IPPE Iron shell transmission experiment with 14 MeV neutron source and its analysis by the Monte-Carlo method

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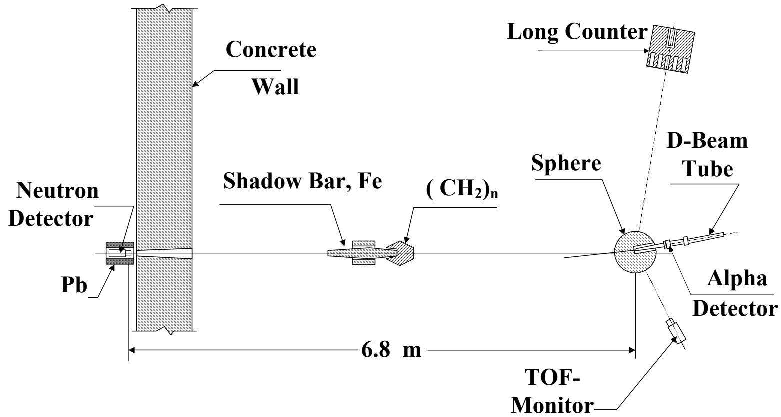
The scope of the Fe-spheres activities in IPPE/Obninsk

- **Neutron leakage spectra Measurements (1989 - 1995):**
  - increasing the number of spheres from 1 to 5
  - increasing flight path from 4 to 7 m (drill a hole in a wall)
  - decreasing the mass (miniaturizing) of target assembly
  - decreasing of scintillation detector threshold from 300 to 50 keV
  - and others
- **Analysis by Monte Carlo and Deterministic methods (1986 - 2000)**
  - elaboration of input files
  - evaluation of corrections for non-sphericality of experiment and TOF measuring technique (first observation and explanation of "resonance" shifting in pulsed spherical benchmarks)
  - benchmarking of all evaluated neutron transport libraries in this period
- **From 2004 experimental data and input files are available in SINBAD**

TOF neutron spectrometer at pulsed Neutron Generator (IPPE, Obninsk)



- **Spectrometry Method:** Time of Flight (TOF)
- **Neutron Source:** TiT target + 280 KeV pulsed (≈ 2 ns) d^+-beam
- **Neutron Source Yield:** Si surface barrier detector at ≈ 35 cm from TiT and Θ =175°
- **Neutron Detector:** p-tf scintillation detector + FEU-143, Δt ≈ 3 ns, E_{thr} ≈ 50 keV, electronic suppression of γ-rays, flight path = 6.8 m, Θ = 8°
- **Detector efficiency**: ^{252}Cf fission chamber (threshold to ≈ 10MeV) + T(d,n)^{4}He (14MeV)

Five Iron Shells

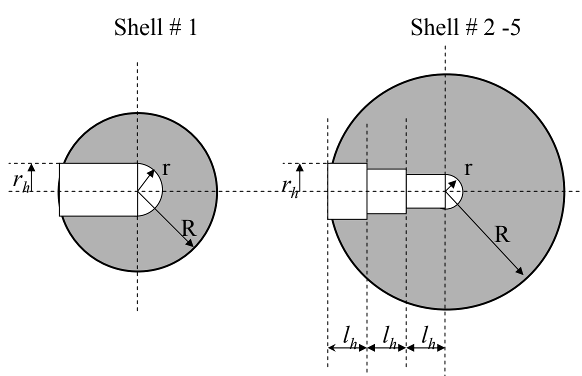
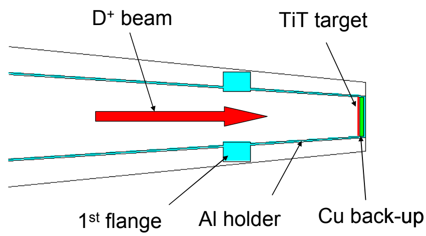


Table 1. Configuration of spherical iron shells

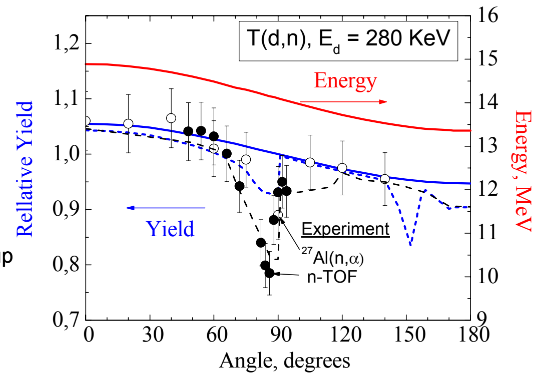
No	Shell Radii		Wall Thickness		Nucl. dens	Hole Configuration	V_h/V
	R, cm	r, cm	R-r, cm	mfp	$10^{22}/cm^3$	$r_h(l_h)$,cm	%
1	4.5	2.0	2.5	0.5	8.385	2.0(2.5)	10.6
2	12.0	4.5	7.5	1.6	8.206	3.2(4), 3.0(3.5)	3.3
3	12.0	2.0	10.0	2.2	8.210	3.2(4), 3.0(3.5), 2.0(2.5)	3.7
4	20.0	1.9	18.1	3.9	8.329	2.5(10.3), 1.9(7.8)	0.9
5	30.0	2.0	28.0	6.1	8.329	4(7), 2.5(7.8), 2.0(13.2)	0.6

d + TiT = 14 MeV neutron source (angular distribution)

TiT-target Assembly



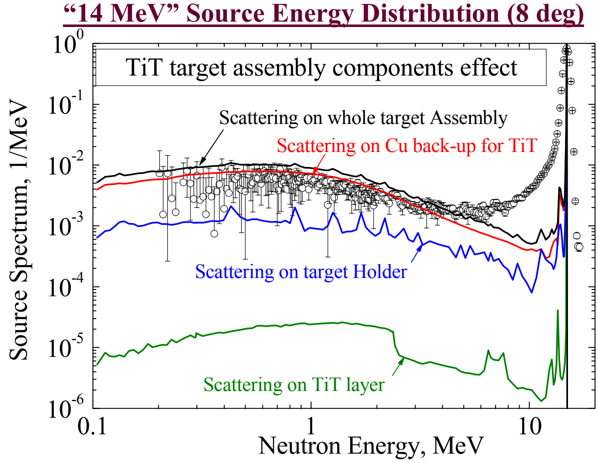
14 MeV Angular Distribution

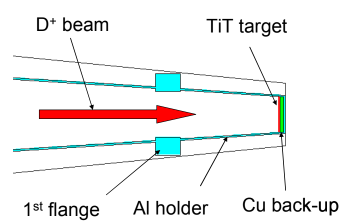


- *Angular distribution of* ***14 MeV*** *neutrons differs from the ideal thick target yield up to ≈ 10% due to attenuation at 90º and 150º (2% reduction in 4π)*
- ***Angular Yield and Energy dependencies on emission angle together with target assembly were included in the MCNP input file to represent real behaviour***

d + TiT = 14 MeV neutron source (energy distribution)

"14 MeV" Source Energy Distribution (8 deg)





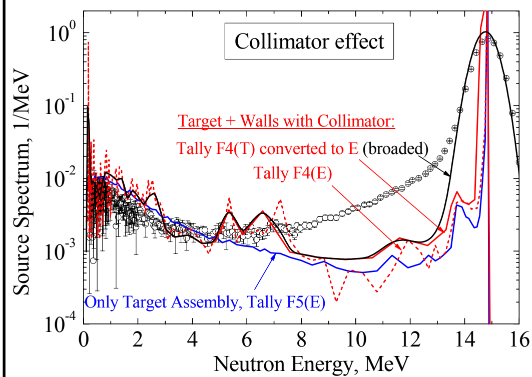
Energy distribution has:
- ***14 MeV peak (98%)***
- ***low energy neutrons (2%)***

MCNP analysis shown: low energy neutrons are caused mainly by 14 MeV scattering on Cu

Low energy neutrons were simulated by inclusion of target assembly in the MCNP input

d+TiT - 14 MeV bare neutron source (wall/collimator effect)

“14 MeV” Source Energy Distribution



MCNP Calculations

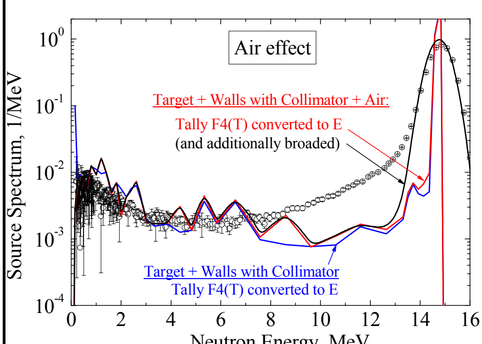
- Point detector (F5) and track length (F4) tallies were used
- Energy and Time of Arrival Spectra
- Variance Reduction Technique: source biasing, cell importances, energy splitting and cut-off
- 10-20 hours wall time on 10 cpu’s
- Bins score statistics mostly below 5-10%

Findings:

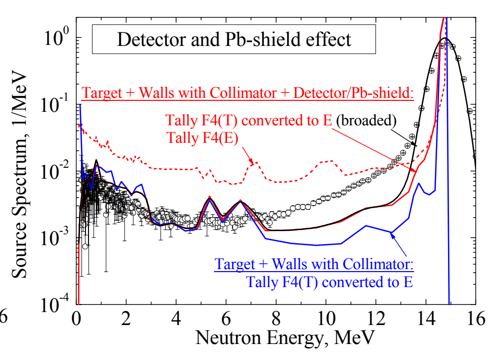
- ***walls contribution is relatively small***
- ***difference between Energy and Time considerations is not statistically clear***

d+TiT - 14 MeV bare neutron source (air & detector effect)

Room Air effect



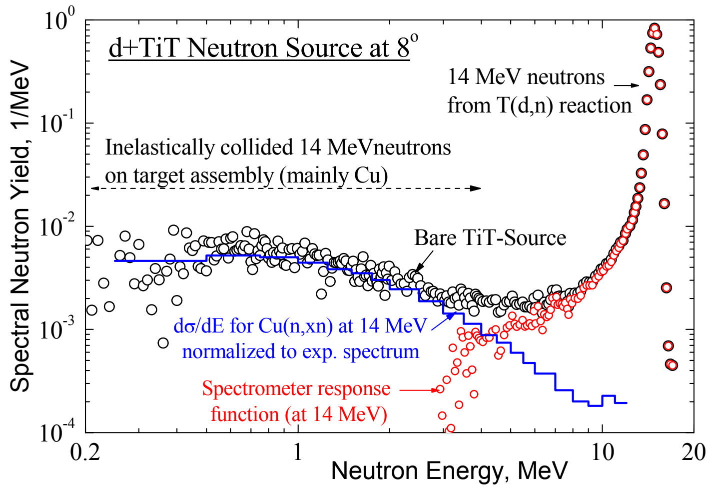
Detector/Shield Effect



Results:

- ***air effect is negligibly small***
- ***scattering on detector surroundings needs more careful simulation but optimistic estimations (upper limit) still underestimate the spectrum***

d+TiT - 14 MeV bare neutron source (target & response function)



Our recommendation for source, collimator … simulation (as it's now in SINBAD):
- MCNP input files contains TiT-target , Fe-sphere & energy point detector in void
- Energy spectrum (MCNP output) needs convolution with quasi-experimental response function at 10-15 MeV and Gauss below 10 MeV

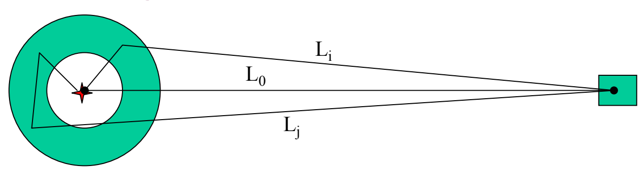
Time of Flight (TOF) technique with bulk samples (basic points)

POINT source and detector: strict relation between Energy and TOF

$$E = mc^2(1/\sqrt{1-(L/ct)^2} - 1) \approx (72.3 \cdot L[\mathrm{m}]/t[\mathrm{ns}])^2$$

where: m – neutron mass, L – flight path, c – light speed, t – time of flight

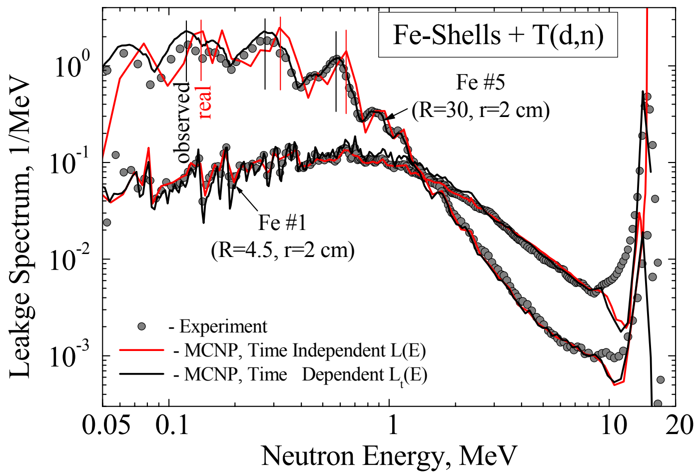
BULK source or detector: No more strict relation between Energy and Time of Flight (Arrival) due to the unknown (fluctuating) flight path



MCNP outputs (F5 or F4 tallies):
- L(E) - energy spectrum (time-independent Monte-Carlo technique)
- L(t) - time of arrival spectrum converted to L(E(t)) (time-dependent Monte-Carlo technique)

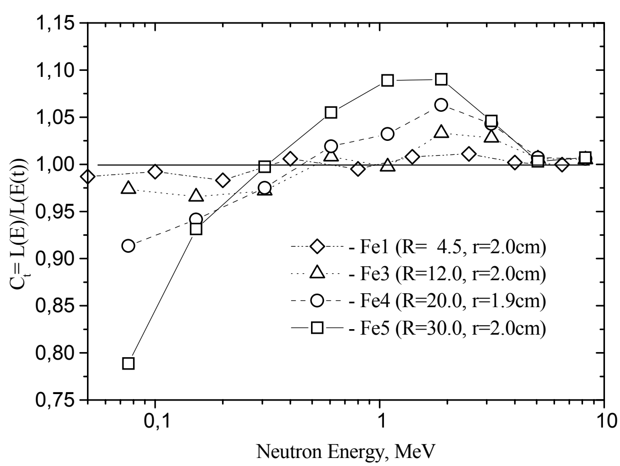
Is there any essential difference between L(E) and L(E(t)) and how it depends on sample sizes ?

Time of Flight technique with Fe shells (peaks energy shifting)



Findings:
- no difference for the smallest shell Fe #1 (dia. 9 cm)
- dips/peaks shifting and smoothing for the largest shell Fe #5 (dia.60 cm)

Time of Flight technique with Fe shells (spectra correction)



Our approach for the data presentation (as it is now in SINBAD):
experimental energy spectra obtained from TOF measurements were multiplied by this correction function to facilitate comparison with MCNP energy tallies

Example: Benchmarking of Iron Evaluated Data Libraries (Shells #1 and #5)