Photoneutron interrogation of U samples by a 4 MeV LINAC - a feasibility study

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1. Introduction

Field: Combating illicit trafficking of nuclear materials (NM)

Need of a method suitable for revealing smuggled NM at border checkpoints; a "portal monitor"

Shielding of smuggled NM hinders detection by direct methods;

passive γ-detection impossible

However, neutrons penetrate shielding → induce fission in NM

Active n-interrogation: detection of fission neutrons

Nuclear material to be assayed**: Seized low enrichment UO_2 (LEU) samples**

2. Method (1)

Advantage of accelerator use: can be switched off

Our small LINAC :Tesla LPR-4; 4 MeV, 100 W max.

Producing photoneutrons: **(e,γ)+(γ,n) double conversion**

D(γ,n)H: threshold energy 2.22 MeV

Energy threshold of (γ,n) reaction below 4 MeV for Be and D only

D: no environmental risk

Interrogation: U(n,f): → fission products+ prompt neutrons

→ +delayed neutrons

Distinction of fission neutrons from interrogating ones:

time discrimination by detection of delayed neutrons

Irradiation possibilities by electron pulses :

-- cyclic: 50, 25, 12.5, or 6.25 Hz

-- single: external triggering

-- pulse length: 2.6 μs

-- mean electron current: 26 μA max.

2. Method (2)

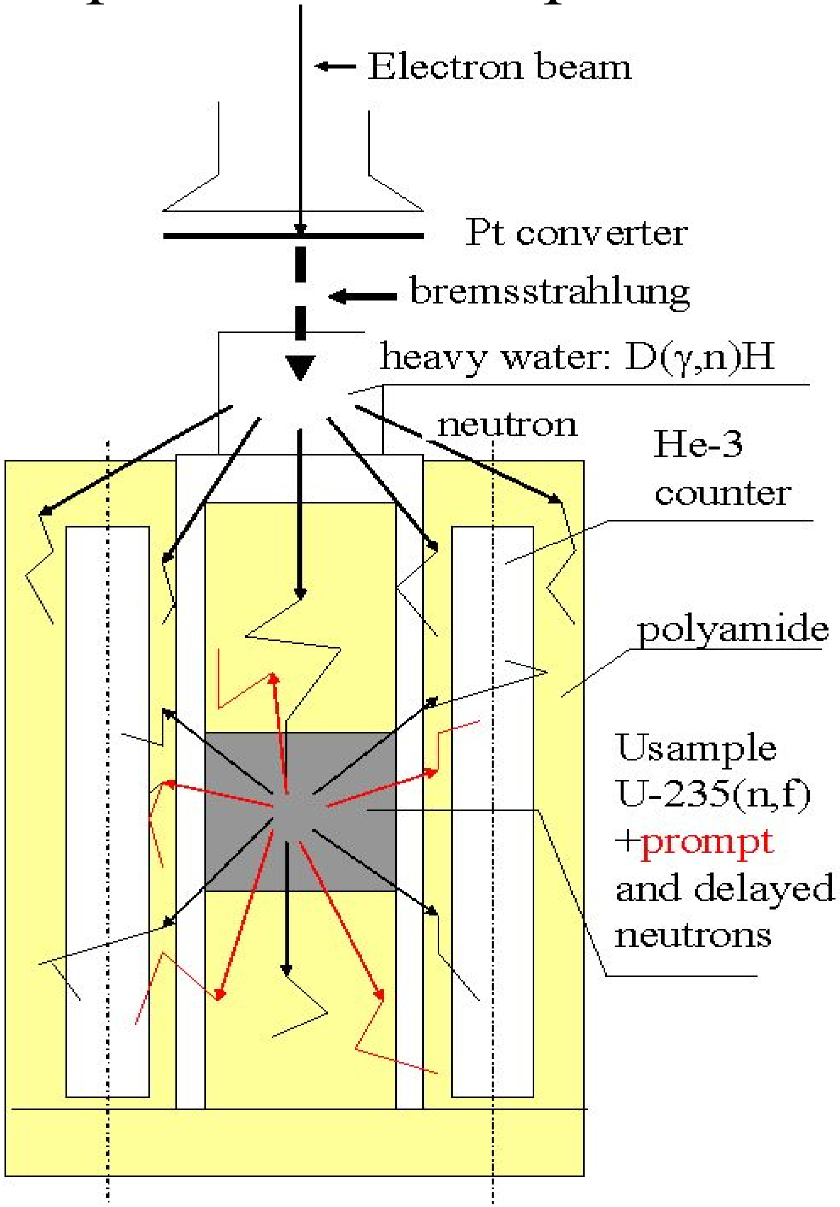
RELATIVE YIELDS AND INTENSITIES OF THE DELAYED NEUTRON GROUPS FROM ^{235}U FISSION INDUCED BY FAST NEUTRONS, AT SATURATION

Group	$T_{1/2}$ (s)	Rel. yield (%)	Rel. intensity (%)
1	0.179	2.6	**23.1**
2	0.496	12.8	**41.1**
3	2.23	40.7	**29.1**
4	6.0	18.8	**5.0**
5	21.84	21.3	**1.6**
6	54.51	3.8	**0.11**

Relative intensities obtained by multiplying yields with respective decay constants. Contribution of the first three groups predominates, i. e. the number of delayed neutrons goes into saturation in the first ten seconds of irradiation.

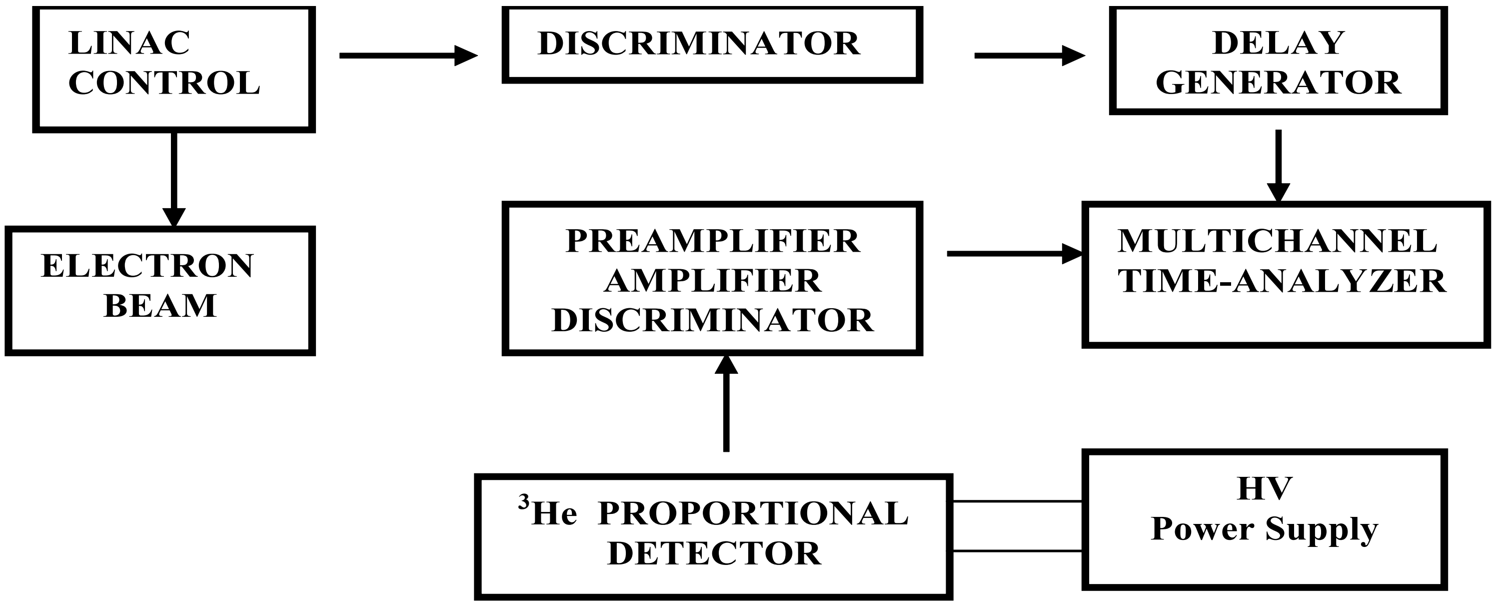
3. Experimental setup (1)

Neutron collar:
Two concentric polyamide cylinders: diam. 20x42 cm. Cavity (inner cylinder) for the material to be assayed: diam. 5.5 cm



3. Experimental setup (2)

Schematic block diagram



Time analyser start-up by external triggering: synchronized with LINAC control

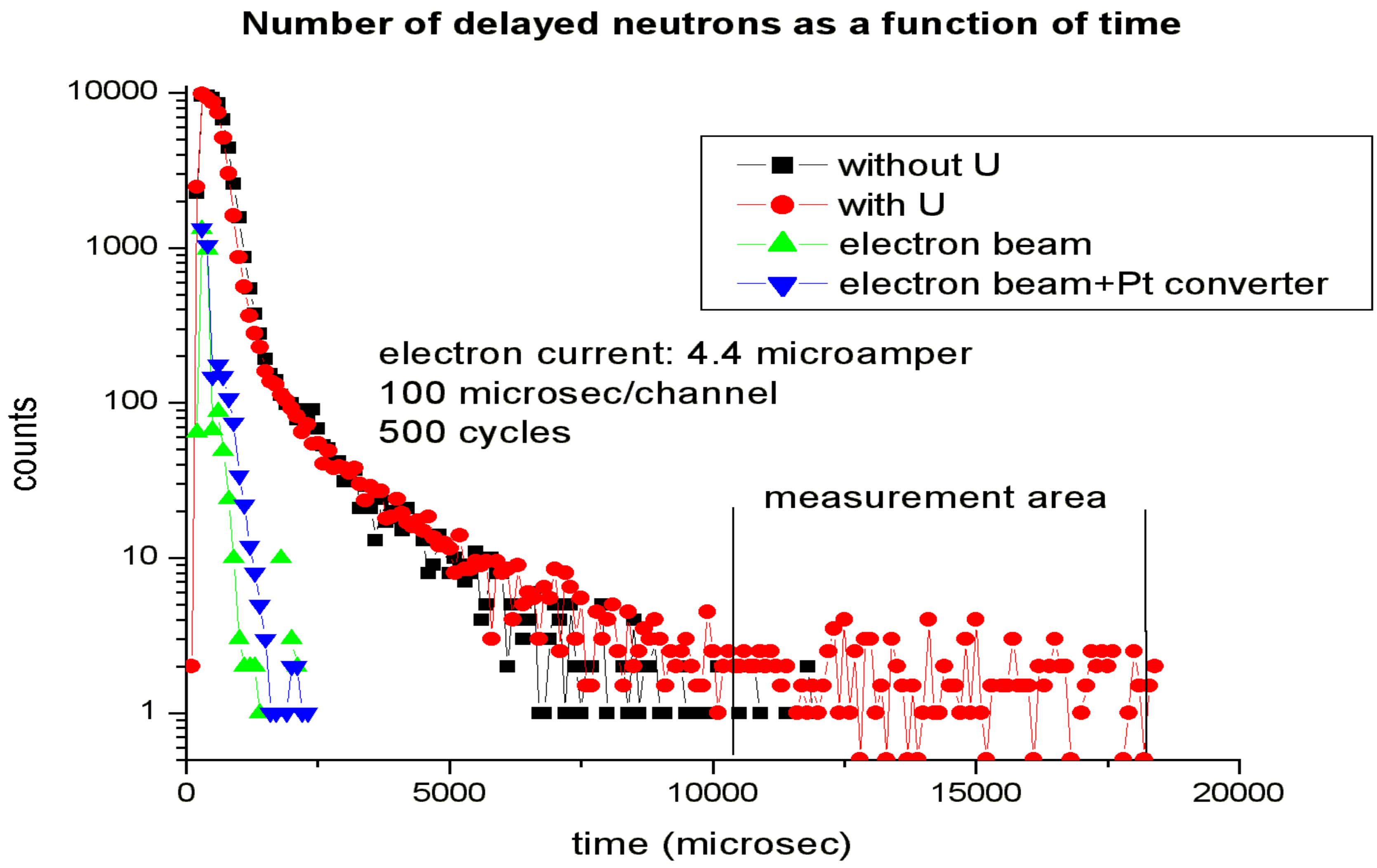
4.1. Measurements (1)

First measurement campaign:

- **He-3 tube: 1 pc**
- **512 channel, 100 μs/channel, 500 cycle, 50 Hz**
- **One measurement: 500x20 ms = 10 s**

Measurements by various amounts of: heavy water, U, and various electron current intensities

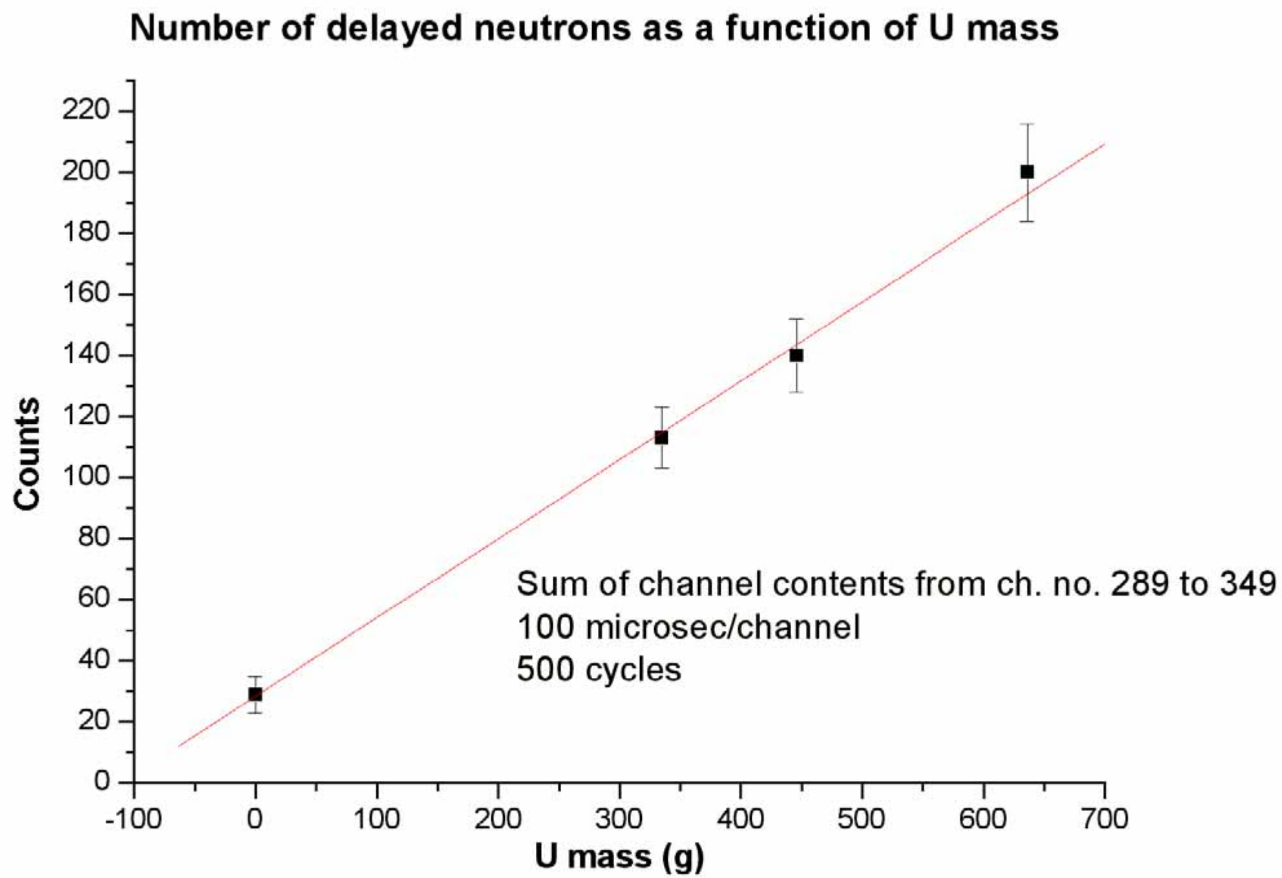
4. 1. Measurements (2)



4.1. Measurements and results (3)

Response to the amount of U mass

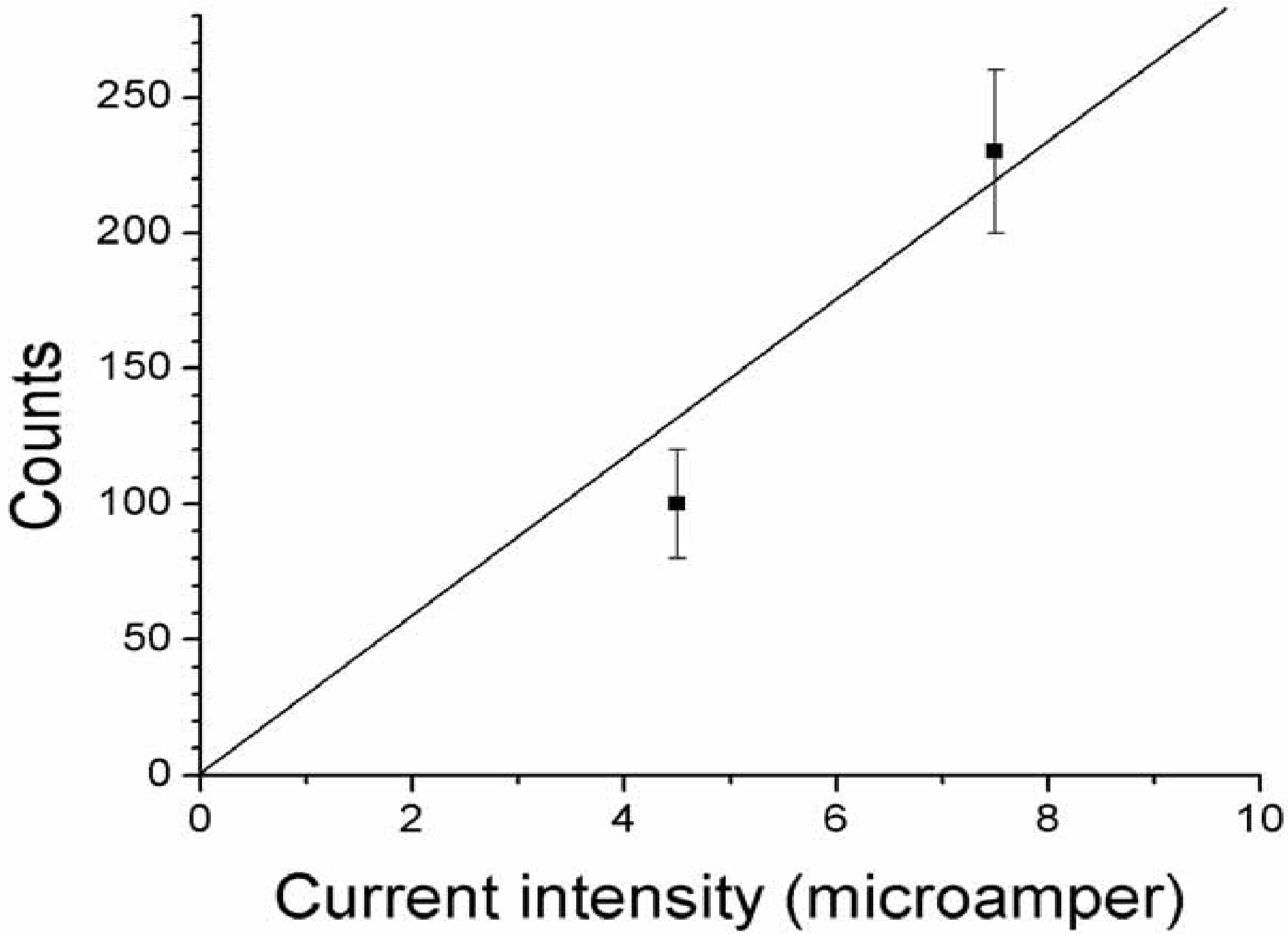
(2.7 % enr.; 4.4 μA; 105 g D_2O; 50 Hz, 500 cycles)



4.1. Measurements and results (4)

Delayed neutron counts against electron current

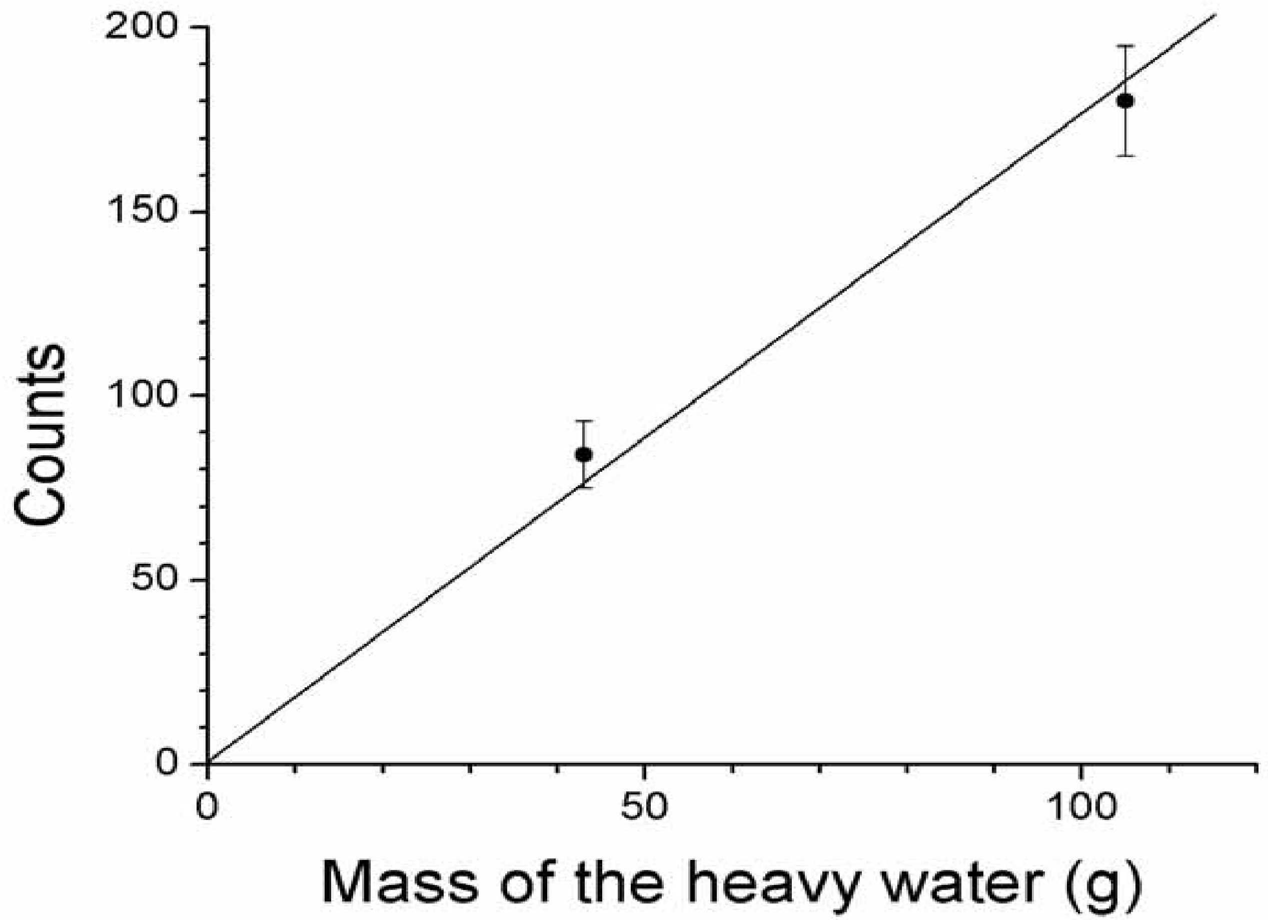
(427g UO2 sample, 2.7 % enr.;105 g D_2O; 50 Hz, 500 cycles)



4.1. Measurements and results (5)

Delayed neutron counts against amount of heavy water

(427 g UO2 sample, 2.7 % enr.; 4.4 µA; 50 Hz, 500 cycles)



4.2. Measurements (1)

DELAYED NEUTRON COUNTS (SATURATED)

FROM 336 g UO_2 (2.7 % enr.), ACQUIRED IN 200 CYCLES, 4.4 µA, 105 g D_2O

Pulse frequency (Hz)	**50**	**25**	**12.5**	**6.25**
Measurement time/pulse (ms)	10	30	70	150
Total effective measurement time (s)	2	6	14	30
Number of counts	**50(5)**	**90(10)**	**85(10)**	**60(10)**
Count rate (cps)	25(2.5)	15(1.5)	6(1)	2(0.5)

Optimum frequency: 25 Hz

By reducing frequency, number of delayed neutron counts grows up first, as expected, because the effective measurement time increases; then starts to decrease, because the saturation level of count rate decreases

4.2. Measurements (2)

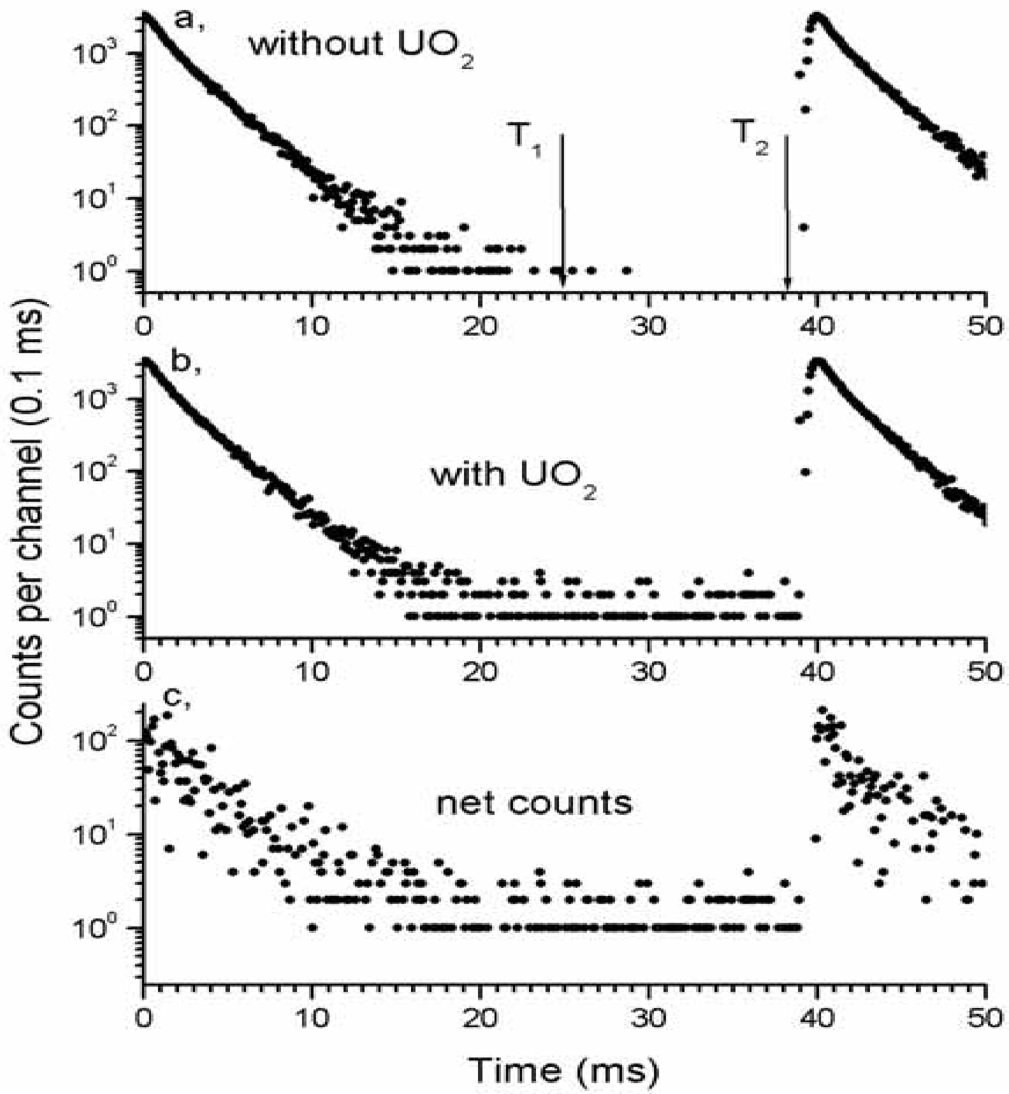
Second measurement campaign:

- **He-3 tubes: 4 pc**
- **512 channel, 100 μs/channel, 500 cycles, 25 Hz**
- **One measurement: 500x40 ms = 20 s**
- **Electron current intensity: 2.2 μA**
- **Heavy water: 103 g**

Measurements of U samples of various amounts and enrichments

4.2. Measurements (3)

Time spectrum of the neutron pulse

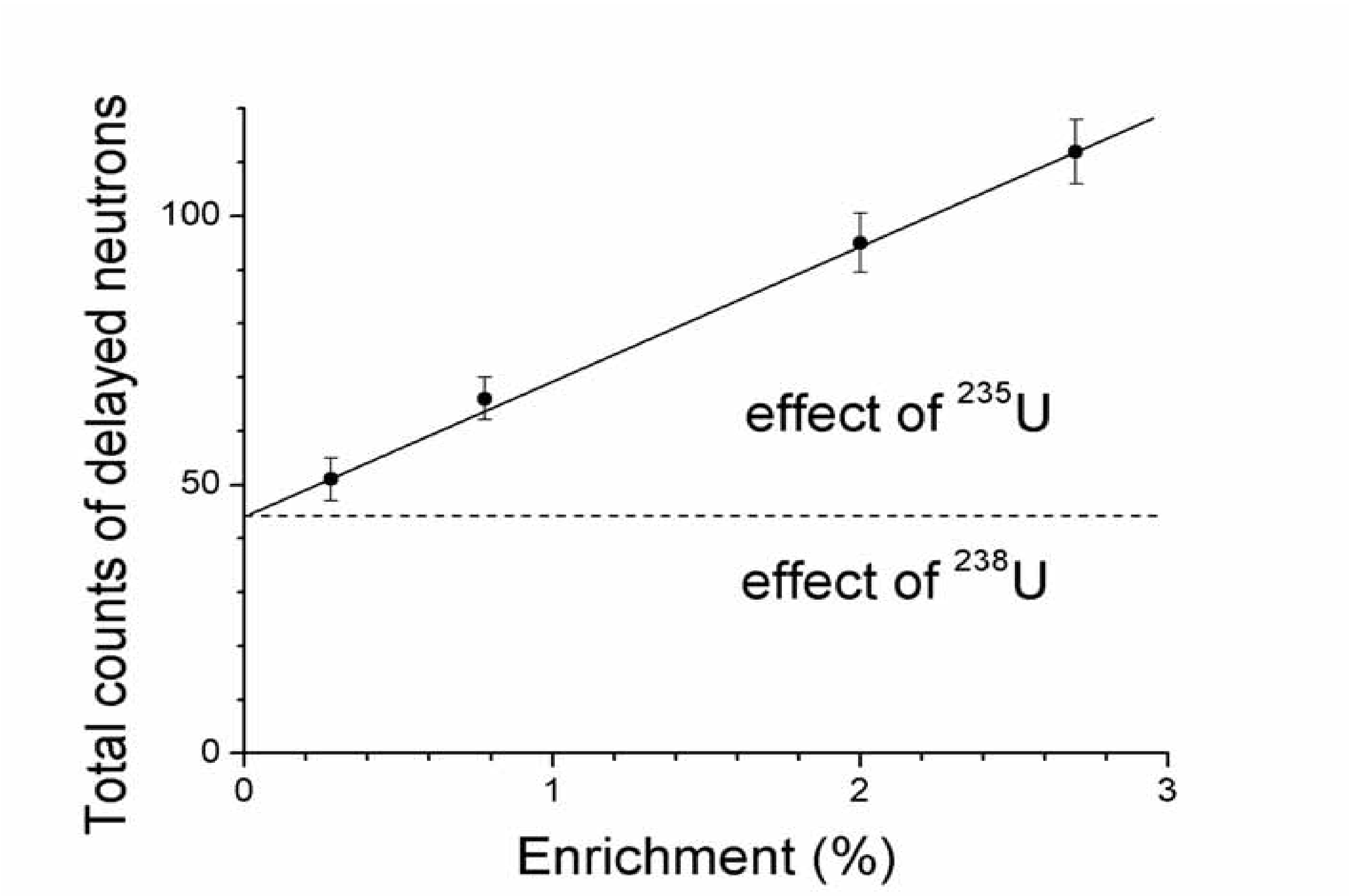


427 g UO_2 (2.7 % enr.)

Response cannot be enhanced by reducing frequency, because saturation level of delayed count rate decreases correspondingly

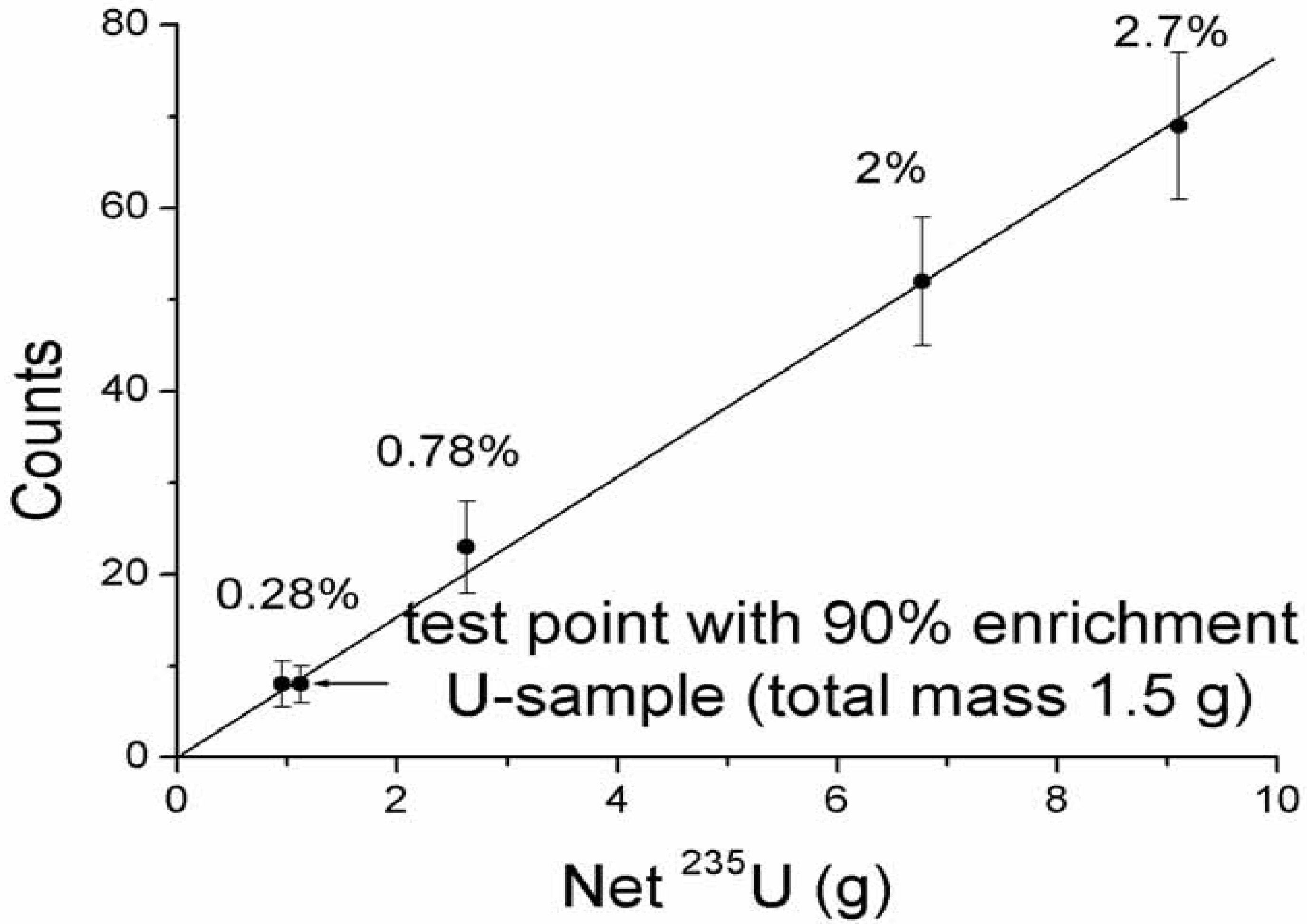
4.2. Measurements and results (4)

Response to the enrichment (normalized to 400 g UO_2)



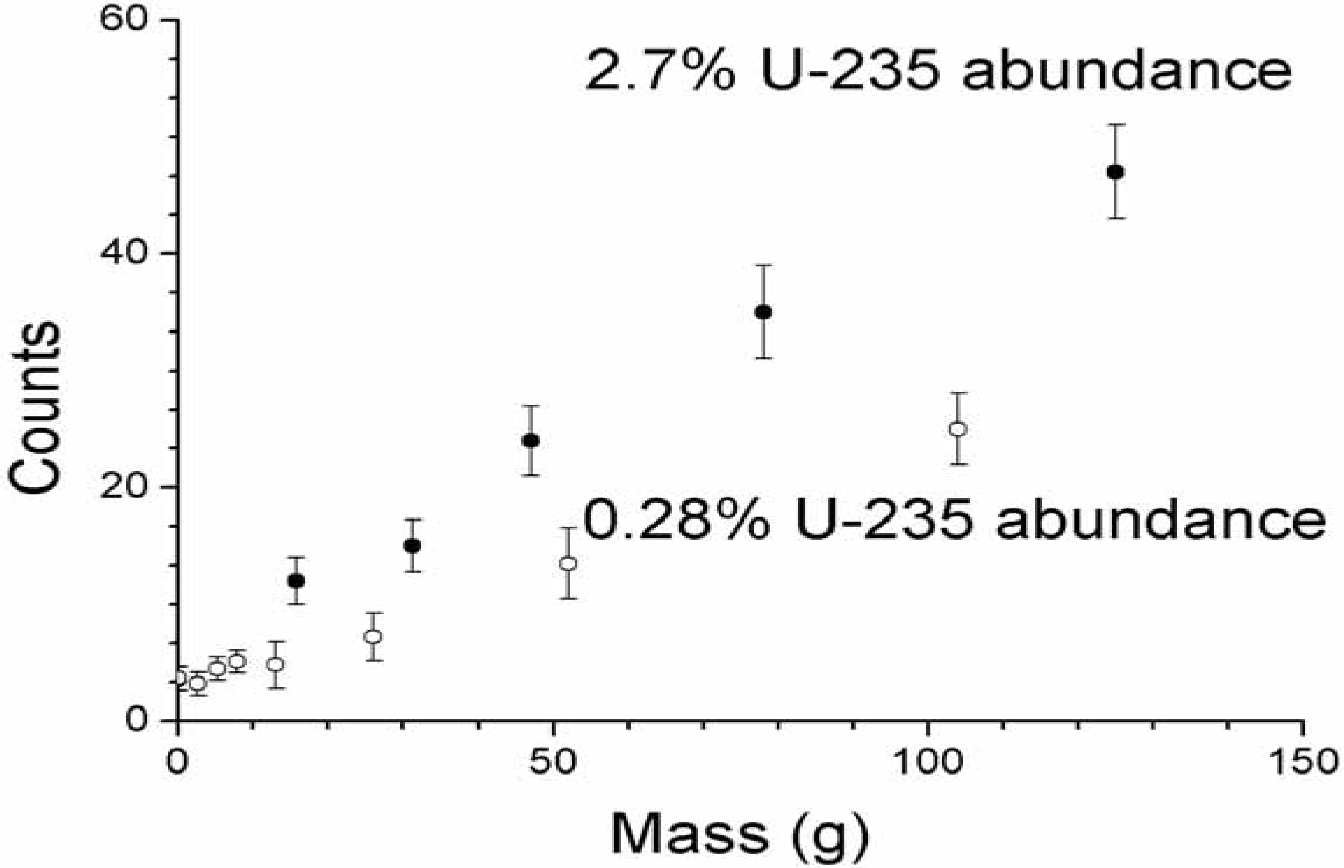
4.2. Measurements and results (5)

Response to the ^{235}U mass (normalized to 400 g UO_2)



4.2. Measurements and results (6)

Response to the total U mass



5. Conclusions (1)

- **A linear relationship was found between the delayed neutron signal on one hand, and the electron current, the amount of heavy water, the enrichment, and the total amount of U mass on the other hand.**
- **A sensitivity limit as 0.5 g ^{235}U and/or 30 g ^{238}U can be achieved in a 20 s measurement time (500 cycles) with the amount of heavy water of 100 g and a mean electron current intensity of 2.2 µA.**
- **The results are – in general - promising in respect of designing an active portal monitor for revealing unauthorised transportation of nuclear material.**

5. Conclusions (2)

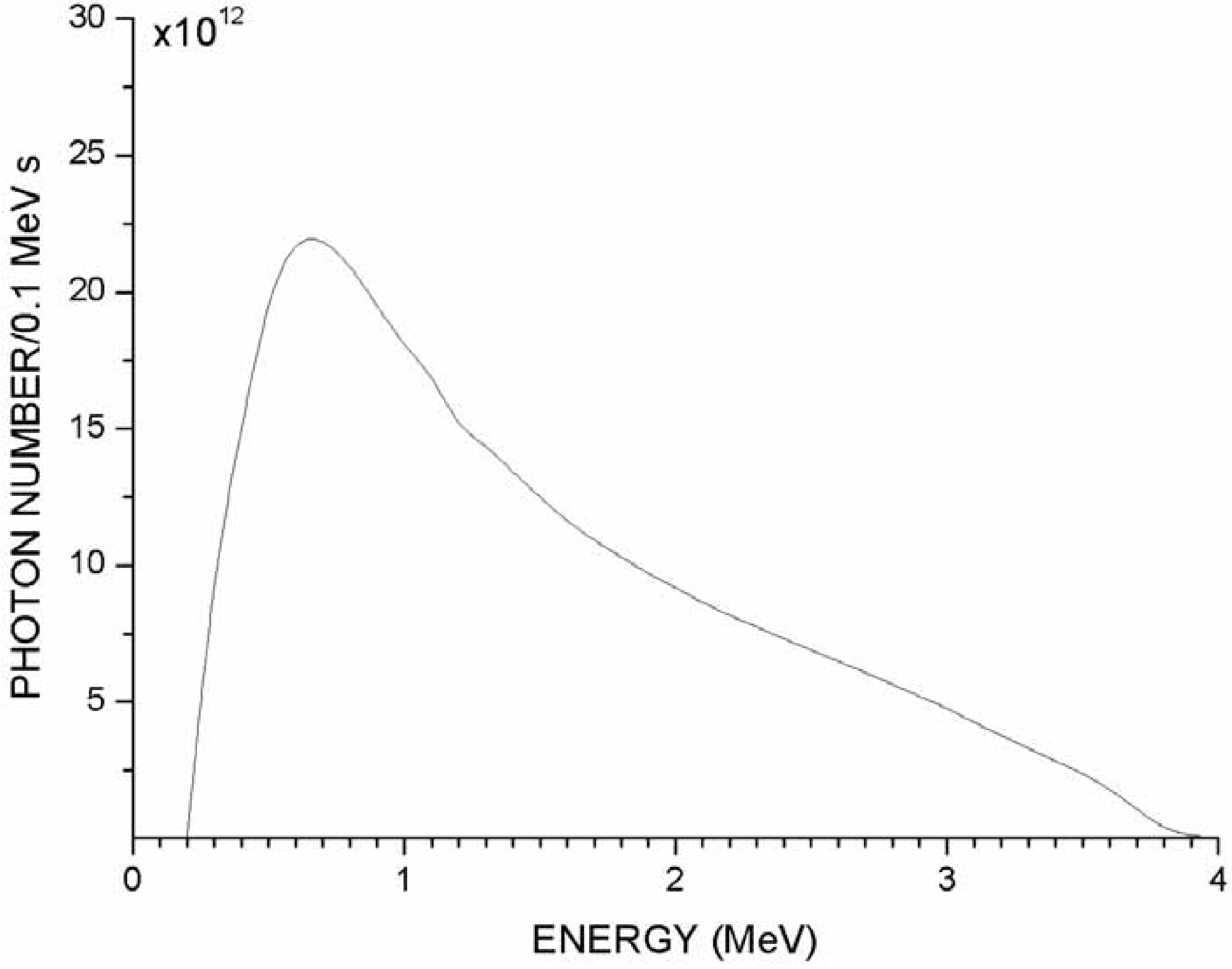
However:

- **The interrogating neutron pulse lasts for tens of ms; a long-tailed pulse is produced.**
- **The long pulse tail cannot be affected electronically, so it may be due to the long die-away time of interrogating neutrons.**
- **Owing to these circumstances, the performance of the accelerator cannot be fully utilized, i. e. it is not worth increasing the electron current, because the pulse tail lengthens, reducing the interval available for counting.**

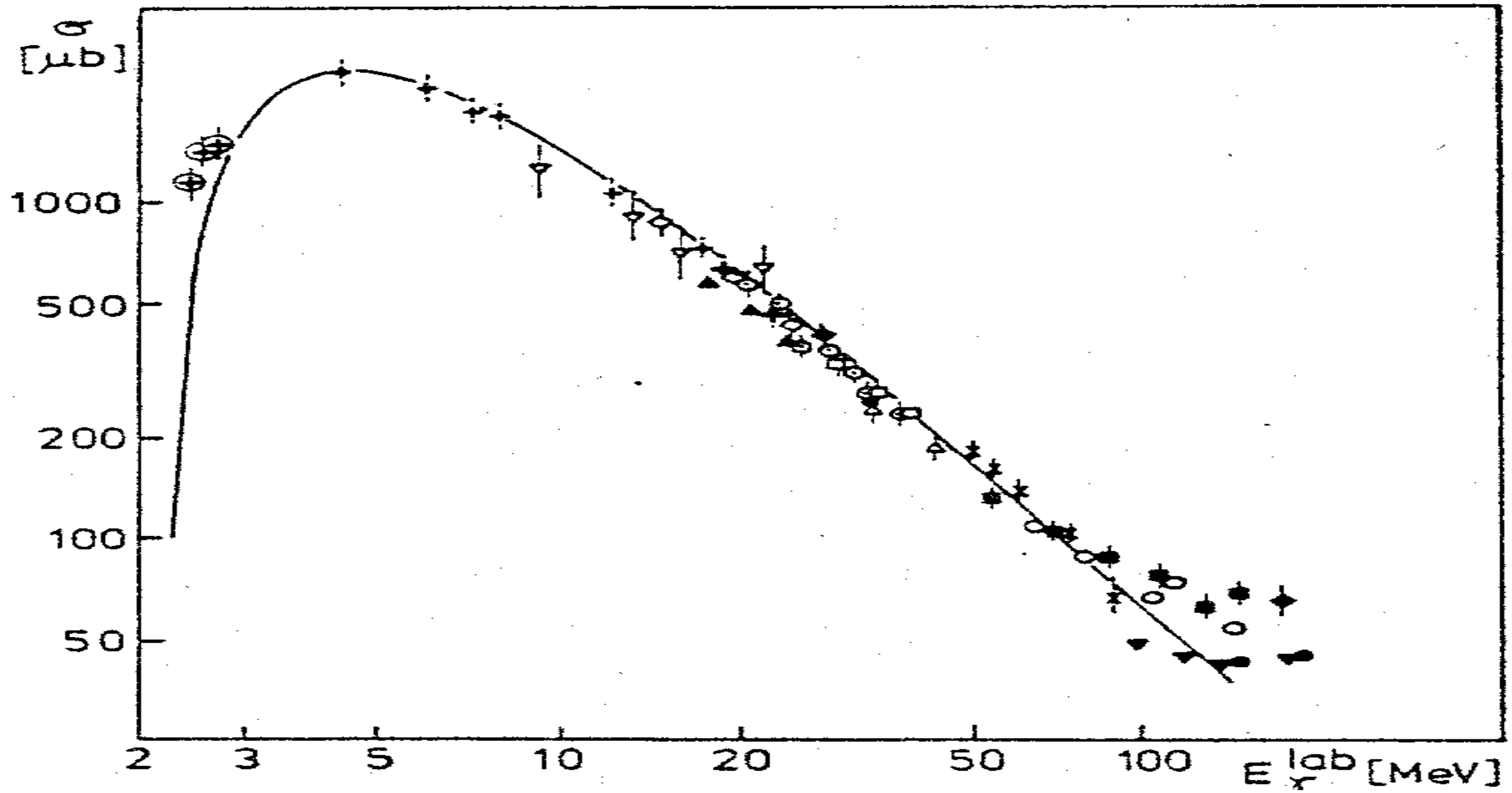
To improve the situation, wrapping the heavy water container and the He-3 tubes by Cd foil is going to be tried.

THANK YOU

Bremsstrahlung spectrum of 4 MeV electrons



Cross section of photoneutron production in D



The total bremsstrahlung output was calculated to be

- ~ 2.4(0.3)x10^13 above 1 MeV
- ~ 7.3(1.1)x10^12 photon/s above 2.22 MeV

at full intensity (26 μA) in all directions [N. C. Tam et al., Rad. Prot. Dosimetry 98 (2002) 401].

The total (interrogating) neutron output was estimated to be ~10^7 neutron/s/μA/cm^3 heavy water.