Open Consultation on Metrology for Radiation Protection

Milano, 5 October 2022

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Lack of calibration facilities for pulsed neutron fields

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Motivation
EURADOS SRA 2020

Application of detectors and instruments in pulsed neutron fields

Modern proton therapy accelerators such as synchrocyclotrons or laser-induced proton beams produce high intensity, micro- or nano-second pulses, which complicates dosimetry with active instruments. New detectors and associated electronics should be developed.

Improved secondary neutron dosimetry, mixed field dosimetry within the treatment room and inside the patient

Current dosimetric techniques are not sufficiently developed to enable full discrimination between neutron and photon components of the secondary irradiation fields. New methods should be developed which properly measure these components at the therapeutic dose-rates.

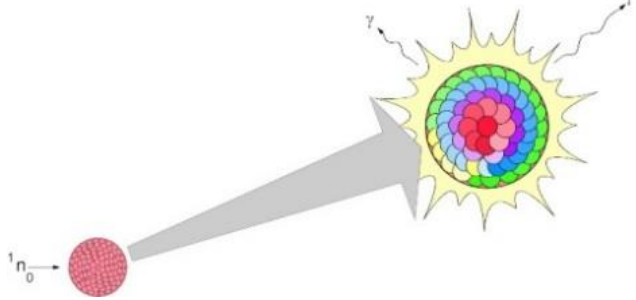
https://eurados.sckcen.be/-/media/Files/Eurados/announcements/2020/0809_Report-2020-04/EURADOS-Report-2020-04.pdf?la=en&hash=348BABCEF87B71988A353B9B0CFB33380C342DE8

Pulsed radiation facilities

Particle accelerators



Material testing
FEL-Laser driven accelerators

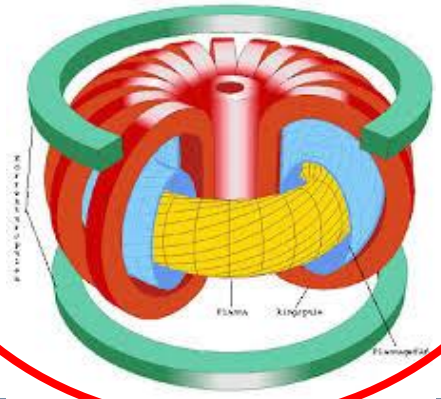


synchrocyclotron



FUTURE?

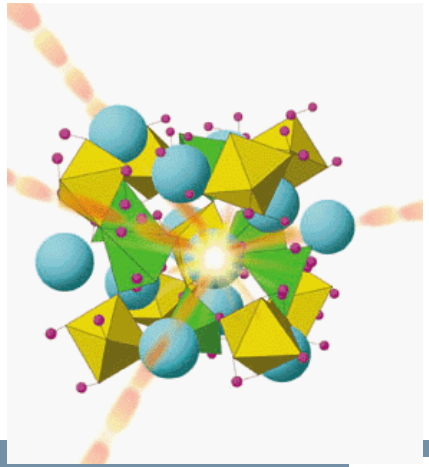
Fusion facilities



Radiation therapy



Spallation sources

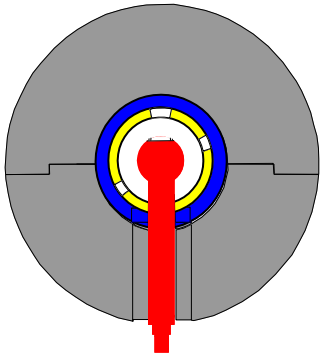


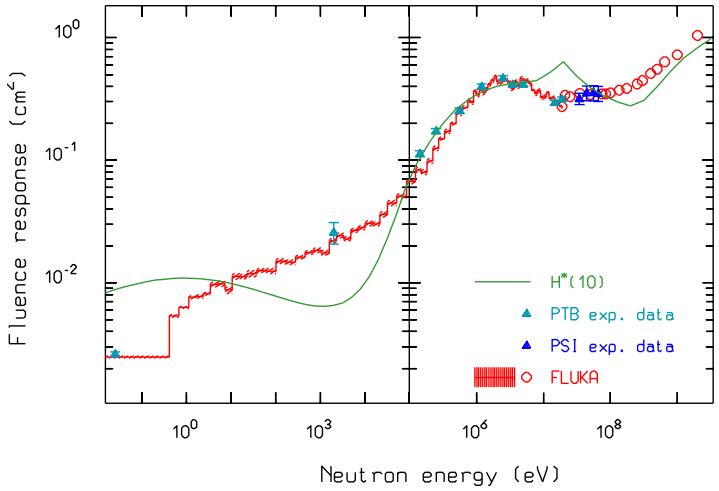
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REM counters

A hypothetical instrument with a response function parallel to the fluence to dose conversion coefficients should have a constant response in terms of H*(10).

$$K = \frac{h^*(E)}{R(E)}$$





$$H^*(10) = \int h^*(E) \cdot \phi(E) dE = \int K \cdot R(E) \cdot \phi(E) dE = K \int R(E) \cdot \phi(E) dE = KL$$

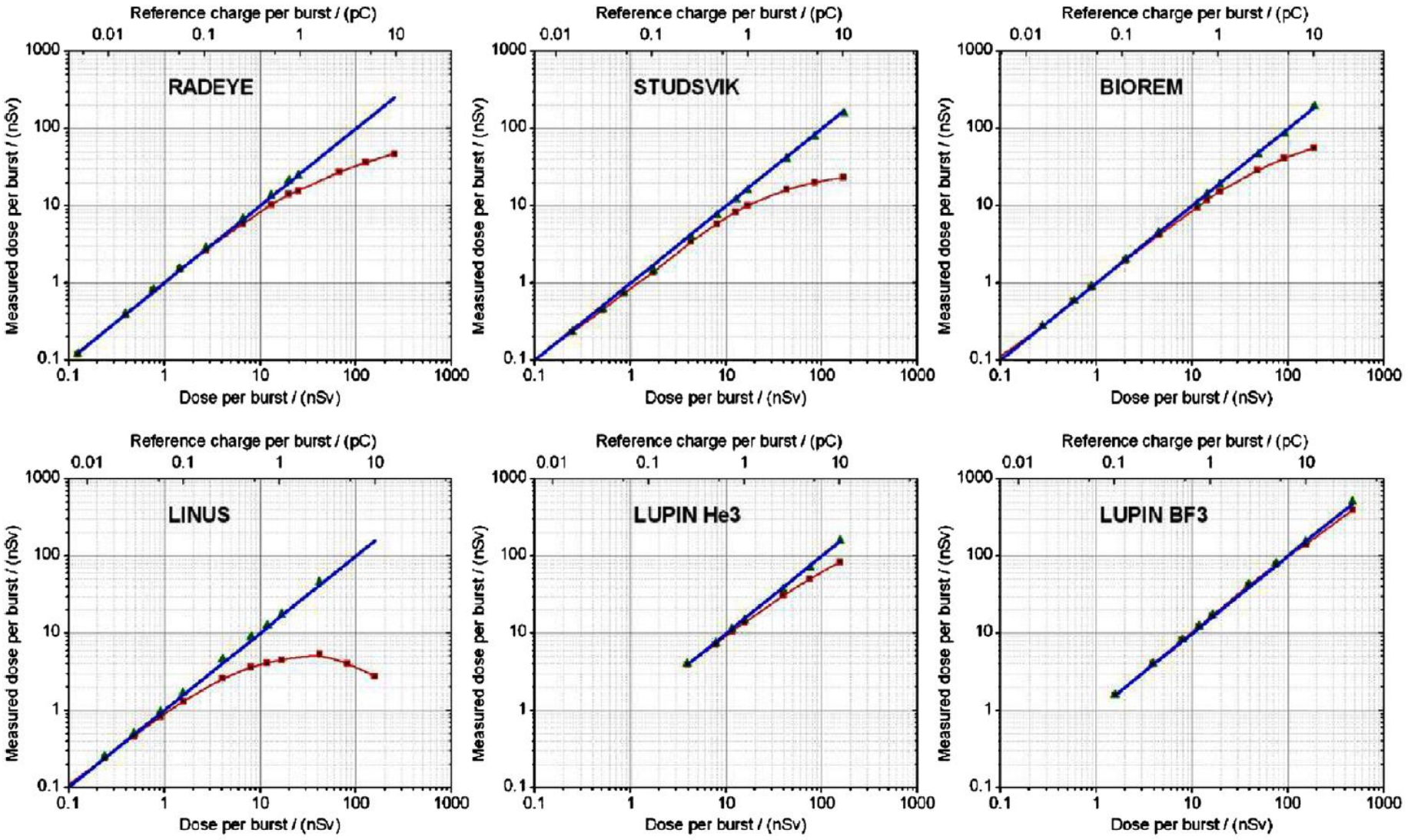
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WG11 experience

Setting number	Ion current [pA]	Burst current [nA]	Burst length [µs]	Burst charge Q_i [fC]	Reference burst yield [nSv per burst]	Average dose rate [µSv·h^{-1}]	Burst dose rate [Sv·h^{-1}]
1	0.5	5	1	5	**0.077**	27.72	0.28
2	1.5	15	1	15	**0.231**	83.16	0.83
3	3	30	1	30	**0.462**	166.32	1.66
4	5	50	1	50	**0.770**	277.2	2.77
5	10	100	1	100	**1.540**	554.4	5.54
6	25	250	1	250	**3.850**	1386	13.86
7	50	500	1	500	**7.700**	2772	27.72
8	75	750	1	750	**11.550**	4158	41.58
9	100	1000	1	1000	**15.400**	5544	55.44
10	250	250	10	2500	**38.500**	13860	13.86
11	500	500	10	5000	**77.000**	27720	27.72
12	1000	1000	10	10000	**154.000**	55440	55.44
13	3000	800	40	32000	**492.800**	177408	44.35

http://dx.doi.org/10.1016/j.nima.2013.11.073

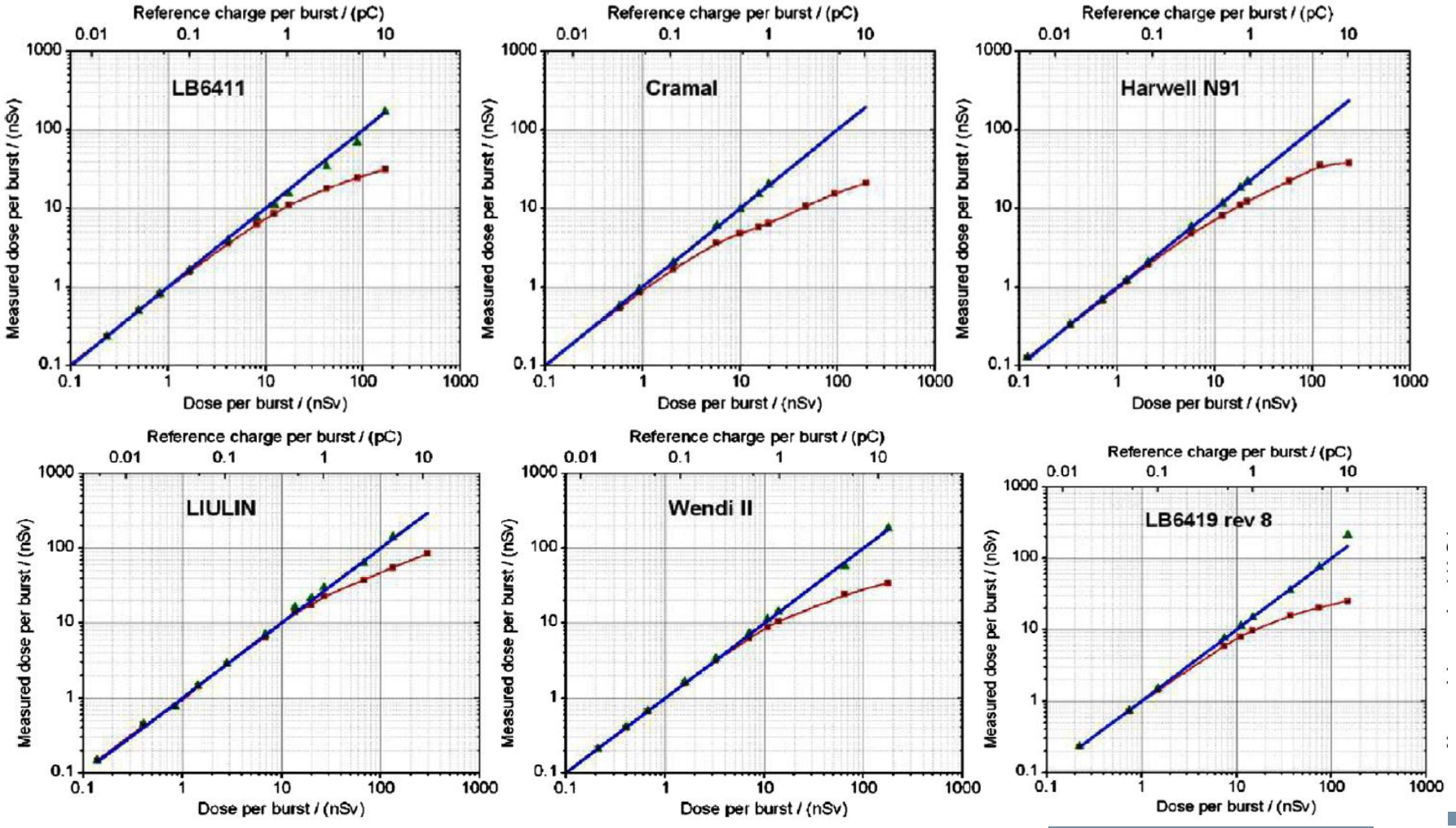
Rem counters comparison



http://dx.doi.org/10.1016/j.nima.2013.11.073

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Rem counters comparison



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Conclusions

Main remarks

1. Most of neutron workplace fields have a pulsed time structure.

2. REM counters linearity starts fail at about 10 nSv/burst

(10 nSv x 10 Hz)x3600 s = 360 µSv/h

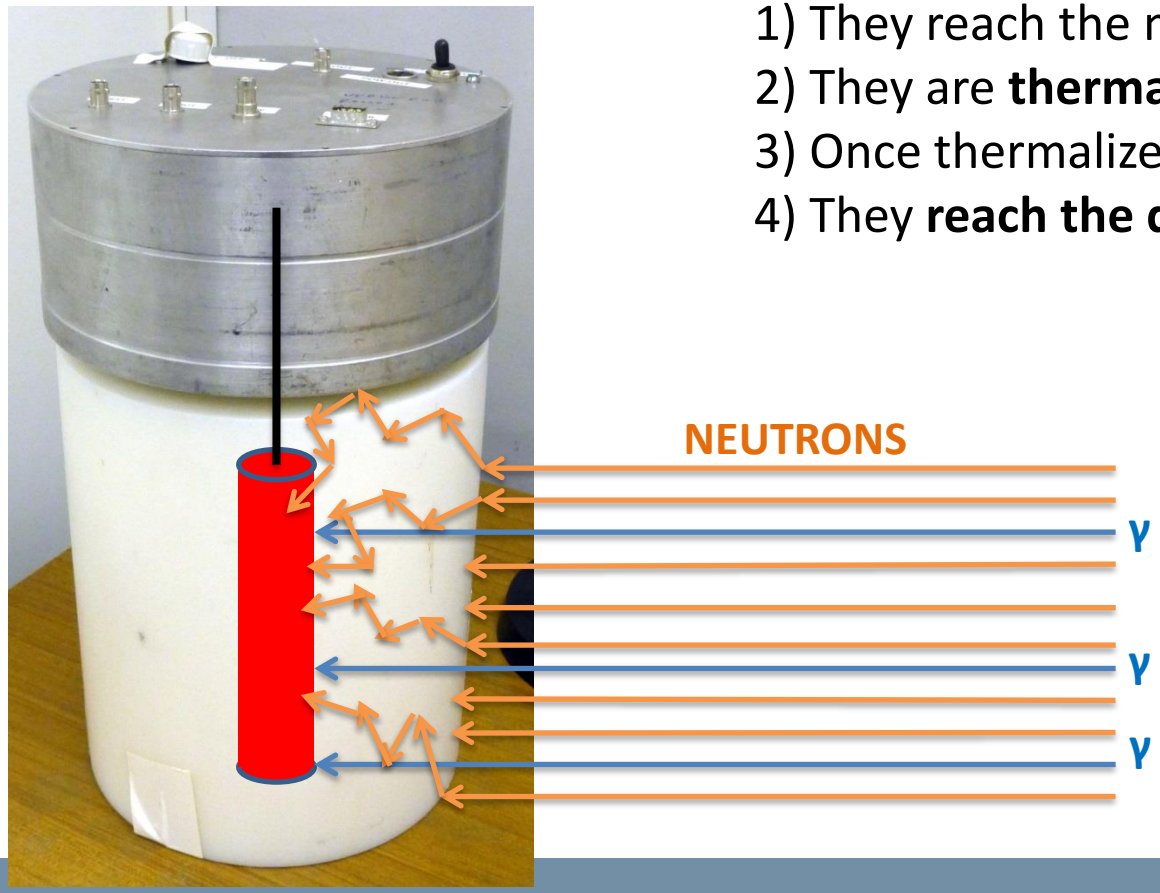
3. **At present a reference facility for pulsed neutrons is not available. A metrological effort to fill this gap is needed.**

Thanks for your attention

Backup slides

Pulsed neutrons

Detection of pulsed **neutron** fields shows an advantage, if compared to photons



Neutron detection mechanism:

1) They reach the moderator surface
2) They are **thermalized** (scattering events)
3) Once thermalized they **diffuse**
4) They **reach the detector** (BF_3 or ^3He)

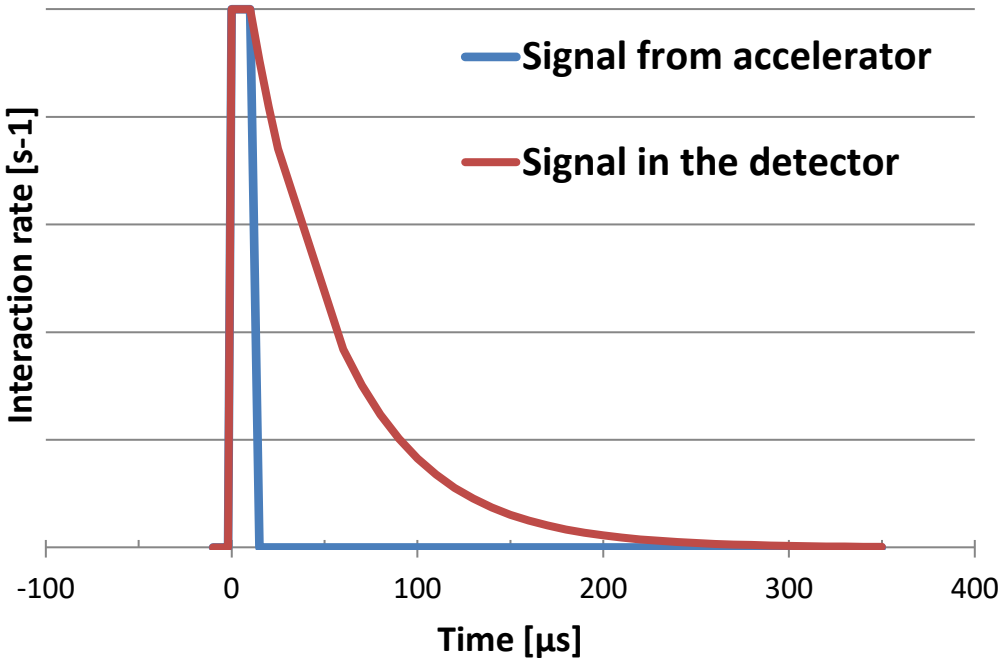
Photons do not need thermalization in order to be detected

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Pulsed neutron

Performances of detectors (rem counters) in pulsed neutron fields:

- **Dead time effects (↓)**
- **Neutrons thermalization and diffusion time (TDT) in the moderator (↑)**



Signal in the detector spread over several hundred µs, regardless of the original pulse width

↓

REDUCED UNDERESTIMATION

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Pulsed neutrons

N(t) = number of thermalized neutrons that reach the gas at a time t:

$$N(t) = N_0 \cdot e^{-t/\tau'}$$

τ' = decay constant of the neutrons in the moderator
(depends only on materials, size and shape of the moderator)



τ' ≈ 140 μs for conventional spherical PE moderators (10-inch diameter sphere)
τ' ≈ 70 μs for cylindrical PE moderators

enriched with Pb and Cd
(extended range detectors)

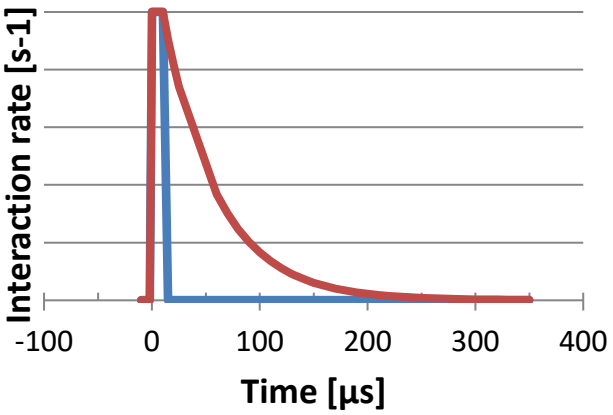


http://refhub.elsevier.com/S0168-9002(13)01635-5/sbref23

Pulsed neutrons

counter typical sensitivity 1-2 counts per nSv

Signal shaping time 2-3 µs



$$N(t) = N_0 \cdot e^{-t/\tau}$$

10 nSv pules → 20 counts

τ=70 µs 68% of counts expected in 70 µs

Interaction rate 0,5 – 1 MHz

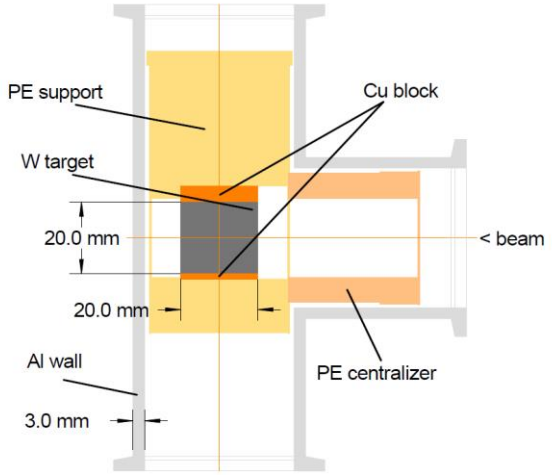
Strong dead time losses

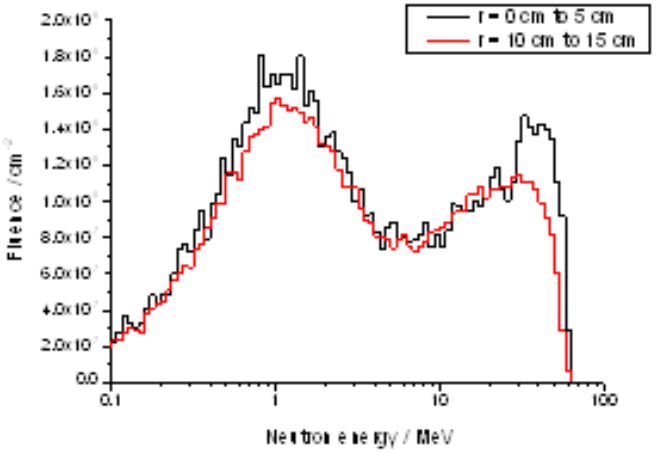
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WG11 experience
Berlin Experiment

Test at HZB 68 MeV protons on W







The proton beam is delivered in bursts with duration of 1 μs, 10 μs, 40 μs

http://dx.doi.org/10.1016/j.nima.2013.11.073

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WG11 experience

Tested Rem counters

1. WENDI-II
2. LUPIN-3He
3. LB 6419 3He
4. Studsvik 2202D
5. Linus
6. LUPIN BF3
7. LB 6411
8. BIOREM
9. Cramal31
10. Harwell N91
11. Radeye
12. Liulin

http://dx.doi.org/10.1016/j.nima.2013.11.073

Measurements at Mevion S250i pulsed proton therapy facility (WG9+WG11)

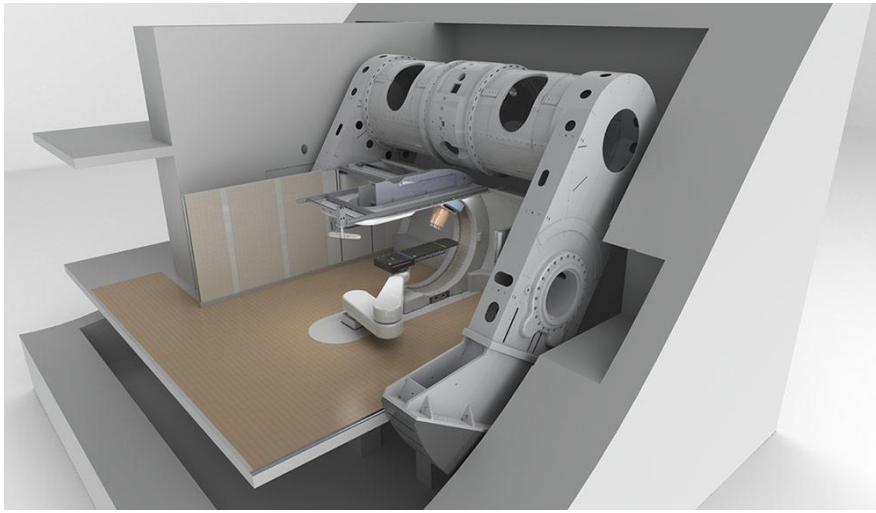
Compact 10 T field synchrocyclotron which requires a single vault of limited dimensions

The proton spots are delivered through a pair of scanning magnets.

The depth of the Bragg peak is modulated by an energy degrader consisting of 18 Lexan (polycarbonate) plates.

minimum proton energy 13.49 MeV
maximum proton energy 227 MeV

the nickel-alloy multi-leaf beam collimator to reduce the lateral penumbra.



Courtesy Mevion

Proton beam delivered in pulses 10 μs in duration at 750 Hz Max

http://dx.doi.org/10.1017/S1460396920000266

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