NESCOFI@BTF

2011 - 2013

2012 Mid-Year Meeting
&
International Review Panel Meeting

INFN-LNF, 16 May 2012

Overview, *Roberto*	*1 h*
Coffee Break	*20 min*
Computational work, *Jose Maria*	*30 min*
Electronics & ATND, *Davide*	*30 min*
Discussion	*1 h*
Lunch	
International Panel report	*30 min*

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) 80%
B. Buonomo (30%), A. Esposito (50%), G. Mazzitelli (40%), L. Quintieri (20%)
M. Chiti (30%), A. Gentile (30%)
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.*

Motivation

(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.

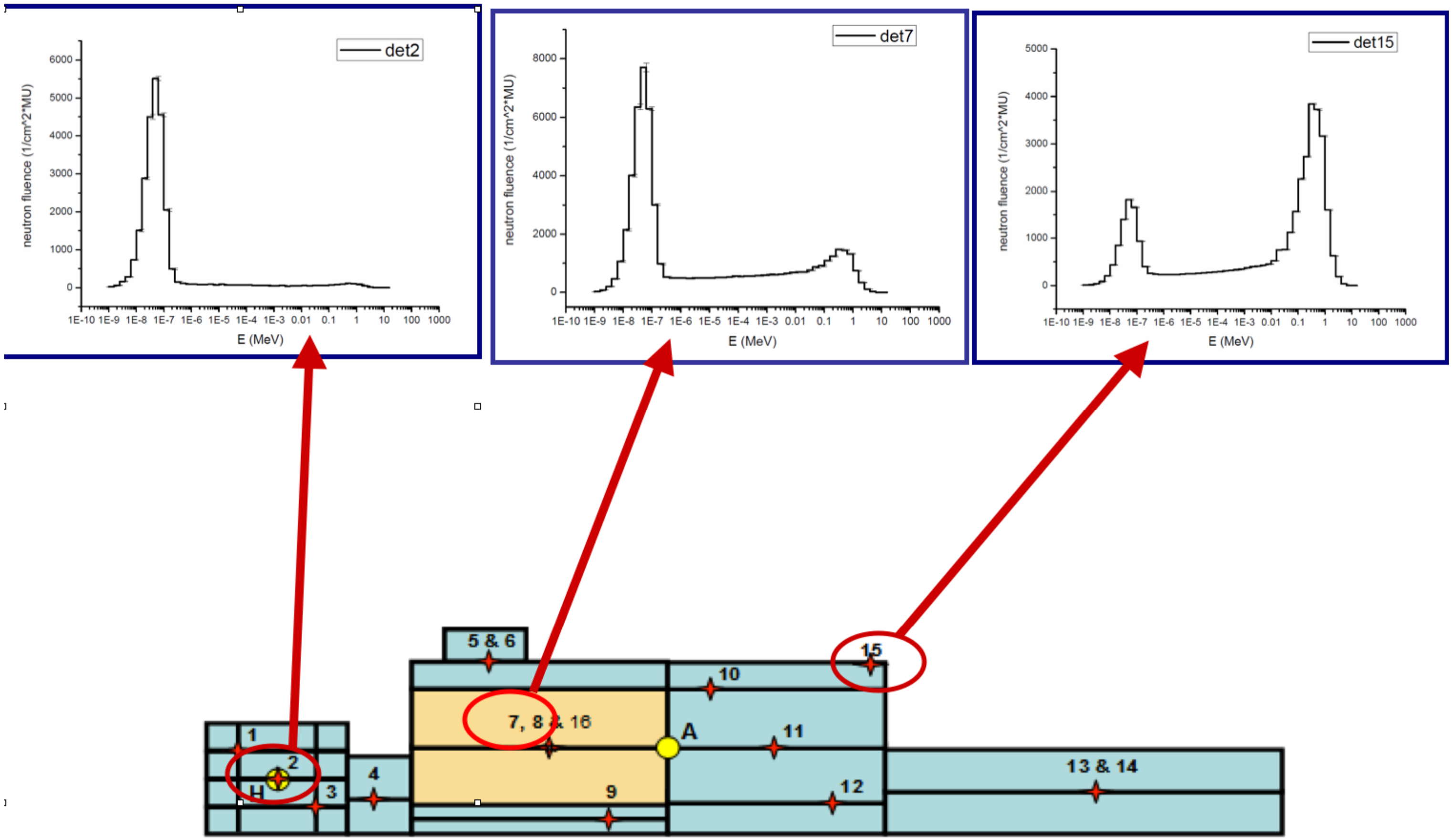
These should be able to reliably measure in a broad range of neutron fluence (from 10^2 to 10^6 cm^{-2} Gy^{-1})

(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.

Motivation

(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.)



Motivation

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

Strategy

Idea: two types of spectrometers for different field geometries:

(SP)² **SP**herical-**SP**ectrometer measure the total spectrum in the measurement position independently from direction distribution

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

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

Physics activities performed during 2011

Phys-1

Identifying, measuring and establishing suitable neutron fields for the future testing needs of the NESCOFI@BTF project purposes during 2012 and 2013

Phys-2

Study and optimization of the geometry of the prototype spectrometers

Phys-3

Testing the experimental prototype spectrometers in neutron reference fields

Considerations about budget and strategy

2011 Assigned budget 67.5 k€ = 48.7% of request (30% for trips)
Impact: only SP^2 could be studied, built and tested in this year.

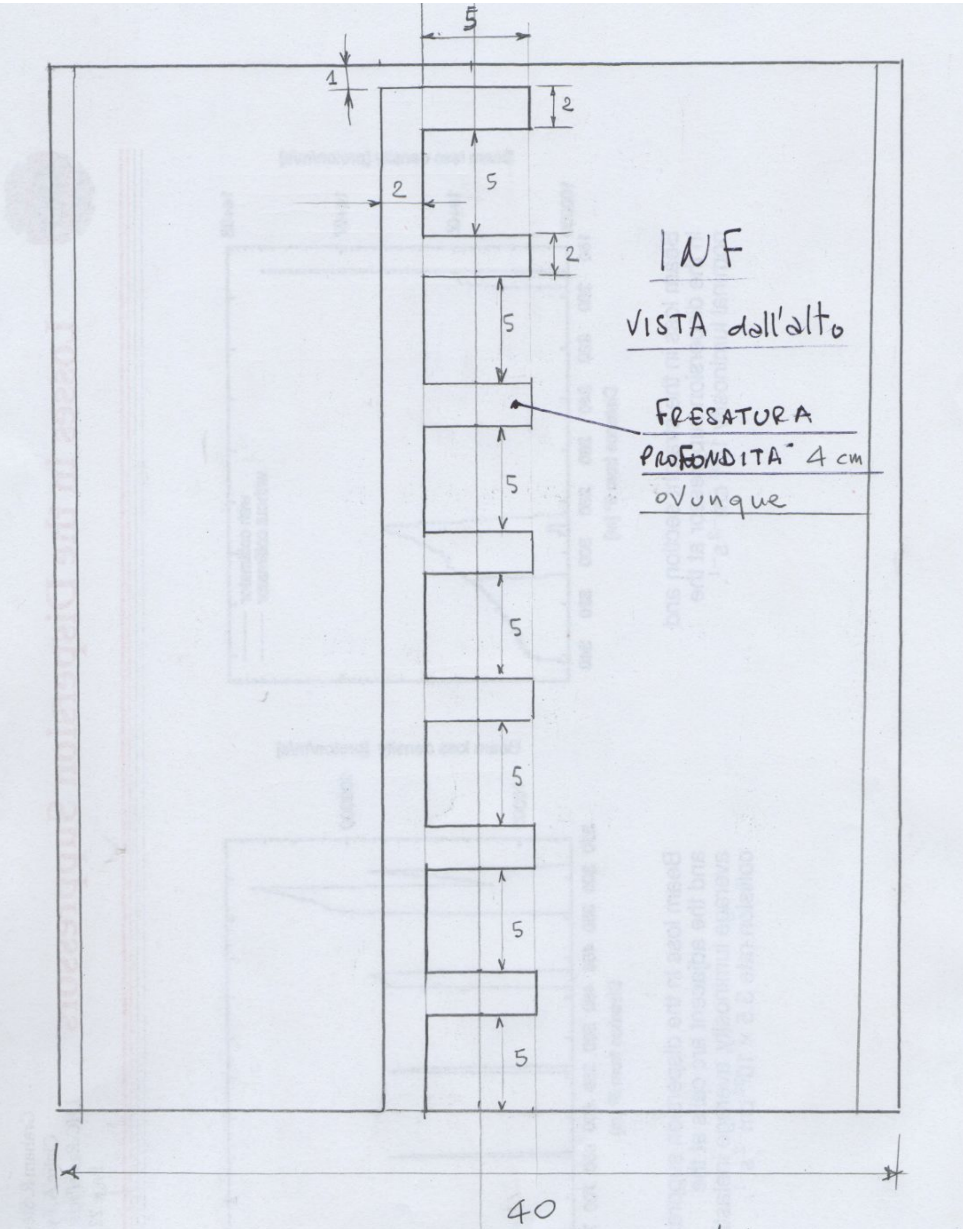
What about the CYSP ?

(1) A mini-CYSP (no lead structure for high-energy, no MC simulated) was built to be used in 2012 for:
  - Learning how to control several detectors in a single moderator
  - Studying detector response in the complex field within moderator
  - Studying saturation, pile up, dead time and how to subtract photon contribution

(2) Final design of CYSP likely to be ready for mid 2012

Skipped: CYSP geometry testing with Dy-foils. Accuracy should be the same as SP^2

In this way, we can still have the possibility to build both active spectrometers in 2013.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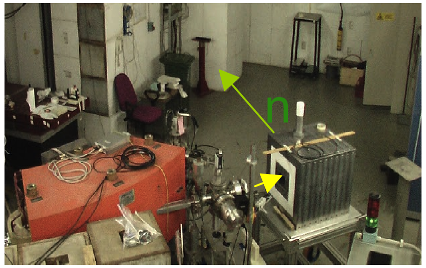
Phys-1 Identifying, measuring and establishing suitable neutron fields for future testing needs during 2012 and 2013



(1) The n@BTF photo-neutron beam at the LNF

Characterization completed.

Permanent neutron monitors operating.

Yield = (8.2 ±0.2) 10^{-7} cm^{-2} per incident electron at the reference position (90° direction, 120 cm from the target). Achievable fast neutron flux may be as high as 10^4 $cm^{-2}s^{-1}$.

- Nucl. Instr. Meth. A 659 (2011) 373-377.

(2) Neutron fields produced by therapeutic beams. These represent the medical radiation environments where the NESCOFI products could operate in future

- Nucl. Instr. Meth. A, 654-1, (2011)

- Bedogni, Amgarou, Domingo, Russo, Cirrone, Pelliccioni, Esposito, Pola, Introini. NIM A, in press.

- Bedogni, Domingo, Garcia Fuste, de-San-Pedro, Esposito, Gentile, Tana, d'Errico, Ciolini, Di Fulvio. Radiat. Meas., in press.

(3) Improving and enhancing the existing spectrometric techniques to provide reliable terms of comparisons for the NESCOFI@BTF new instruments

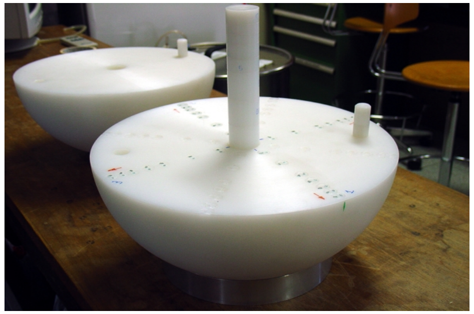
- Radiat. Meas., 46 (2011) 1757-1760.

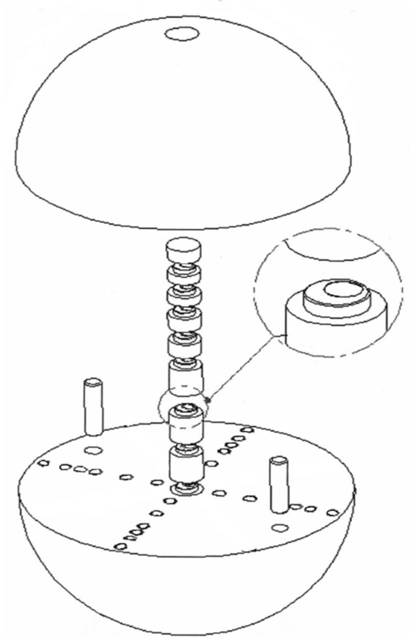
- Radiat. Meas., 46 (2011) 1686-1689.

- Radiat. Meas. 46 (2011) 1737-1740.

Phys-2 Study and optimization of the geometry of the prototype spectrometers

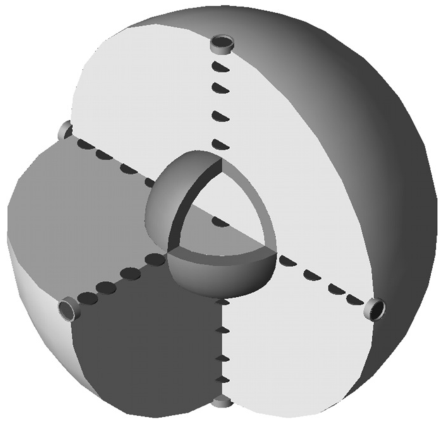
Simulation campaign for SP². Two versions





Low-Energy SP²
37 detectors/ 30 cm diameter / no lead

High-Energy SP²
31 detectors / 25 cm diameter / 1cm Pb



- Radiat. Meas. 46(2011) 1712-1715.
- Nucl. Instr. Meth. A 677 (2012) 4-9.

Phys-3 Testing the experimental prototype spectrometers in neutron reference fields

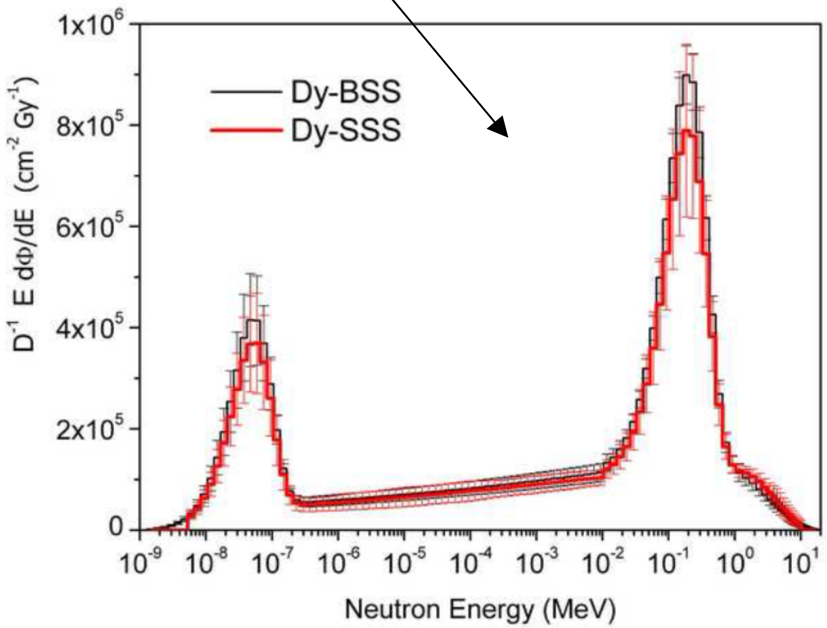
Low-Energy SP^2

Equipped with Dy activation foils, tested in neutron fields previously characterized by a well-known Bonner Sphere spectrometers.

- 2.5 MeV and 14 MeV mono-chromatic neutrons (ENEA Frascati)
- Photo-neutron field produced in a 15 MV medical Linac.

The experimental results confirm that:
-spectrometric capability
-similar performance as the BSS
-Advantage of single exposure

Response matrix accuracy 3%



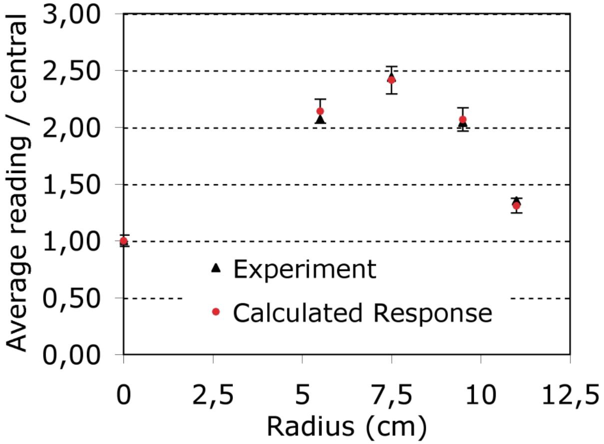
R. Bedogni, J. M. Gomez-Ros, A. Esposito, A. Romero, M. Angelone. Calibration and workplace testing of a single-sphere multi-detector neutron spectrometer. NIM A, in press.

High-Energy SP²

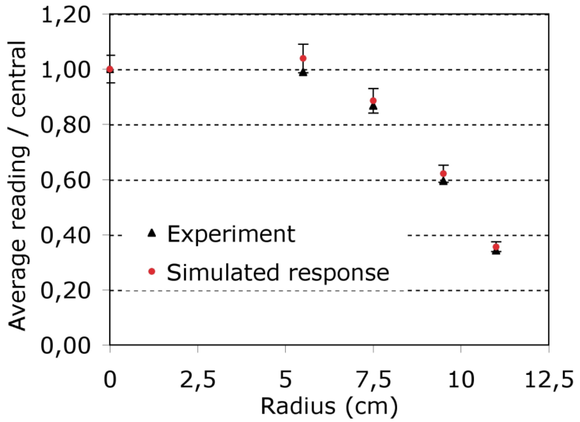
Equipped with Dy activation foils, tested in CALIBRATION neutron fields
- PTB Braunschweig (144 keV, 565 keV, 1.2 MeV, 5 MeV, 14.8 MeV)
- TSL Uppsala (quasi mono-energetic fields at 50, 100, 150 and 180 MeV plus ANITA, a white spectrum with end point at 180 MeV).

The analysis of these data are currently under elaboration (!!), but preliminary results show that the experimental and the calculated responses generally differ by less than 5% for all energies.

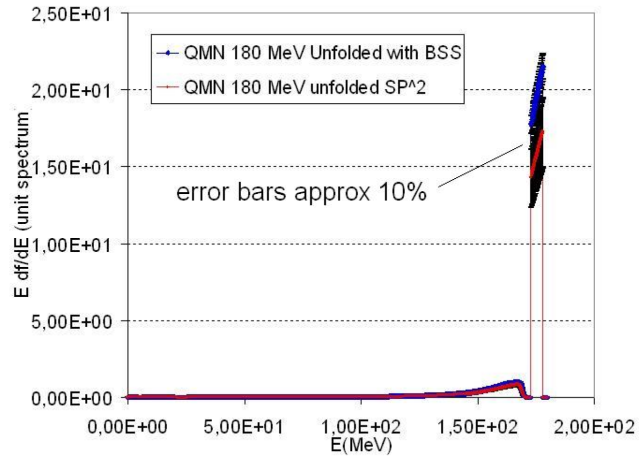
The PTB and TSL experiments have been partially supported by EU FP7 ERINDA 2011 program (PAC 1/3 and PAC 1/8).



1.2 MeV



14.8 MeV



180 QMN

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

Physics activities planned for 2012

X1. CYSP response matrix (01-07-12) See *Gomez* talk

X2. Test of ATND in thermal field (31-10-12) See *Bortot* talk

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

X3. Test of parallelized ATND within mini-CYSP (31-10-12)

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 ATND for Lo-Rate / Hi-Rate (31-12-12)

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

2012 Budget needs / assignment

Missioni interne ………………………………………………………………………… 12 k€ / 3.5 k€

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)

Missioni estere ………………………………………………………………………… 10 k€ / 5 k€

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)

Trasporto strumentazione (DHL via aerea assicurato)………………………….. 4 k€ / 1 k€

4 campagne, 1 k€ cad.

Consumo …………………………………………………………………………..……… 62.5 k€ / 18 k€

Acquisizione circa 60 rivelatori n termici e relativa elettronica (preamplificatori e amplificatori)

Inventario …………………………………………………………………………..……… 42 k€ / 12 k€

Sistema digitale per filtraggio segnali e spettrometria

Spese servizi (beam time NPL e campo da fast neutron irradiation**)……………… 10 k€ / 5 k€**

Costruzione spettrometri finali (moderatori, filtri in Cd e Boro, degradatori in Pb)

TOTALE 140.5 k€ / 44.5 **k€**

(31.7%)

2012 Achievements:

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

ATND in pulse mode

- A single semiconductor detector in-house covered by appropriate converter
- Because thermal neutron signal is a fairly narrow peak, the contribution of photons and other particles can be easily subtracted.
- Acquisition system based on
  1) Detector supply -12 V
  2) charge preamplifier
  3) spectroscopy amplifier
  4) Digital oscilloscope (NI, PICO)
- In view of the simultaneous acquisition of multiple detectors, parts 1) 2) 3) have been integrated and parallelized in portable 8-channels and 2-channels board (currently under test).

2012 Achievements:

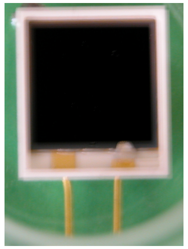
Semiconductor-based ATND, pulse mode.

Disclaimer: *Detector constructive details are reserved because of patenting work pending*

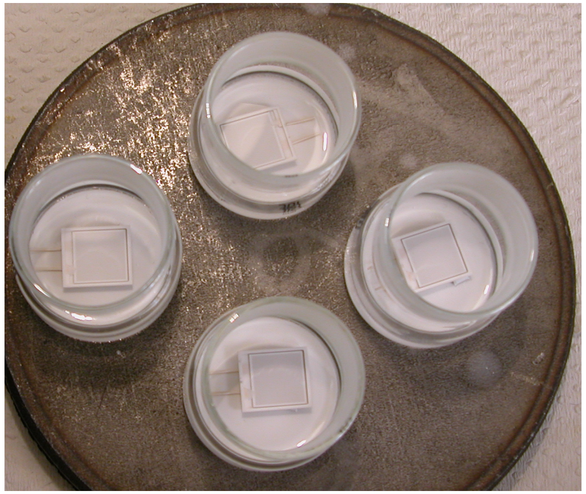
Crucial points are

- choice of the converter type
- deposition technique (deposit thickness well-controlled a posteriori)
- Optimization of the sensitive layer
- Understand detector response and extract thermal neutron signal correctly
- approx 30 native detectors "used" / 60

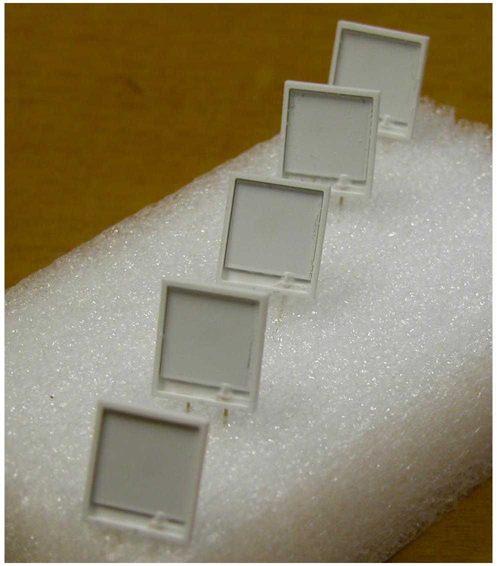
Virgin detector



Deposition factory



Final detectors



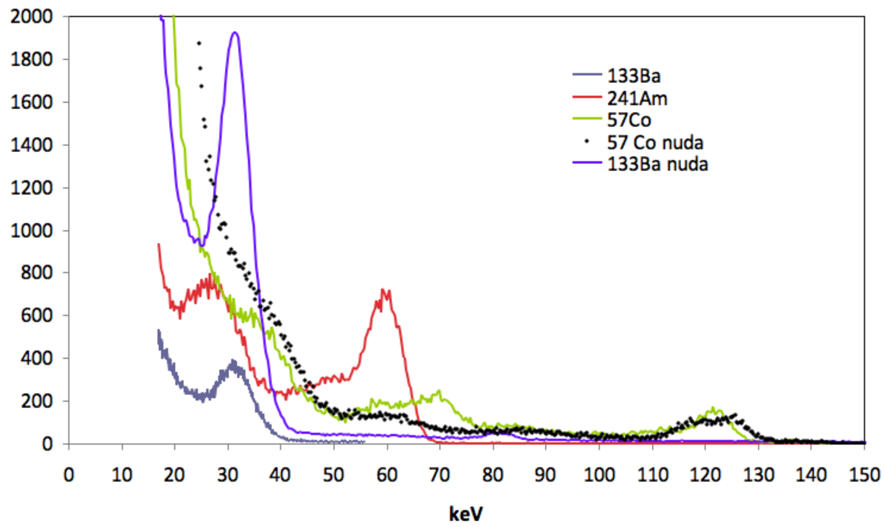
2012 Achievements:

Semiconductor-based ATND, pulse mode.

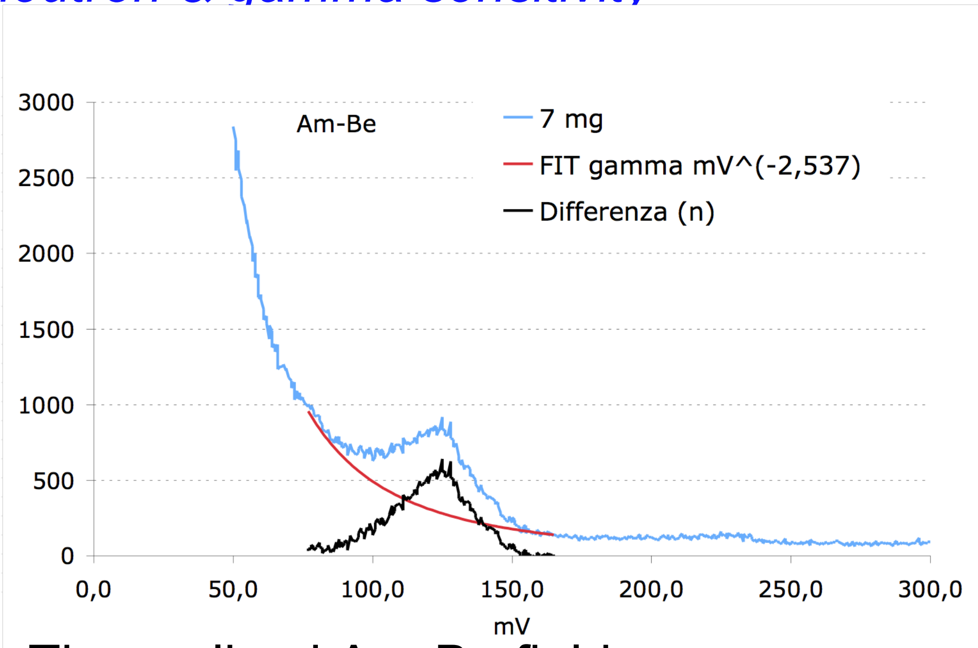
PRELIMINARY tests performed at:

- LNF (Am-Be moderated source), gamma sources
- ENEA Frascati FNG

For every ATND: *individual thermal neutron & gamma sensitivity*



Gamma calibration



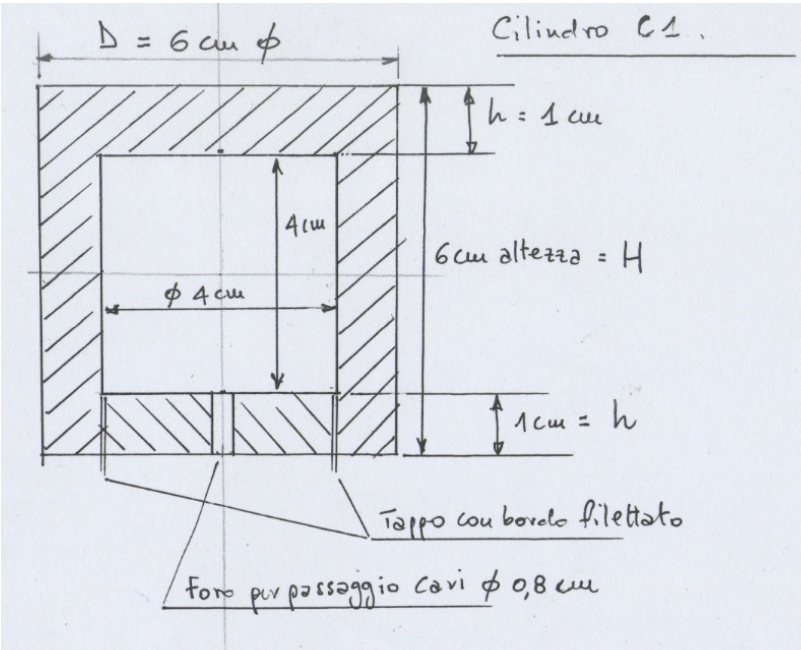
Thermalized Am-Be field

2012 Achievements:

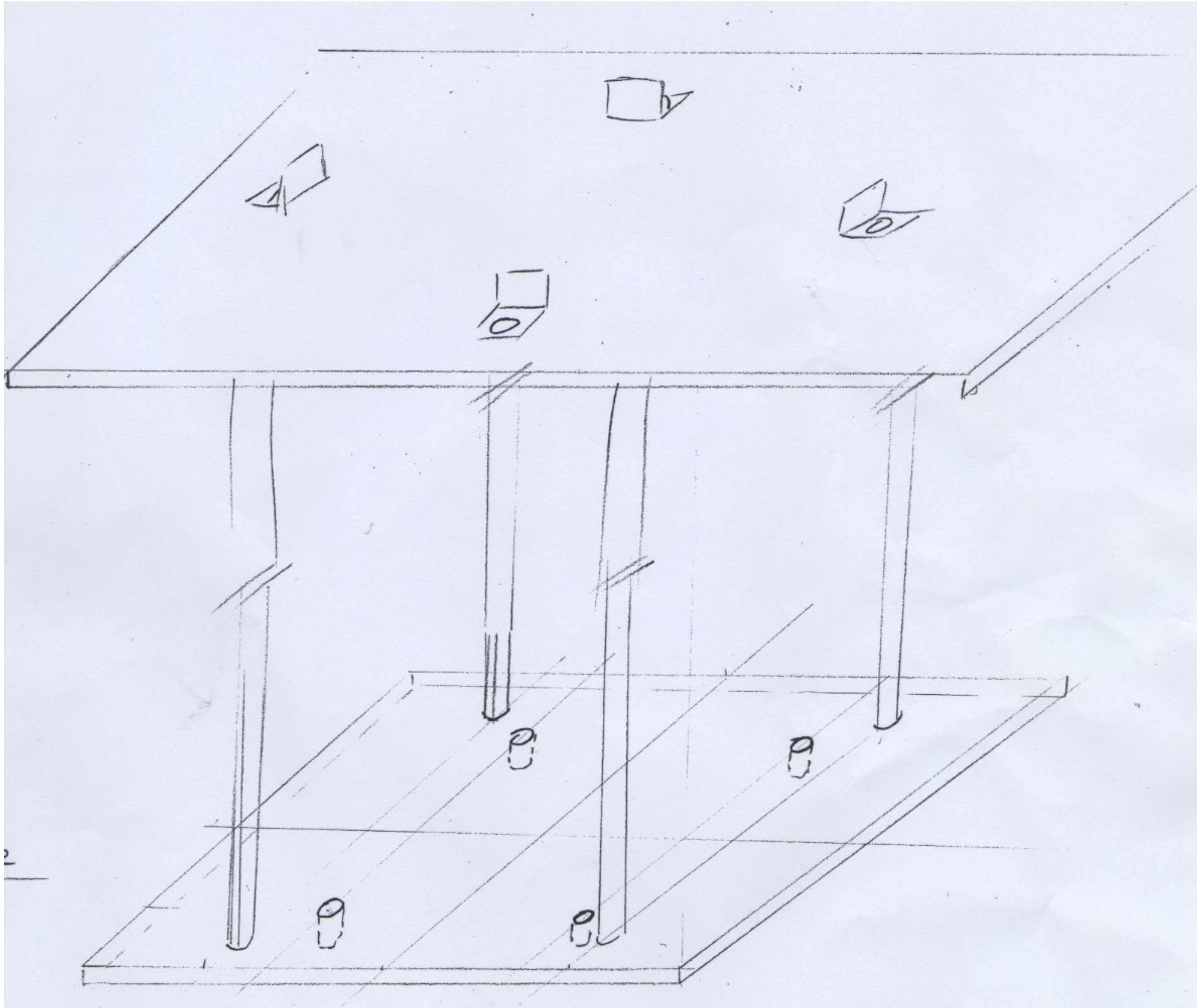
Spectrometric capability of the ATND - pulse mode within moderating structures.

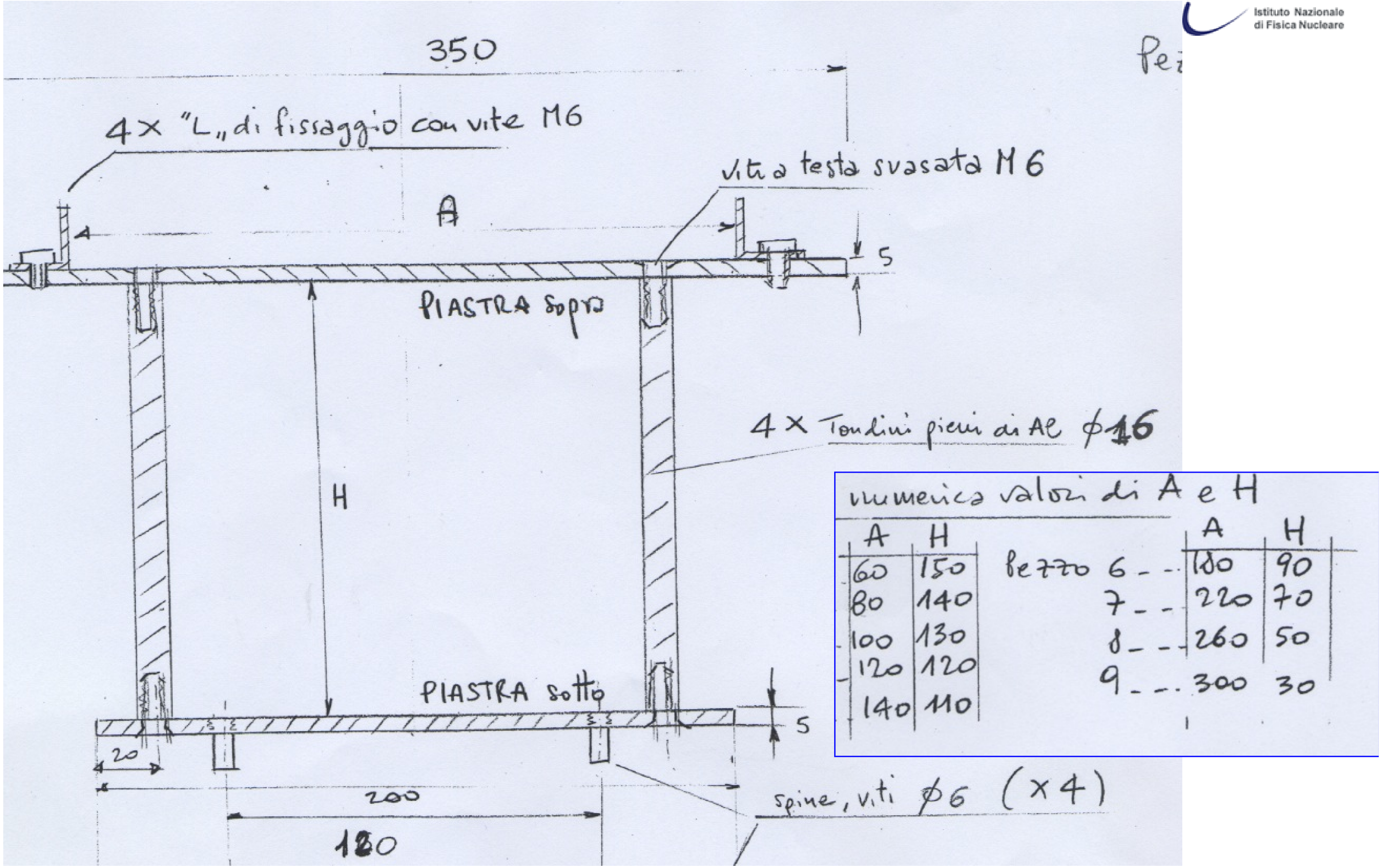
A set of polyethylene cylinders (BSS-like) + related positioning-centering system was fabricated (partially with support of INFN mechanical workshop)

- calculation of cylinders response matrix (to be done in 2012)
- verification under known spectrum (TSL Uppsala, june 2012)



Cilindro	D = H (cm)	h (cm)
C1	6	1
C2	8	2
C3	10	3
C4	12	4
C5	14	5
C6	18	7
C7	22	9
C8	26	11
C9	30	13





A	H
60	150
80	140
100	130
120	120
140	110

	A	H
pezzo 6	180	90
7	220	70
8	260	50
9	300	30

2012 Achievements:

Radiation ageing of ATND in pure thermal n field

(*thermal neutron resistence*)

Done at NPL in thermal field.

No appreciable ageing observed with a cumulative fluence of

5E+10 cm^{-2}

The test should be completed in a reactor where cumulative fluence of 1E+12 can be easy reached in tens of minutes

2012 Achievements:
ATND in current mode

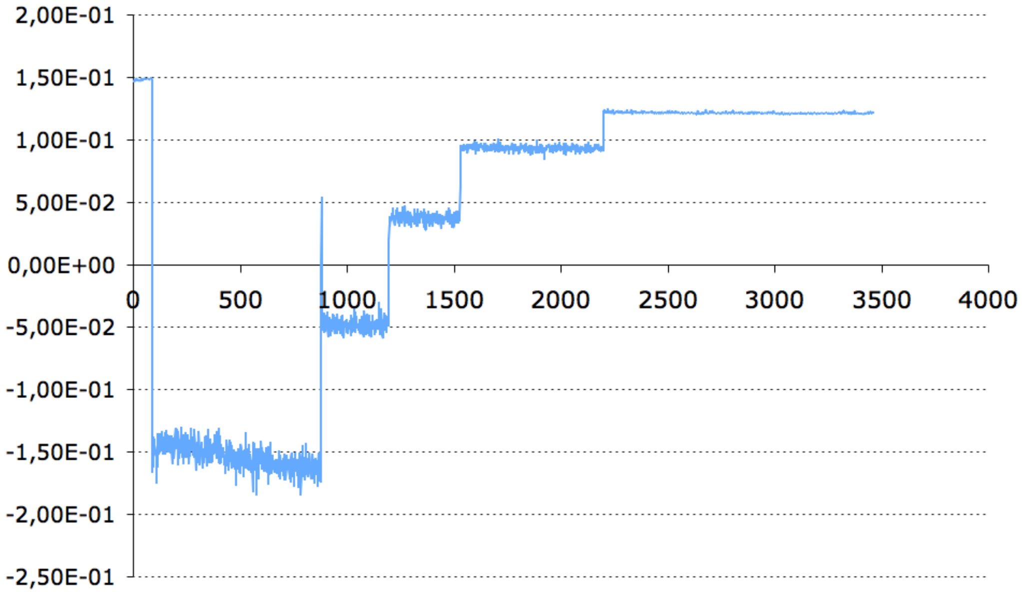
- Similar detector configuration as pulse mode- different DAQ
- Radiation-induced current is sent to an AMP OP. An ADC reads the output DC voltage from a PC.

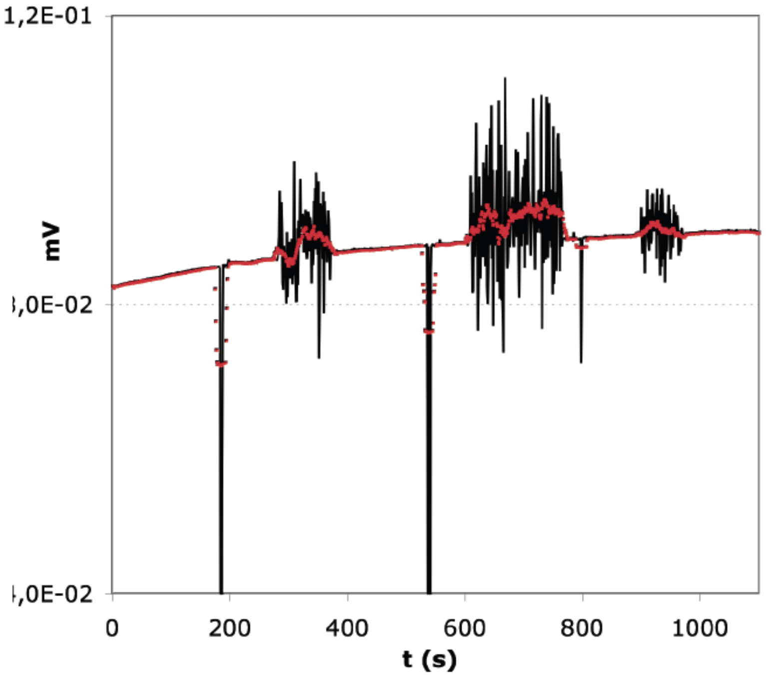
The cost is a factor 10 lower than the ATND solution. Sensitivity is also lower.

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

Stability and reproducibility issues to be addressed and finally solved.

2012 Achievements:
ATND in current mode





Approx. 20 μV / (n cm^{-2} s^{-1}) thermal n

0.8 mV / mGy/h @ 662 keV

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

2012 Achievements (CO-FUNDERS)

Uppsala University
18 - 22 June 2012: TSL Uppsala
44 beam hours in the n field induced by 30 MeV protons on Be + 2500 €

(1) UU request: Characterize the neutron field induced by 30 MeV protons on Be (using standard ERBSS)
(2) OUR request: use this n field to
- test ATND-pulse within set of cylinders
- perform fast n ageing of bare detector
- perform 30 MeV p+ ageing of bare detector
- complete current probe testing

UE CRISP project
4 k€ for detector purchasing
4 k€ trips for experimental campaigns
CRISP request: prove experimental activity on n detectors

Politecnico di Milano
3 k€ trips for experimental campaigns

To be done during 2012

ELABORATION
- Complete elaboration of ERINDA 2011 experiments (passive SP^2 at low & high-E)
- Complete elaboration of NPL 2012 experiments (ATND -pulse or -current in thermal or 565 keV or 5 MeV @NPL)

MEASUREMENT CAMAPAIGNS
- For -pulse mode: complete efficiency & noise vs. depletion layer study
- ATND-pulse testing within set of cylinders (TSL)
- Enhanche radiation ageing in thermal field (in-core column, TRIGA Casaccia, end of June 2012, 10^{12} $cm^{-2}s^{-1}$)
- Perform radiation ageing in p+ & FAST neutrons (TSL, June 2012)
- Test new current-probe (TSL)
- TESTING current-probe in-phantom (in coll. S.Camillo & NEUTOR)

WEB SITE
- important for marketing purposes!

To be done during 2012

ORDERS

- Design and produce a mini-board for current probes
- Design and acquire DAQ for final spectrometers
  - one 8 channel / 2 MS/s / 64MS at home, another ordered
  - 2 slow DAQ (16 SE inputs) at home
  - 2 slow DAQ (32 SE inputs) ORDERED
- ONCE geometry is established, build a CYSP at INFN workshop (BEFORE June !!!)

  to be ordered: lead disk (1000 €) and borated plastic SWX-238 80x80x0.5 cm is $1,150
- 30 native detectors at home + 30 ORDERED (CRISP funds)

PHYLOSOPHY

- Understand HOW small CAN BE the ATND (current or pulse) for final spectrometer's design
- # ATND & # chains per spectrometer:

  CYSP < 10 (ATND and chains)

  SP^2 (sum over 6 but aggregate by 2)

  total 31 ATND & 16 chains
- Establish optimal working conditions of ATNDSs ad their range of response in thermal flux (-pulse or -current)

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)

Publications

(7 publications in peer reviewed journals in 2011), among those:

3 low-E Passive SP^2 testing done

3 high-E Passive SP^2 design done

To do (using 2011 and 2012 data):

- Passive SP^2 testing (2011 experiments)
- CYSP design
- New ATND -pulse (conceptual and basic testing)
- New ATND -current (conceptual and basic testing)
- Mini-CYSP testing (pulse mode)
- Use of current probe to monitor n field in radiotherapy

2013 Budget needs

Missioni interne ……………………………………………………………………… 12 k€
Permanenze al Politecnico o LNF per messa a punto dell'elettronica di acquisizione e testing degli spettrometri (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)

Missioni estere ……………………………………………………………………… 15 k€
1 campagna CALIBRAZIONE low-E NPL (10 gg x 3 persone)
1 campagna CALIBRAZIONE high-E (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€
4 campagne, 2 k€ cad.

Consumo ……………………………………………………………………………..………
Acquisto materiali borati e piombo per SP^2 finale + ……

Inventario ……………………………………………………………………………..………

Officina LNF
Costruzione spettrometri finali (verificare se possono fare una sfera!)

Spese servizi (beam time NPL e TSL)**…………………………………………………… 10 k€**