Transmission measurements of UCN guides using UCN capture activation analysis of vanadium

A. Frei, K. Schreckenbach, B. Franke, F. J. Hartmann, T. Huber, R.Picker, S. Paul , P. Geltenbort

TU München, Physik Department E21/E18,
James Franck Str., 85748 Garching, Germany

Institut Laue Langevin, 38042 Grenoble, France

TECHNISCHE UNIVERSITÄT MÜNCHEN

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Problem:
Suitable UCN guide for a long distant transport

in particular 40 m guide for the future UCN source at the FRM II
(see talk by Igor Altarev)

Choice of the guide:

non-magnetic Ni, replication technique (“replika” surface=copy of float glas)

Loss per reflection by absorption, non-specular reflection, up-scattering:
<0.1% per reflection (C. Plonka et al, NIM A578(2007)450)

Available Ni replika guides for the present investigation:

66 mm diameter

About 2 m length in 3-4 sections

a) manufactured by PNPI,

b) manufactured by S-DH, Heidelberg

Present talk:

How to measure the transmission of a UCN guide reliably?

- Measurement of the transmission per meter of UCN guides produced by the replication technique

- Almost all UCN should be absorbed at the end of the guide and measured

- The losses per meter should be determined with an absolute precision of about 0,5%

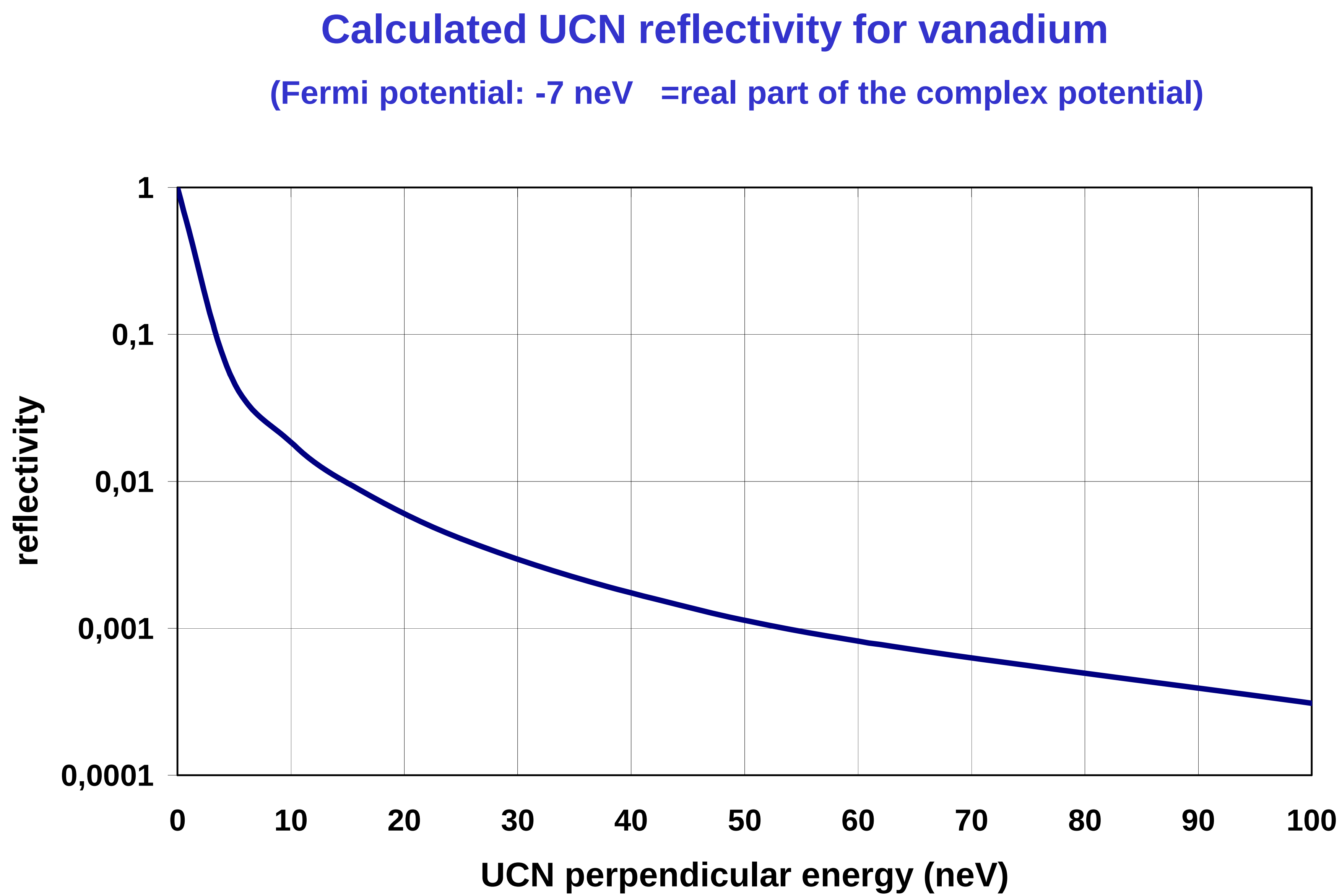
method: UCN activation analysis

- Absorption of UCN by neutron capture at the end of the guide
- Measurement of the produced radioactivity of the absorber

Choice of the absorber:

- Small reflectivity for UCN („black absorber“)
- Reasonably high neutron capture crosss section, producing a beta instable isotope with a few minutes half live
- Suitable gamma line in the beta decay for the meaurement

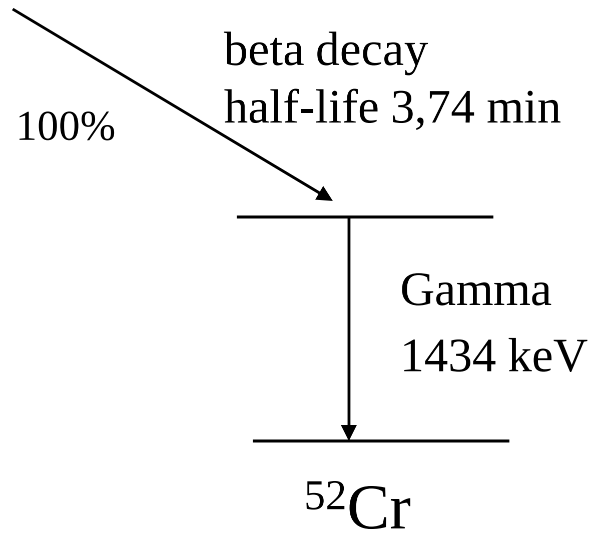
Good candidate : vanadium (natural)



Calculated UCN reflectivity for vanadium
(Fermi potential: -7 neV =real part of the complex potential)
reflectivity
1
0,1
0,01
0,001
0,0001
0
10
20
30
40
50
60
70
80
90
100
UCN perpendicular energy (neV)

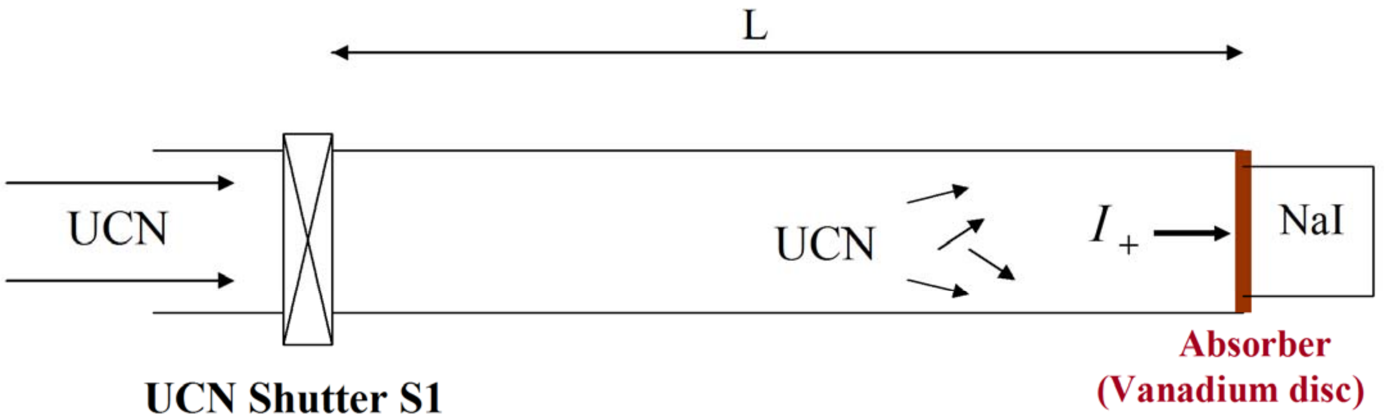
activation of nat. Vanadium with 99,75% ^{51}V by neutron absorption

$$^{51}V + UCN \xrightarrow{\text{4,9 barn (thermal)}} {}^{52}V + \text{gammas(prompt)}$$

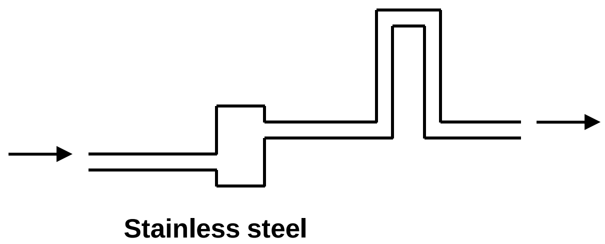


Principle of the transmission measurement

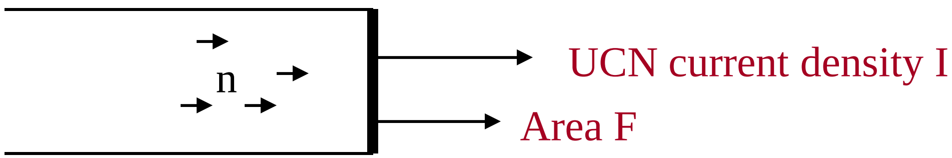
from shaper
3-5 m/s



UCN spectrum shaper:



Black absorber via (n,gamma) followed by beta decay



$$^{51}V(n,\gamma)^{52}V$$

β decay to ^{52}Cr

$$\frac{dN_{V52}}{dt} = \vec{I}\cdot\vec{F} - \lambda\, N_{V52} \qquad \lambda = \frac{1}{\tau} = \frac{\ln 2}{t_{1/2}}$$

Capture rate R for monoenergetic UCN of velocity υ :

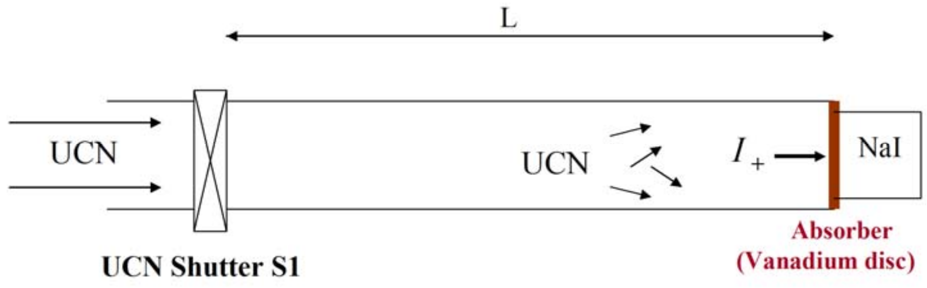
parallel beam $\quad R = \vec{I}\cdot\vec{F} = n\upsilon F \equiv \phi\,\mathrm{F} \qquad n$ UCN density; ϕ flux density

isotrope in half-space $\quad R = \vec{I}\cdot\vec{F} = \frac{1}{2} n\upsilon F$

activation: $\quad N_{V52}(t_a) = \frac{\vec{I}\cdot\vec{F}}{\lambda}(1-\exp(-\lambda t_a)) = N_{sat}\cdot(\ldots)$

decay: $\quad N_{V52}(t) = N_{52}(t_a)\exp(-\lambda t)$

measurements



UCN test beam from UCN turbine PF2 at ILL

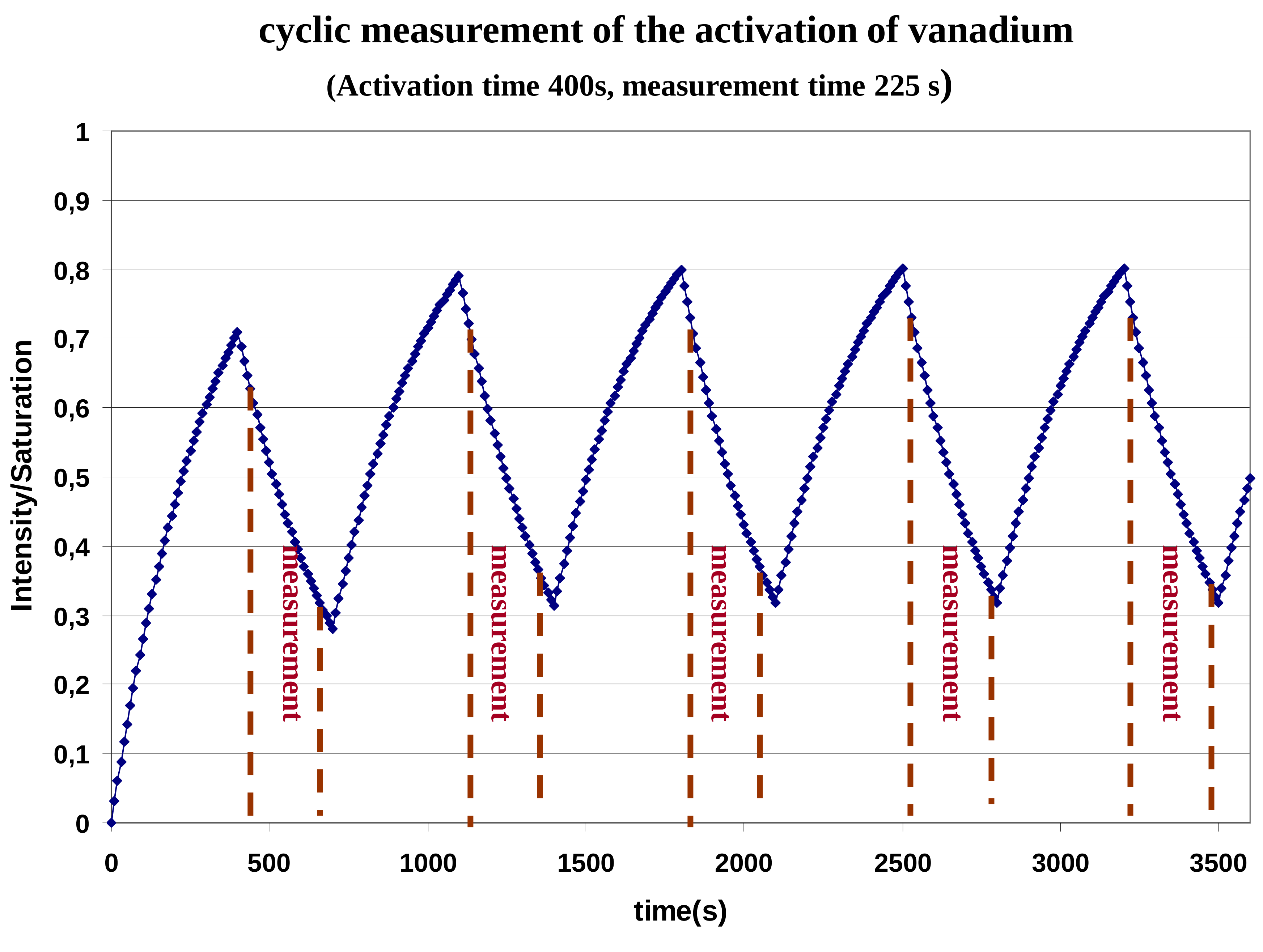
- filtered around 4m/s; about 0.1 UCN/cm^3
- Length L of the guide is varied within 0-2 m; constant diameter of 66 mm
- Activation of the Vanadium is determined in units of saturation value as function of the length L

Cyclic measurements:

- UCN Shutter open: Activation of the Vanadium
- UCN Shutter then closed: Measurement of the 1434 keV gamma line in the decay of ^{52}V by a NaI detector

...next activation...

- UCN Shutter closed and after ^{52}V activity decay: back ground measurement

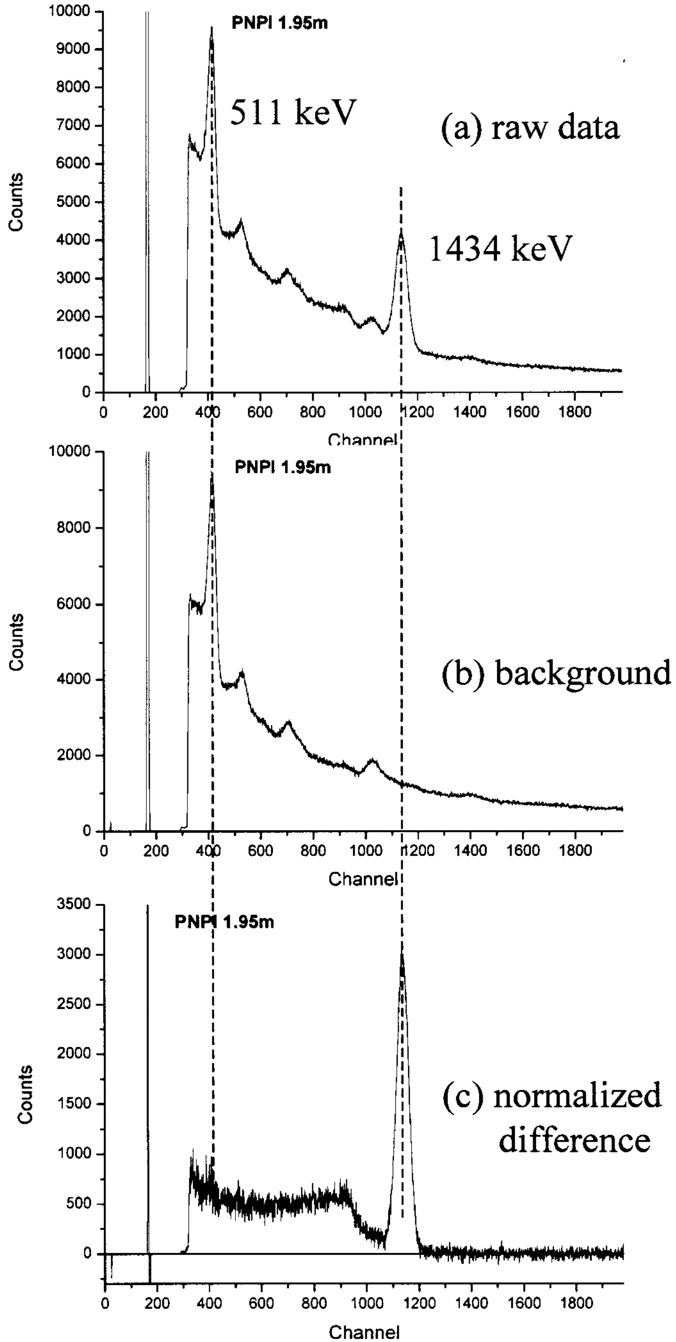

cyclic measurement of the activation of vanadium
(Activation time 400s, measurement time 225 s)
Intensity/Saturation
time(s)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
500
1000
1500
2000
2500
3000
3500
measurement
measurement
measurement
measurement
measurement

Evaluation:

- a) calculation of the sum intensity in units of the saturation activity

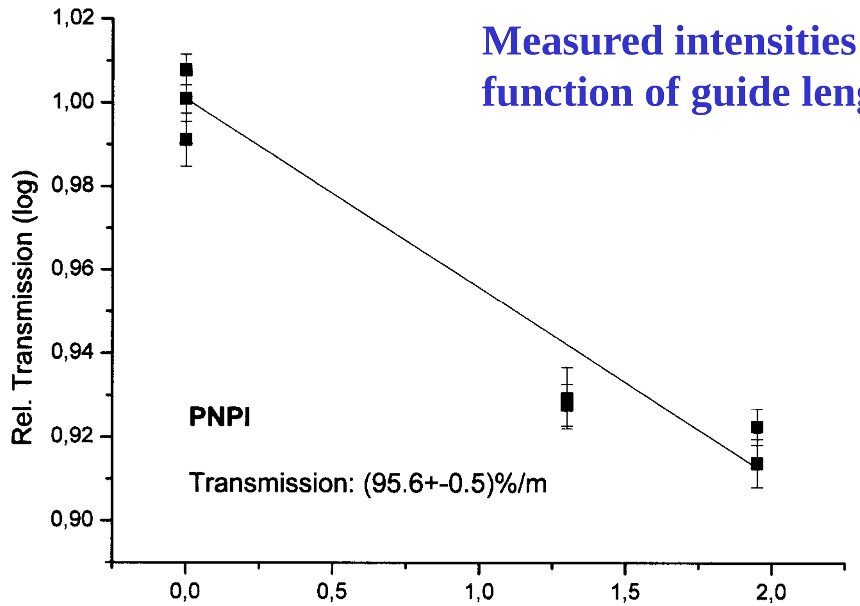
- b) Summation of the corresponding, measured gamma line intensities after background subtraction

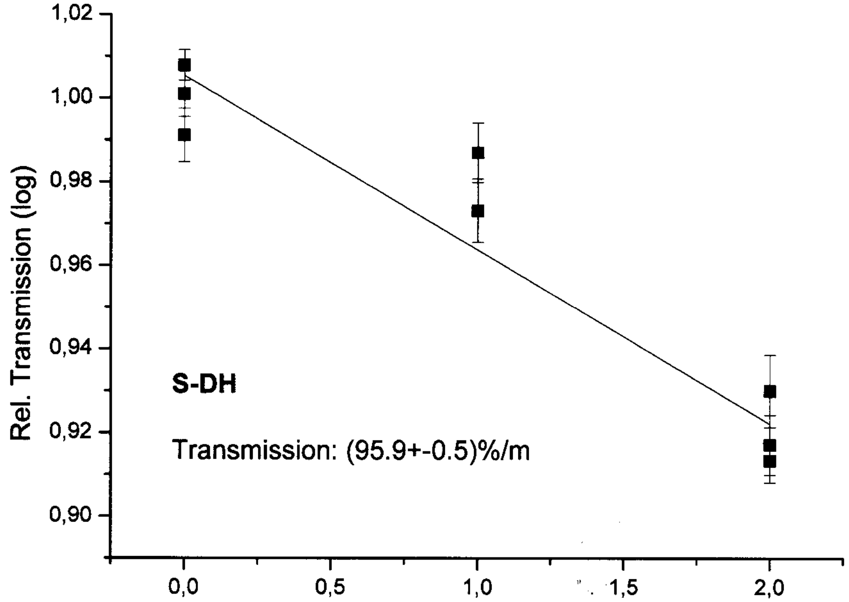
- ratio between a) and b) results in relative intensity for comparison between the different lengths of the guides



PNPI 1.95m
511 keV
(a) raw data
1434 keV
Counts
Channel
PNPI 1.95m
(b) background
Counts
Channel
PNPI 1.95m
(c) normalized difference
Counts
Channel

Measured intensities as function of guide length





Corrections and systematic precision

UCN flux from the source (UCN turbine) during the measurement stable?

➢check 511 keV line: stems mostly from neutron capture gammas in turbine

❖ Normalization to the 511 keV gamma line for one guide length (constant geometry)

➢ check with control room registration of the reactor power

Normalization between different guide length to reactor power (correction was <0,2 %)

➢Time of flight of UCN to the absorber after opening of the shutter depends on length of the UCN guide (here only a few seconds and negligible)

Remaining problems:

- leakages of UCN at the guide links
- Is Vanadium a perfect black absorber?

Absolute calibration of the NaI gamma detection system

- Homogenous activation of the vanadium disc in a cold neutron beam (neutron tomography station ANTARES at FRM II)
- Determination of the absolute activity of the irradiated vanadium disc by a calibrated HPGe detector
- Measurement of the sample after the same irradiation with the NaI detector and same geometry as during UCN transmission measurements
- Correction for the penetration depth of cold neutrons relative to that of UCN

Result:

absolute efficiency for the 1434 keV gamma ray with the NaI set-up in the given geometry: (4.7 +-0.2)%

→ Absolute UCN current: 10.1 UCN/cm^{2}s

Summary and outlook

- First measurements with this method were carried out at a low density UCN test beam at the ILL
- The measured transmission values were 95.5% (PNPI) and 95,9% (S-DH) per meter. Precision 0.6%.
- For the FRM II UCN guide (40 m, 120 mm diameter) a transmission of 50 % (98.3% per meter) may be achievable, avoiding UCN leakages
- The reflectivity of the vanadium UCN catcher should be measured separately
- An absolute efficiency calibration of the set-up was performed with a precision of 4% (could be improved if necessary)
- For the determination of the UCN density the angular distribution of the UCN at the beam catcher must be known.
- The method is suited for special calibration purposes, for instance also for measuring the absolute number of stored UCN in a bottle (UCN activation analysis by emptying the bottle on a vanadium absorber)