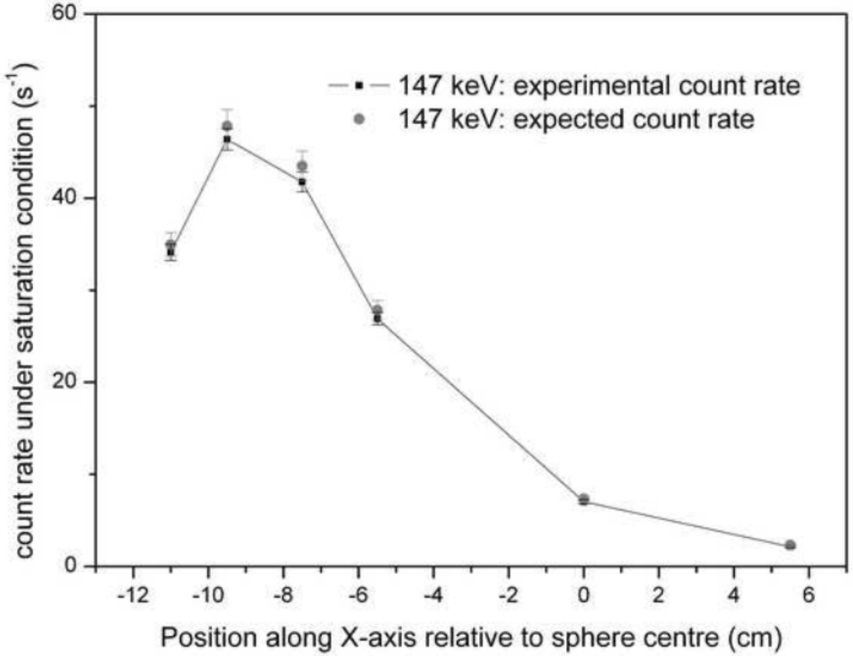
[3] Politecnico di Milano - Dipartimento di Energia, Via Ponzio 34/3, 20133 Milano, Italy

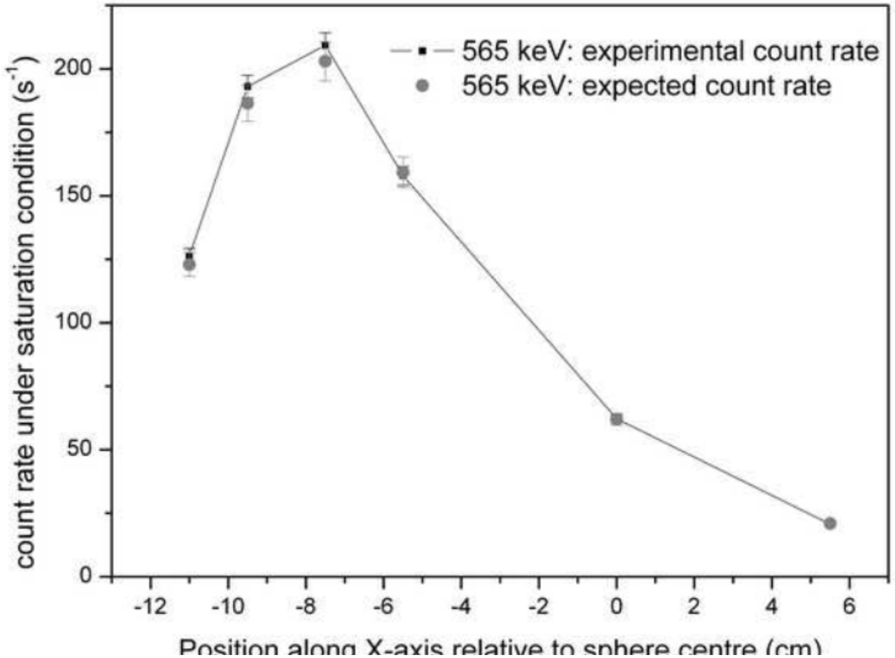
Submitted to NIM A - under review

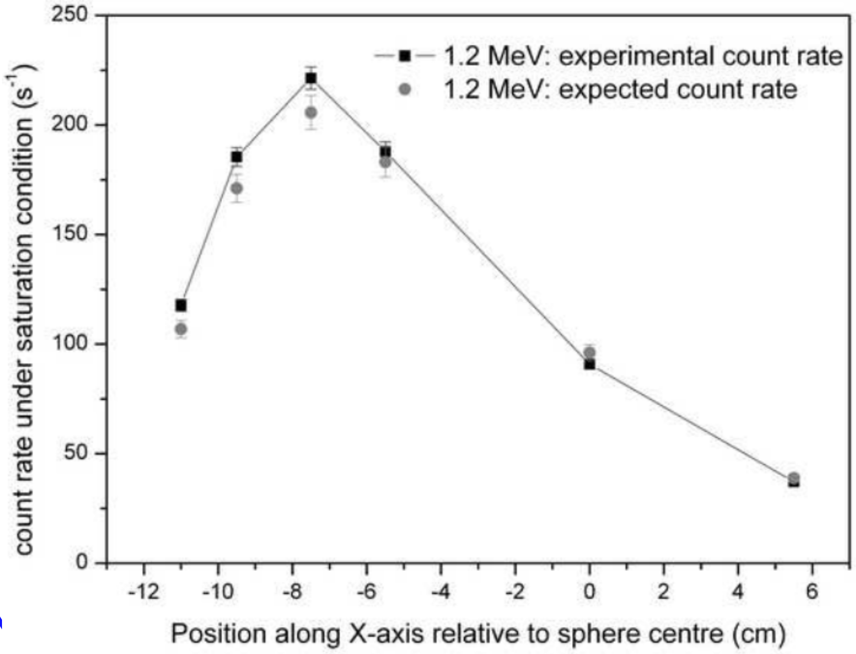

SOTTO

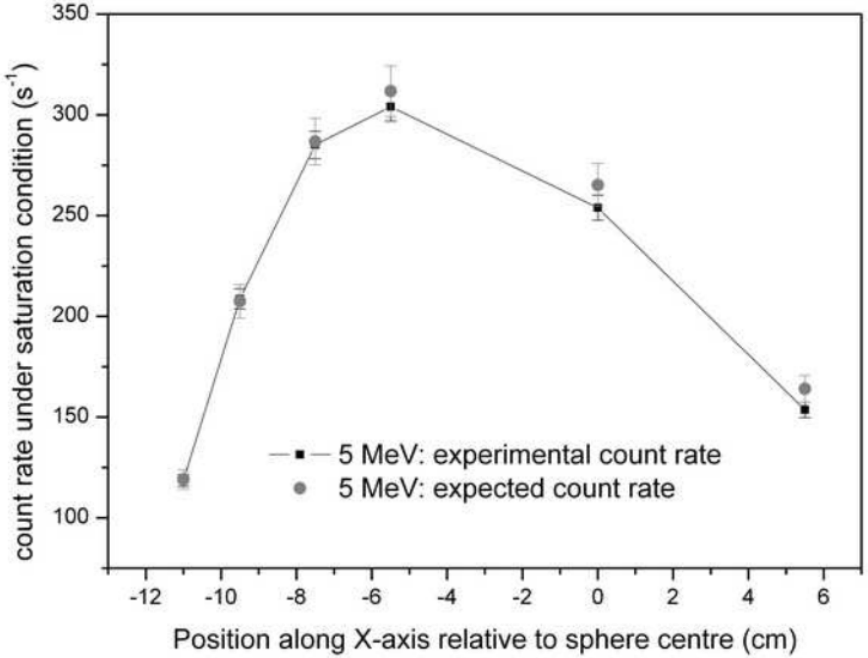


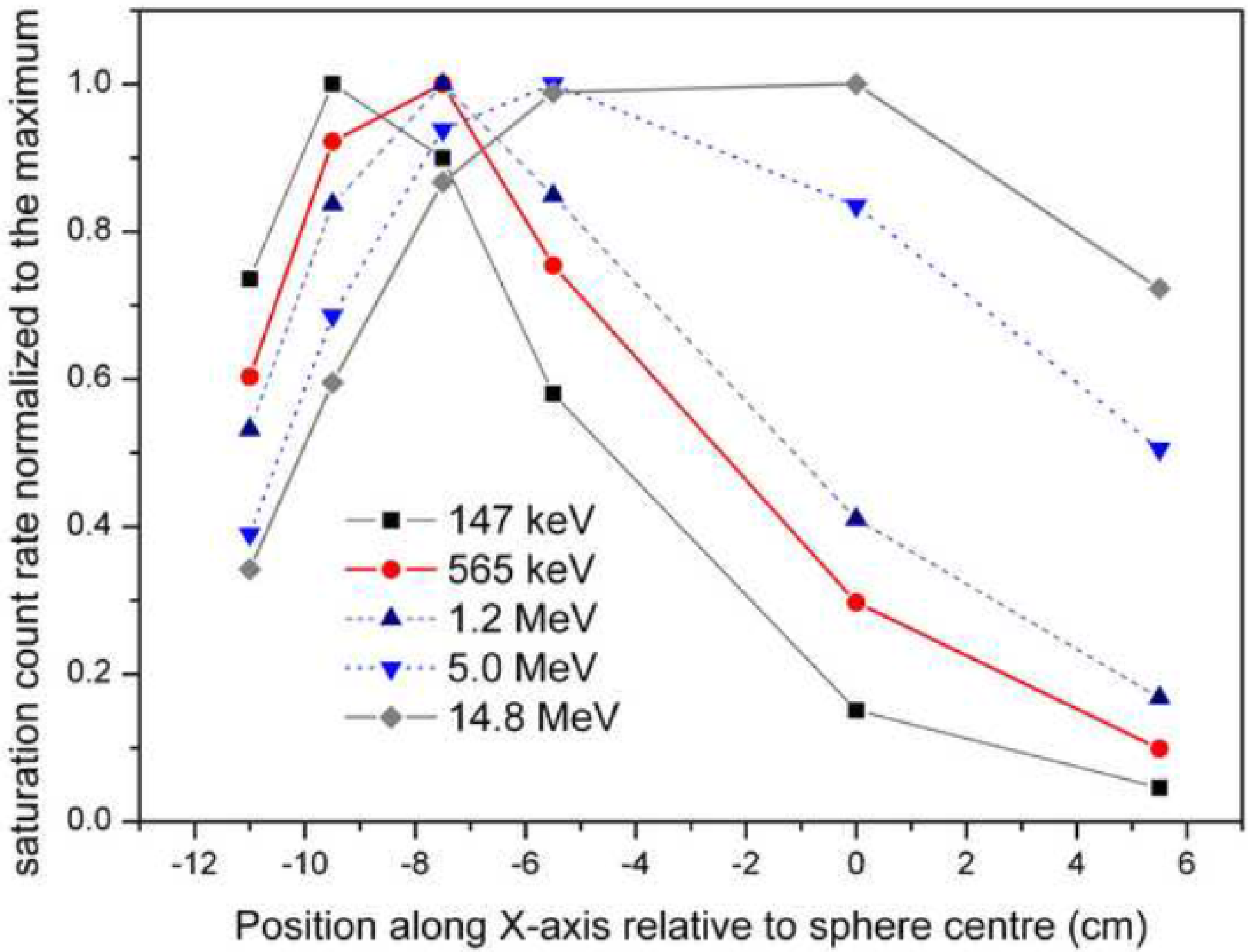

Y
X


147 keV: experimental count rate
147 keV: expected count rate
count rate under saturation condition (s-1)
Position along X-axis relative to sphere centre (cm)

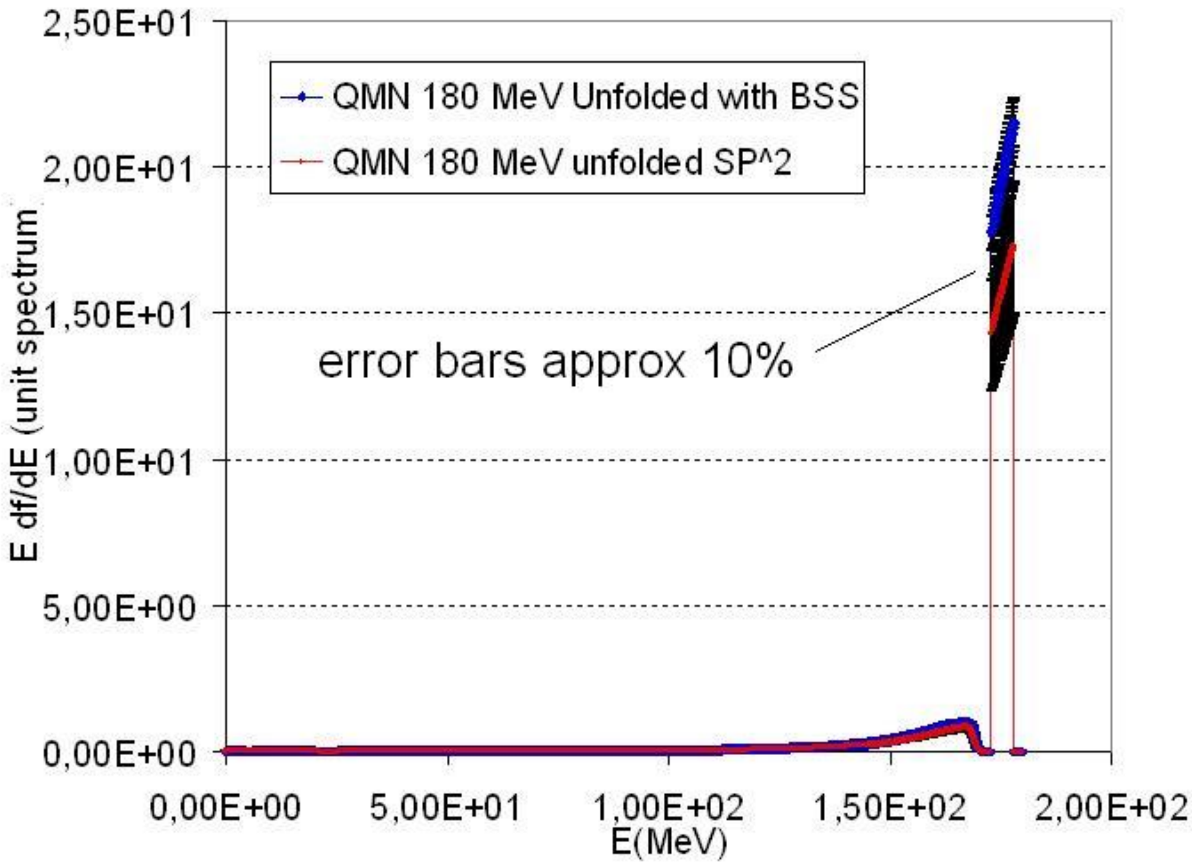

565 keV: experimental count rate
565 keV: expected count rate
count rate under saturation condition (s-1)


1.2 MeV: experimental count rate
1.2 MeV: expected count rate
count rate under saturation condition (s-1)
Position along X-axis relative to sphere centre (cm)


5 MeV: experimental count rate
5 MeV: expected count rate
count rate under saturation condition (s-1)
Position along X-axis relative to sphere centre (cm)


saturation count rate normalized to the maximum
1.0
0.8
0.6
0.4
0.2
0.0
-12
-10
-8
-6
-4
-2
0
2
4
6
Position along X-axis relative to sphere centre (cm)
147 keV
565 keV
1.2 MeV
5.0 MeV
14.8 MeV

SP² at high-Energy (ms under elaboration)



2012 Budget needs / assignment

Missioni interne *Permanenze al Politecnico o LNF per messa a punto dell'elettronica di acquisizione e testing dei ATND (30 gg x 2 persone in 8 missioni)* *2 campagne presso centri di radioterapia con elettroni e adroni (10 gg x 2 persone in 2 missioni)*	**12 k€**	**3.5 k€**
Missioni estere *1 campagna testing neutroni termici NPL-UK (10 gg x 3 persone)* *1 campagna in una facility per fast neutron irradiation (10 gg x 3 persone)*	**10 k€**	**5 k€**
Trasporto strumentazione (DHL via aerea assicurato) *4 campagne, 1 k€ cad.*	**4 k€**	**1 k€**
Consumo *Acquisizione circa 60 rivelatori n termici e relativa elettronica (preamplificatori e amplificatori)*	**62.5 k€**	**18 k€**
Inventario *Sistema digitale per filtraggio segnali e spettrometria*	**42 k€**	**12 k€**
Spese servizi (beam time NPL e campo da fast neutron irradiation *Costruzione spettrometri finali (moderatori, filtri in Cd e Boro, degradatori in Pb)*	**10 k€**	**5 k€**
TOTALE	**140.5 k€**	**44.5 k€**
		(31.7%)

Physics activities "declared" for 2012

X1. CYSP response matrix (See Gomez talk)

X2. Test of ATND in thermal field (see Bortot talk)

In variable flux (10^2-10^7), to study saturation, pile up, radiation ageing. NPL.

X3. Test of parallelized ATND within "hybrid" cylinder, called mini-CYSP (see Bortot talk)

In field with different energy composition to mimic different working environments.
Study of in-moderator response (gammas, high-E neutrons) and refine subtraction techniques to eliminate the non-thermal signal.

X4. Selection of optimum detector-converter coupling and readout electronics of ATND for Lo-Rate / Hi-Rate (31-12-12)

The Lo-Rate or Hi-Rate versions will be achieved by using detectors working respectively in pulse- or current- modes.

X5. Acquiring DAQ systems for parallel control of multiple ATND (31-12-12)

Pulse mode detector

X4. Selection of optimum detector-converter coupling

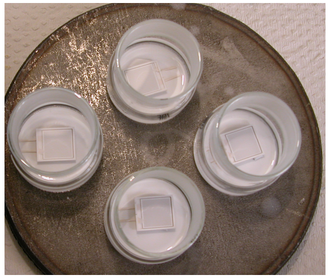
After evaluating and rejecting diamond detectors (for low sensitive area and high cost) and miniaturized gas counters (too large and expensive) the final choice was *Silicon detectors adequately covered.*

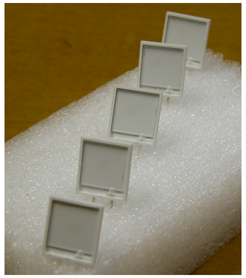
- High sensitivity. For 1 cm^2 area adequately covered, the final spectrometer may easily detect fluxes below 100 $cm^{-2}s^{-1}$
- By varying the converter mixture, sensitivity can be tuned over more than a factor 10-15.
- low cost: 120 € + converter (< 1 €) per detector.
- sufficient miniaturization: 12 x 14 x 2 mm3,
- Good n/γ separation.
- Satisfactory response up to 1E+5 cm^{-2} s^{-1} (total external flux)
- Very low voltage supply (Volt region)

Silicon may suffer radiation damage at very large fluxes. For particularly “harsch” environments, rad hard detectors (SiC or diamonds) may be implemented, but additional support (e.g. from the final user) is required.

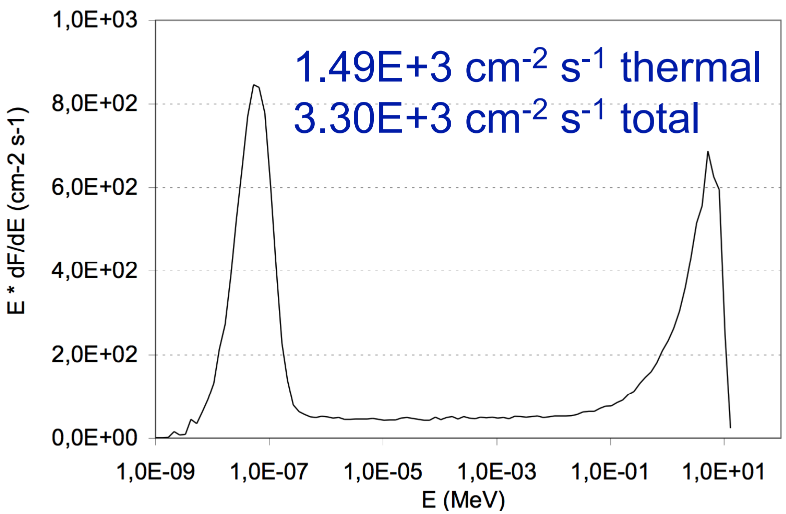
Two types of converter implemented and tested (C1 and C2)

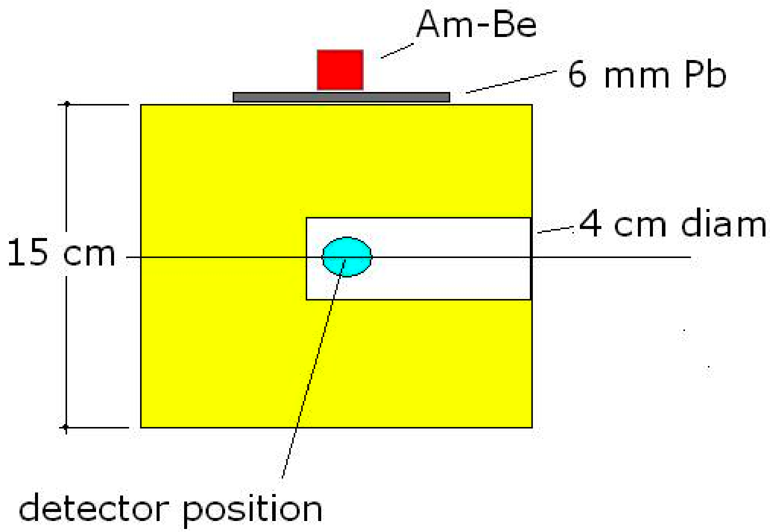
- mixture preparation “in house”. This allows modulating the detector sensitivity by varying (1) mixture composition and (2) thickness
- deposition in-house. Uniformity? Batch variability?
- QA/QC on the whole process (thickness control, gamma and n response).





Successive phases of the deposition process

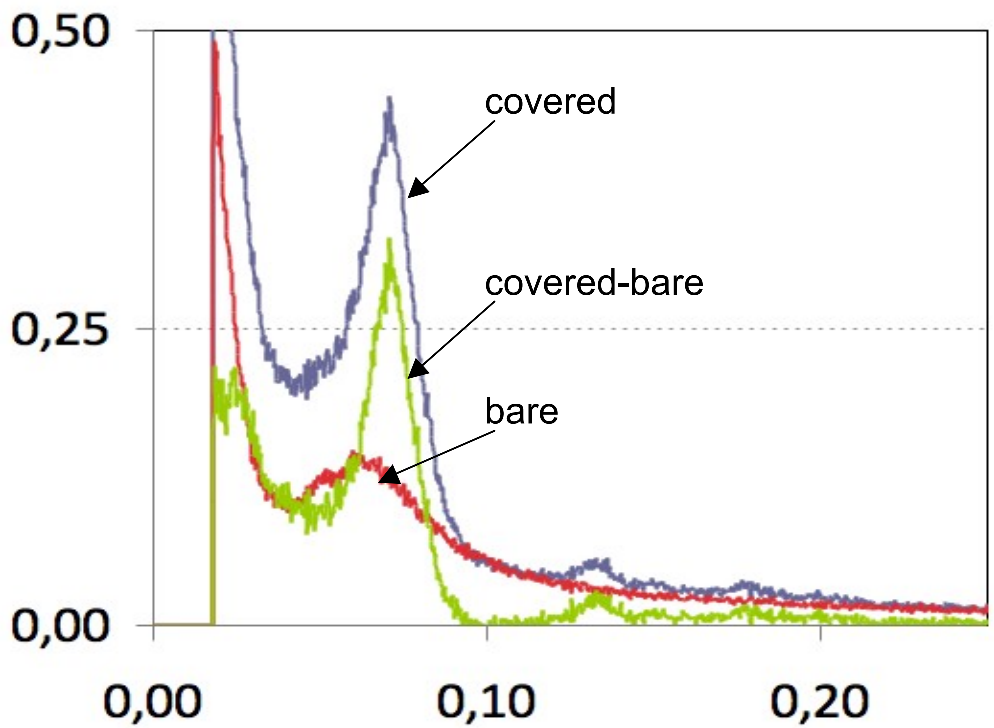




Thermal neutron QA/QC facility (spectrum and layout)

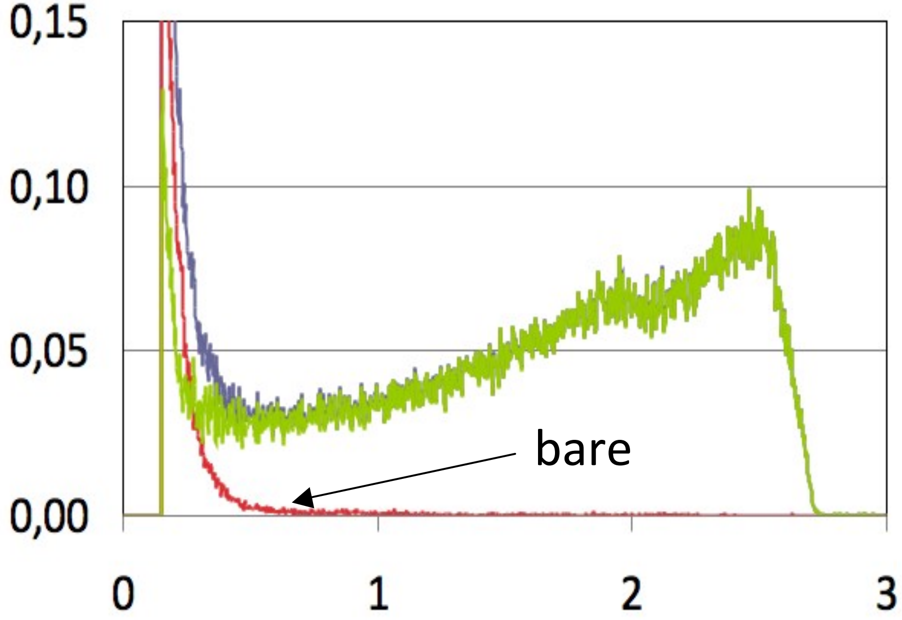
Converter type C1

- Different thicknesses fabricated
- Optimal thickness chosen on the basis of sensitivity and spectrum shape
- Sensitivity of optimum combination: 0.02 cm^2 (counts/fluence)
- fabrication reproducibility <8%.
- Need to expose pairs of detectors (bare and covered) to eliminate gamma contribution



Converter type C2

- Different thicknesses fabricated
- Optimal thickness chosen on the basis of sensitivity and spectrum shape
- Sensitivity of optimum combination: 0.026 cm^2 (counts/fluence)
- fabrication reproducibility (to be determined)
- A single detector may accurately determine the thermal fluence !!



Testing campaigns (X2. and X3.):

Converter C1

March 2012 at NPL (UK)

(1) mono-E beams (0.5 and 5 MeV), hybrid cylinder. Acquisitionof multiple ATNDs in parallel

(2) thermal pile (1E+3 up to 1E+7 cm-2s-1). Linear response up to 1E+6

Radiation damage: ABSENT for accumulated fluence 5E+10 cm-2.

Converters C1 and C2

June 2012 at TSL (ERINDA approved experiment. Beam-time + 2240 €)
Verify spectrometric capability “in moderator” compared with 6LiI(Eu)

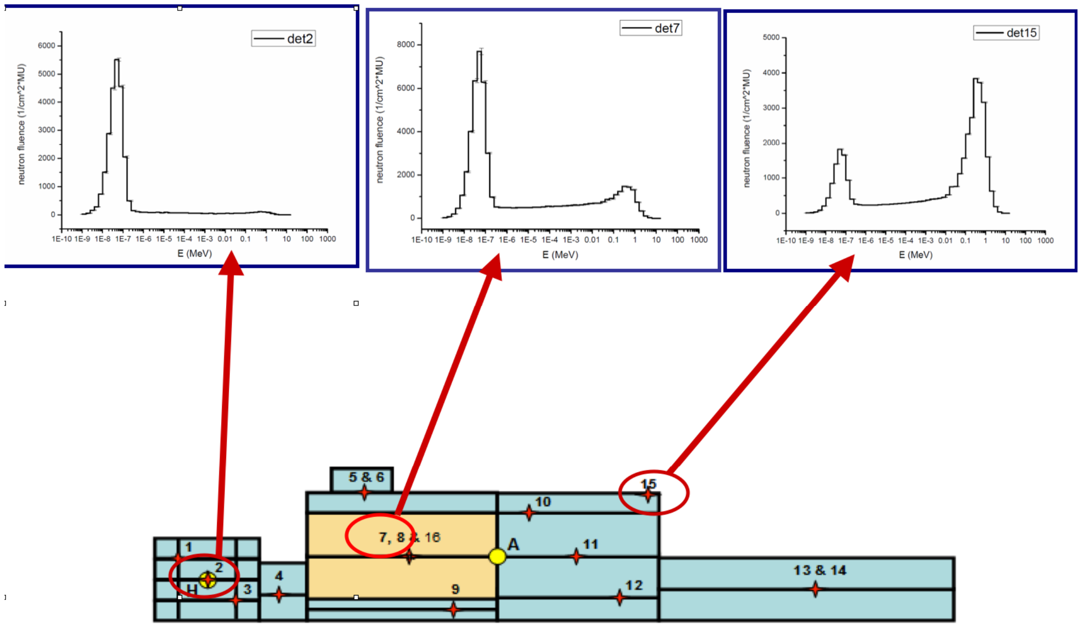
July 2012 TRIGA reactor, ENEA Casaccia.
Verify response linearity for C2
Radiation damage starts at accumulated fluence ~ 3E+12 cm^{-2}
(detector becomes an intense beta source)

Converter C2

(Collaboration with Sevilla)

In phantom measurements of thermal neutrons @ 15 MV medical LINAC.
10 Gy at isocenter (head treatment)

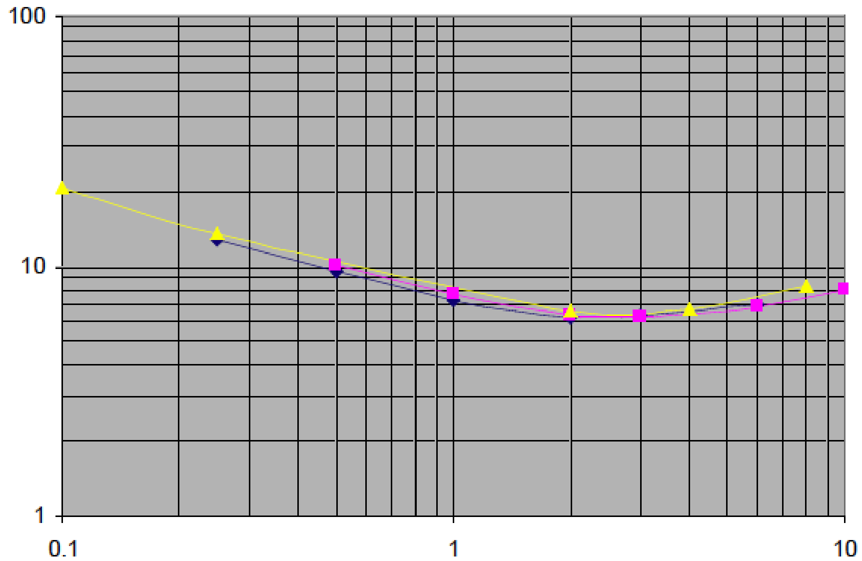
Positions off axis:		
	Lung	2.0E+4 cm^{-2} MU^{-1} / 2.3 (passive)
	Abdomen	0.1E+4 cm^{-2} MU^{-1} / 0.1 (passive)
	skin	0.9E+4 cm^{-2} MU^{-1} / 0.7 (passive)



X5. Electronics

(1) Single detector acquisition chain (pre, amp, digitalization)

A low-cost chain was set up starting from commercially available integrated circuits for pre e amps.
This solution was compared with commercial “high-cost” modules (Silena, Ortec)



Noise-FWHM in keV in funzione del tempo di formazione dell’impulso (us).

Blu = SILENA;
ROSA = ORTEC,
GIALLO = “low-cost”.

(2) Parallel acquisition from multiple detectors: dedicated **2 channels** and **8 channels** boards have been designed (Poli-Mi) and developed

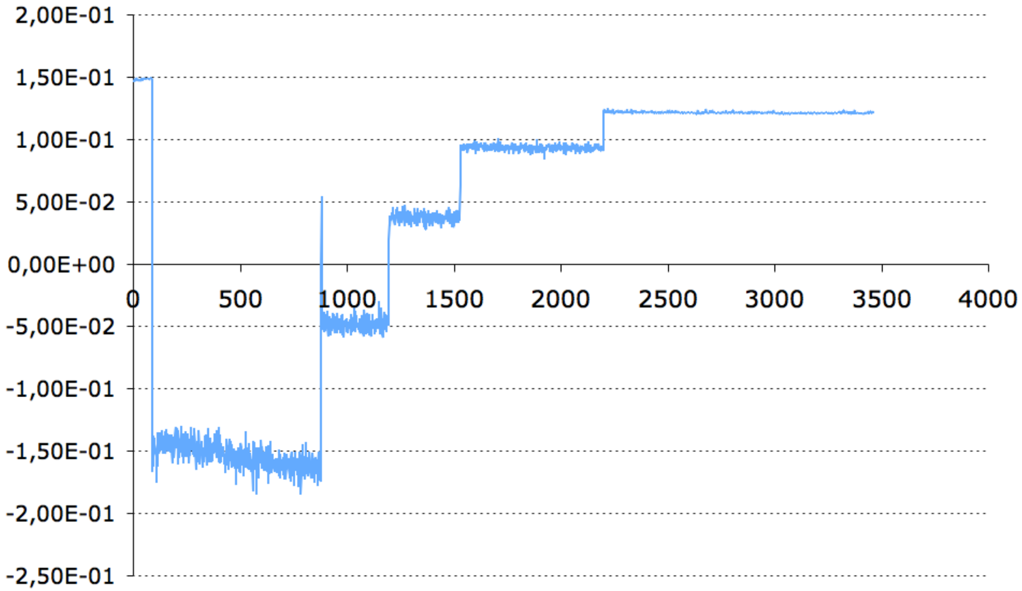
(3) Digitalization: digital oscilloscopes PICO 4227 (2 CH) and NI USB 6366 (8 CH 2 MS/s/ch)

ATND in current mode

- Similar detector-converter coupling
- Radiation-induced signal

The cost is a factor 10 lower than the ATND solution. Sensitivity is in principle lower.

-accuracy of the subtraction
-Rejection of common mode gamma signals



Response in the order of
20 μV / (n cm^{-2} s^{-1}) thermal n

Gamma sensitivity:
0.8 mV / mGy/h @ 662 keV

25 μGy/h gamma <=> 1 n_{th} cm^{-2} s^{-1}

Cofinanziamenti & collaborazioni 2012

- EU FP7 Erinda Program: 2.5 k€ (instrument shipment) + 35 beam hours at TSL
- CIEMAT Madrid 35,000 equiv-hours CPU time on EULER cluster
- CRISP (INFN-LNF): 12 k€ (neutron converters, trips exp. campaigns)
- Politecnico di Milano 6 k€ (trips at experimental campaigns) + support for electronics design and testing
- Ospedale San Camillo: tempo macchina al LINAC da 15 MV per radioterapia

Supporto dei LNF

- una settimana di run presso n@BTF
- 2 mesi uomo presso officina meccanica
- 30 notti in foresteria
- Tutte le misure sperimentali e i processi di fabbricazione dei rivelatori si sono svolti nei laboratori del Servizi FISMEL

http://www.lnf.infn.it/acceleratori/public/nescofi/

Project meetings

16 May 2012: *NESCOFI@BTF 2012 Mid-Year Meeting & International Review Panel Meeting*

International Review Panel

E' stato stabilito un review panel di due esperti internazionali nel campo della dosimetria e spettrometria neutronica.

(1) Prof. Carles Domingo, Profesor Titular of the Universitat Autonoma de Barcelona, UAB Head of the Neutron Measurement group of the UAB carles.domingo@uab.cat

(2) Prof. Francisco Sanchez Doblado, Profesor Catedratico of the Universidad de Sevilla, Head of the Physiology Department. paco@us.es

2012 Publications

R. Bedogni, K. Amgarou, C. Domingo, S. Russo, G.A.P. Cirrone, M. Pelliccioni, A. Esposito, A. Pola, M.V. Introini. Experimental characterization of the neutron spectra generated by a 62 AMeV carbon beam on a PMMA phantom by means of extended range Bonner sphere spectrometers. NIM A 681 (2012) 110–115.

R. Bedogni, C. Domingo, M. J. Garcia Fuste, M. de-San-Pedro, A. Esposito, A. Gentile, L. Tana, F. d'Errico, R. Ciolini, A. Di Fulvio. Calibration of neutron sensitive devices in the neutron field produced in the treatment room of a medical LINAC. Radiation Measurements (2012), doi:10.1016/j.radmeas.2012.04.009.

J. M. Gomez-Ros, R. Bedogni, M. Moraleda, A. Esposito, A. Pola, M.V. Introini, G. Mazzitelli, L. Quintieri, B. Buonomo. Designing an extended energy range single-sphere multi-detector neutron spectrometer. Nucl. Instr. Meth. A 677 (2012) 4-9.

R. Bedogni, J. M. Gomez-Ros, A. Esposito, A. Gentile, M. Chiti, L. Palacios-Perez, M. Angelone, L. Tana. Workplace testing of the new single sphere neutron spectrometer based on Dysprosium activation foils (Dy-SSS). NIM A 684 (2012) 105–108.

R. Bedogni, A. Esposito Experimental study for improving the angle dependence of the response of PADC-based personal neutron dosemeters. Radiation Measurements (2012), http://dx.doi.org/10.1016/j.radmeas.2012.10.005

POLITECNICO DI MILANO
Scuola di Ingegneria dei Processi Industriali

Corso di Laurea Specialistica in Ingegneria Nucleare

FEASIBILITY STUDY OF A NEUTRON SPECTROMETER FOR COMPLEX FIELDS

Relatore:
Prof. Andrea POLA

Correlatore:
Dott. Roberto BEDOGNI

Tesi di Laurea di:
Davide BORTOT
Matr. 745880

Activities planned for 2013 (before assignment)

(1) Costruire un prototipo ATTIVO per ognuno degli spettrometri CYSP ed SP^2 e
- calibrarli presso fasci di riferimento low-E (PTB or NPL) and high-E (TSL)
- Testarli a ISIS o TSL in spettri "realistici"

(2) Trovare collocazione (e relativi co-finanziamenti) per gli strumenti

Commissione Scientifica Nazionale V

Request and assignment

Missioni interne		**12 k€**	1.5 + 2 s.j.
Permanenze al Politecnico-Milano o LNF per messa a punto dell'elettronica di acquisizione e testing degli spettrometri	(60 giorni uomo in 12 missioni)		
2 campagne presso centri di radioterapia	(20 giorni uomo in 4 missioni)		
Missioni estere		**15 k€**	3
1 campagna CALIBRAZIONE low-E reference field	(10 gg x 3 persone)		
1 campagna CALIBRAZIONE high-E reference field (TSL)	(10 gg x 3 persone)		
2 campagne Fast N irradiation in spettri diversi (TSL + ISIS)	(10 gg x 3 persone)		
Trasporto strumentazione (DHL via aerea assicurato)		**8 k€**	1.5
4 campagne estere, 2 k€ cad.			
Consumo (vedere offerte O-1, O-2, O-3)		**31.5 k€**	21.5
60 rivelatori a 164 €/cad	(offerta O-1)	10 k€	
3 schede da 8 canali a 1000 € / scheda		3 k€	
24 preamplificatori a 61 € cad	(offerta O-2)	1.5 k€	
24 amplificatori a 61 € cad	(offerta O-2)	1.5 k€	
polietilene, Pb e gomma borata (per DUE spettrometri)	(offerta O-3)	15.5 k€	
Inventario		**19.5 k€**	18
3 digitalizzatori a 5 k€ cad	(offerta O-4)	15.0 k€	
3 PC di acquisizione a 1.5 k€ cad		4.5 k€	
Spese servizi (beam time per calibrazioni)	(offerte O-5 e O-6)	**16 k€**	4
		102	**49.5 (+2 s.j.)**

Altro

1. Abbiamo tempo-officina meccanica (prestazioni limitate)
   In parte già impegnato per fabbricare il CYSP finale (pronto in febbraio)

2. Presso FISMEL: campo di prova X (40-130 kV) in corso di qualificazione.
   Emissione continua o pulsata (singoli pulsi rettangolari da min 10 ms)

3. Abbiamo un irraggiamento in colonna termica ENEA TRIGA da utilizzare

Prevediamo un co-finanziamento da Siviglia (est. 20 k€)
- sviluppo di un SP^2 attivo per campo ospedaliero di bassa energia
- Fornitura di singoli ATND per misure "in phantom"

Vorremmo proporre il CYSP alle sorgenti di spallazione

Varie ed eventuali. Discussione con i beam-line experts

Useful Conferences

2012

- IEEE October 29 - November 3, 2012, Disney Hotel, Anaheim, California -
  Workshop Perspectives on ^{3}He Replacments for Neutron Detection - Friday, November 2, 2012

2013

- NEUDOS (Aix en Provence, 3-7 June 2013)

- 17th International Conference on Solid State Dosimetry (Recife, Brazil)