Measurements of Neutron total cross-sections of Nb & Pd from 0.1 to100 eV

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Introduction

Neutron cross-sections & resonance parameters are basic quantities of nuclear data that plays important roles in nuclear science and technologies.

Neutron cross-sections are used to obtain information about the internal structure of atomic nuclei and their constituents.

The Precise measurements of neutron cross-sections are of great importance for the safety design of nuclear reactors, for the evaluation of the neutron flux density, the energy spectrum around a reactor, etc.

Neutron resonance's parameters are finding an increasingly important role in practical applications that are concerned with computations of reactor temperature coefficients, neutron reaction yields, self-protection effects, etc.

Nuclear databases have to be constantly improved for the accurate values.

Present Work : At a glance

Neutron Total cross-sections

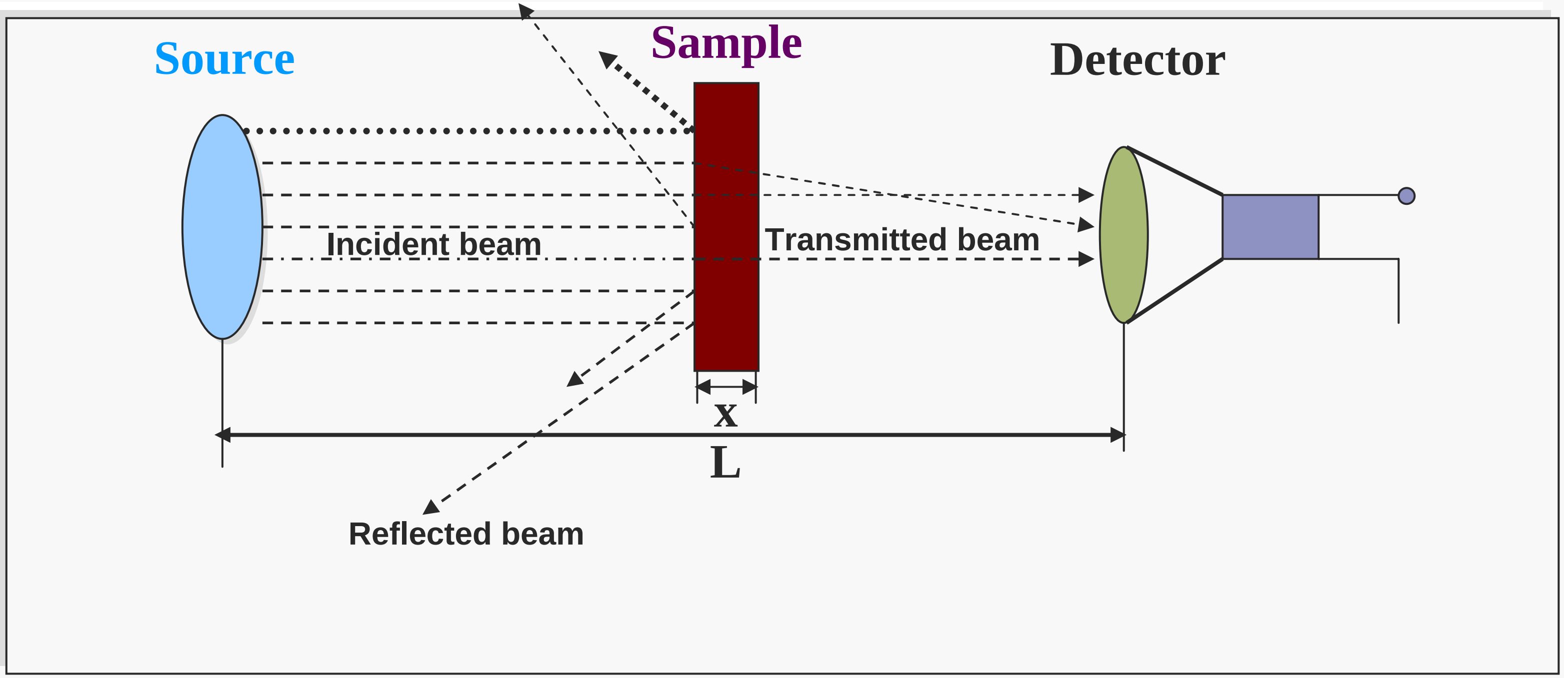
- Transmission experiments
- n_TOF path length
- Background Estimation
- Energy Resolutions

Resonance parameters

- Fitted transmissions/cross-sections by SAMMY

Comparison with others Reported & Evaluated values

TOF Method



TOF is a general method for finding the energy of a neutron by measuring the time it takes to fly between two points

Experimental Facility

An e_LINAC (100 MeV)
A water cooled Ta Target with water moderator
12m long Flight Path Length
4 position automatic sample changer
A 6Li-ZnS(Ag) Detector (BC702)

Linac Consists of

- A thermioninc RF gun
- An alpha magnet
- Four quadropule magnet
- Two SLAC-type accelerating sections
- A quadropule triplet
- A beam analyzing magnet

The linac Profile

Beam energy 65 MeV
Repetition rate 10-15 Hz
Pulse width 1-1.5 µs.
Peak beam current 30-50 mA

Ta Target (Water cooled)

• Ta has advantages of high density, high melting point and high resistant against the corrosion by cooling water.

• The target is composed of 10 Ta plates with a radius of 2.45 cm and an effective thickness of 7.4 cm.

• There is a 0.15 cm water gap between Ta plates for cooling the target effectively.

• The housing of the target is made by titanium.

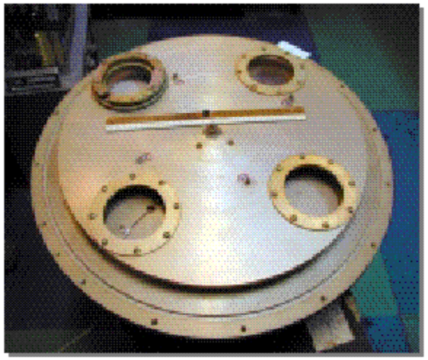
•Water moderator contained in a aluminum cylinder with a thickness of 0.5 cm, a radius of 15 cm and a height of 30 cm and the target is aligned vertically with the center of the TOF tube.

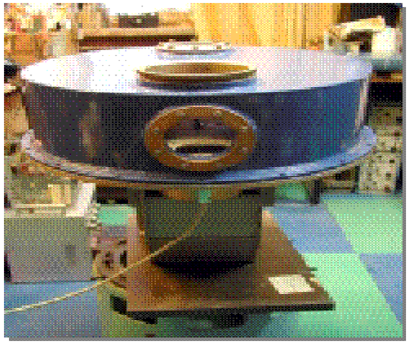
• The water moderator level is 3 cm above the target space.

• The calculated neutrons yield per kW of beam power at the Ta target was 1.9×10^12 n/s

Sample Changer

- •Four position sample changer
- •Radius of Each holder: 4 cm
- •The distance between two opposite holes: 32 cm
- •A pressurized cover with a O-ring prevents penetration of dust & moisture into the device
- •The holders permit solid samples as well as liquid or powder to be kept in a special cassette.

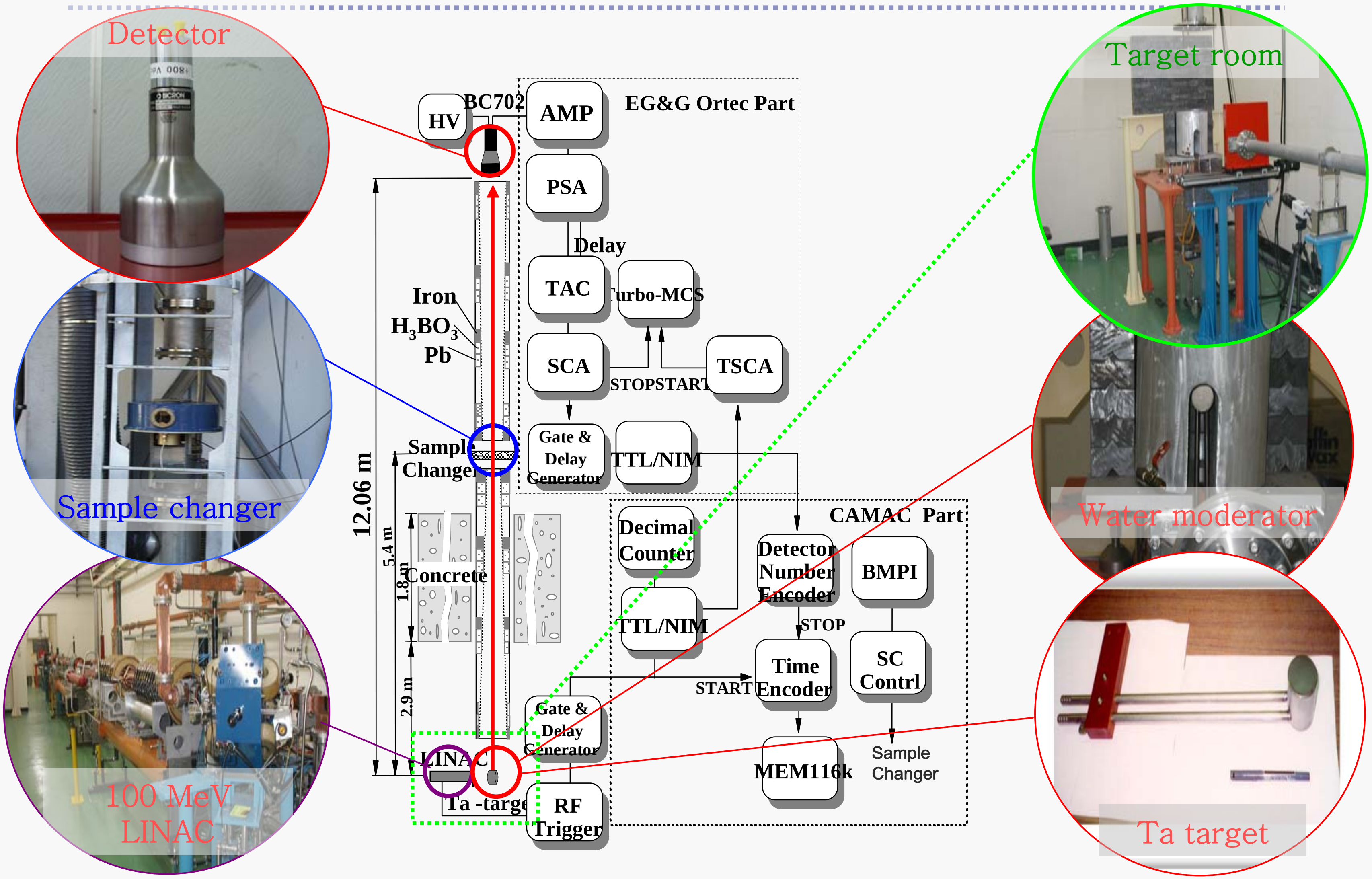




Detector

- A 6Li-ZnS(Ag), BC702 from Bicron (Newbury, Ohio)
- This detector consists of a disc of 16 mm in thickness, 125 mm in diameter
- BC702 is good for thermal and epithermal and is quite insensitive to gamma radiation
- It is applicable if the gamma background is high

Experimental Facility



Physical Parameters

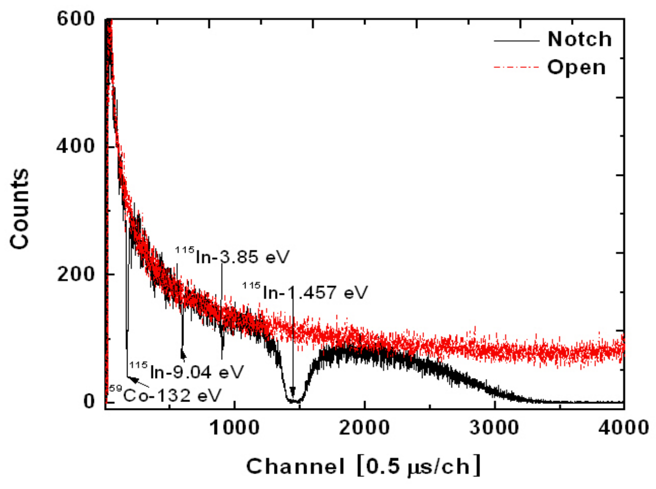
Information of Samples

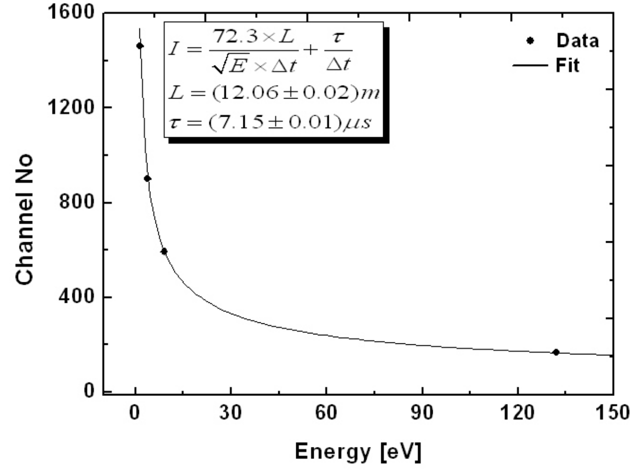
Size	Purity [%]	Measured Time [hr]	
		Sample Run	Open Run
Nb: 60 mm Dia., Thick 15 mm	99.98	65.00	65.00
Pd : 50 × 50 ×1.0 mm	99.99	65.00	65.00

Information of Notch Filter

Sample	Size [mm^3]	Mass [g]	Purity [%]
Cobalt	100 × 100 × 0.50	47.467	99.98
Indium	100 × 100 × 0.20	09.840	99.99
Cadmium	100 × 100 × 0.50	44.319	99.99

TOF Path Length





Nuclide	Resonance Energy [eV] 1	Channel Number *
59 Co	132	167.89 ± 0.23
115 In	9.04	592.82 ± 0.30
115 In	3.85	901.22 ± 0.58
115 In	1.46	1461.13 ± 1.13

$$L = (12.06 \pm 0.02)m$$

$$\tau = (7.15 \pm 0.01)\mu s$$

1. Landolt-Brönstein /New Series: Numerical Data a Functional Relationships in science and technology Group I: Elementary Particles, Nuclei and Atoms Vol 16: Low Energy Neutron Physics, Sub volume B: Tables of Neutron Resonance Parameters, (Ed. by H. Schopper, Springer, Feb. 1998)

* $$y = y_0 + \frac{2A}{\pi} \frac{w}{4(x - x_c)^2 + w^2}$$

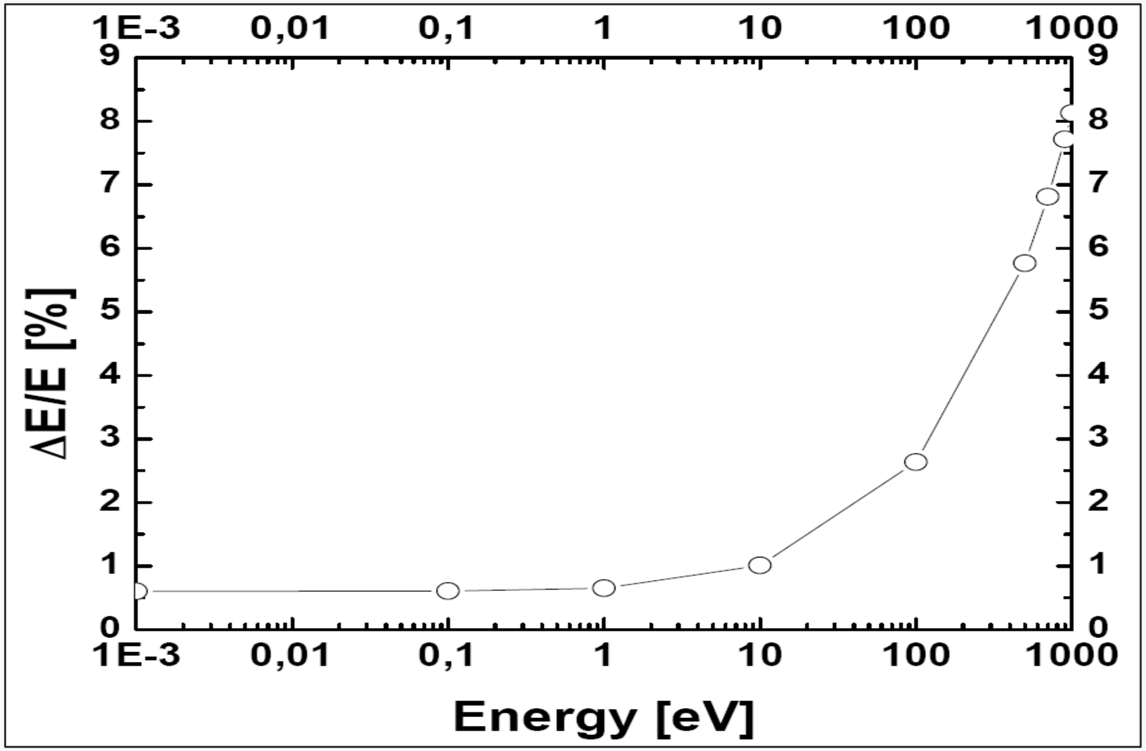
Energy Resolutions

$$\frac{\Delta E}{E} \approx 2\frac{\Delta t}{t}$$

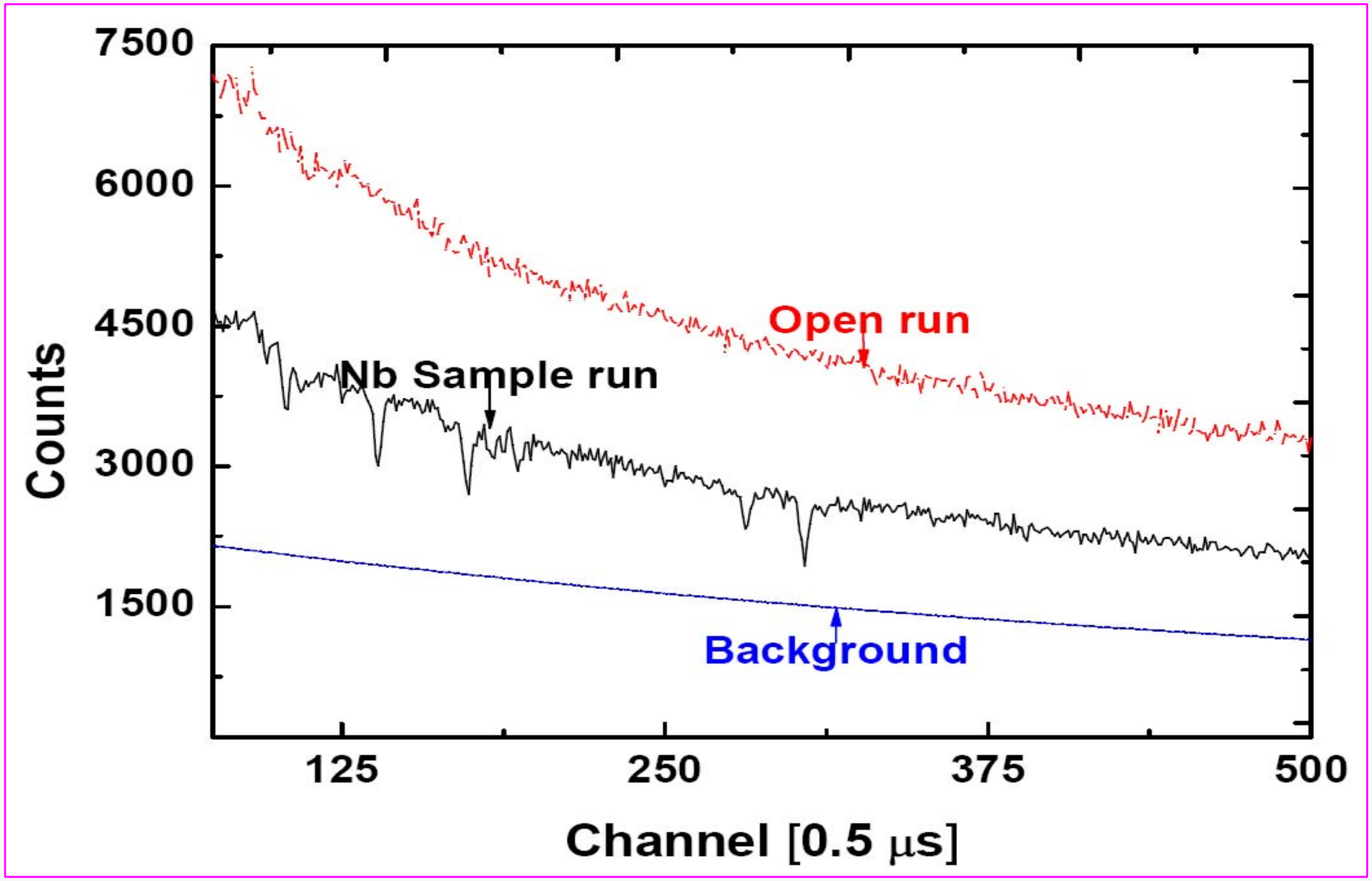
$$\frac{\Delta E}{E} = \frac{2}{L}\sqrt{(\Delta L)^2 + (1.91313 \times E \times \Delta t^2)}$$

The uncertainty (Δt) of the n_TOF (t) is composed of

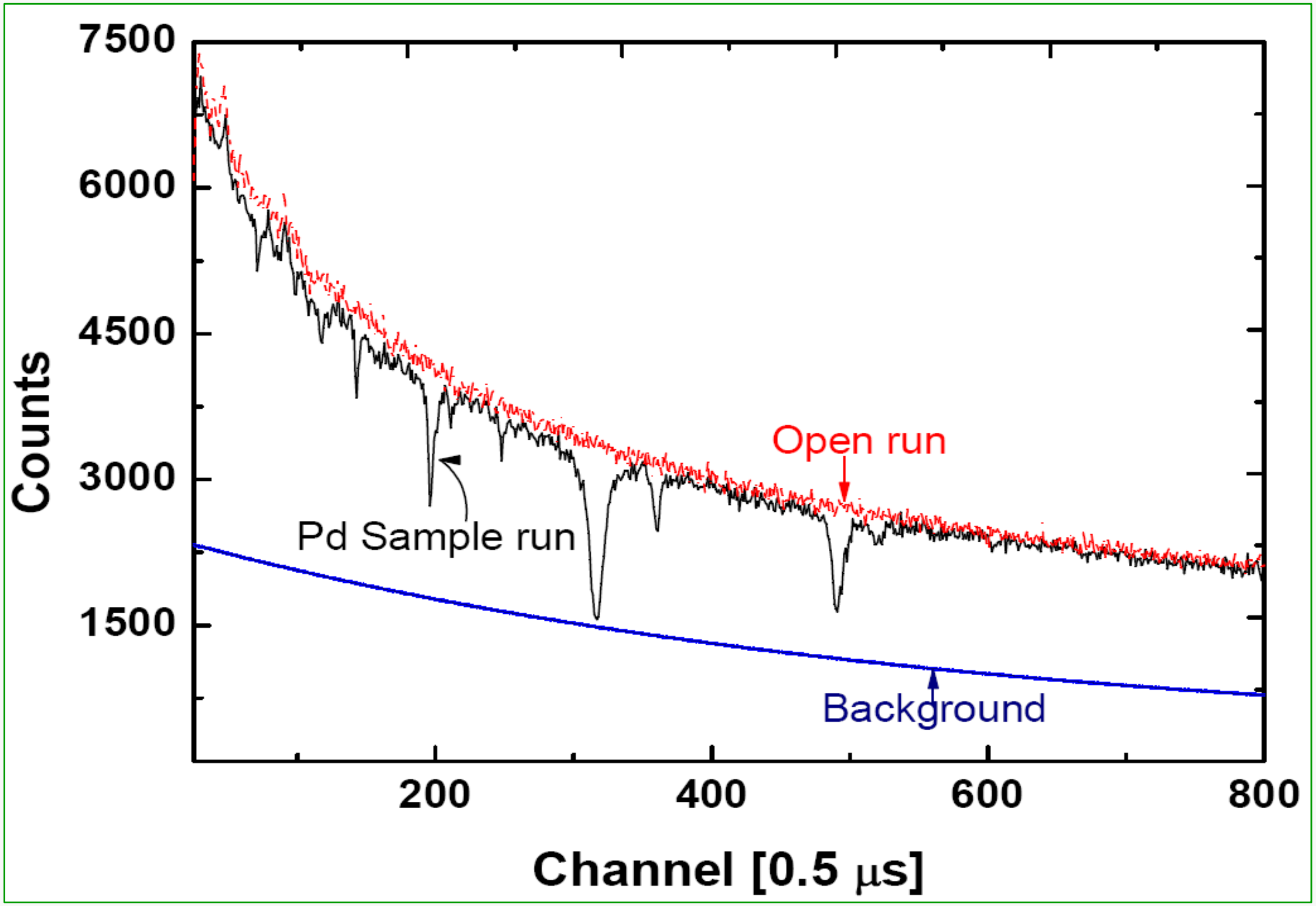
- **uncertainties due to the flight path (2 cm)**
- **the moderator thickness (3 cm)**
- **the pulse width of the electron beam (1 μs)**
- **the channel width of the time encoder (0.5 μs)**



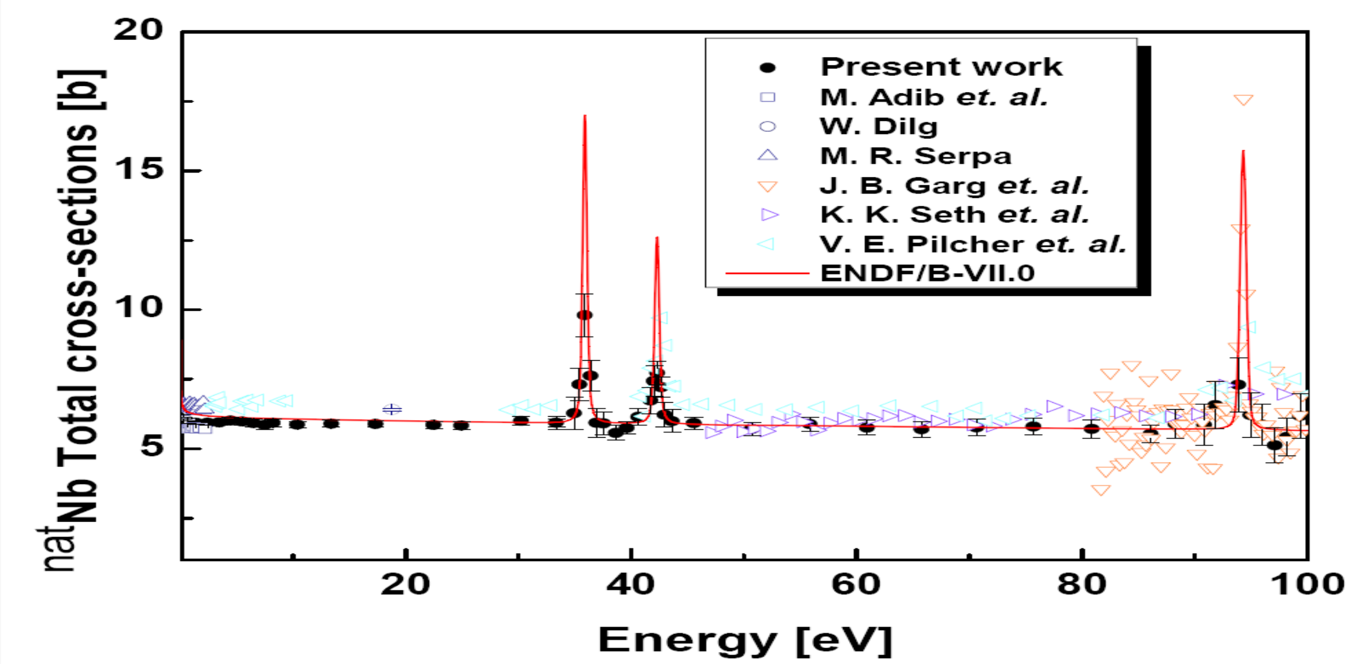
Nb TOF Spectra



Pd TOF Spectra



Nb Cross-sections



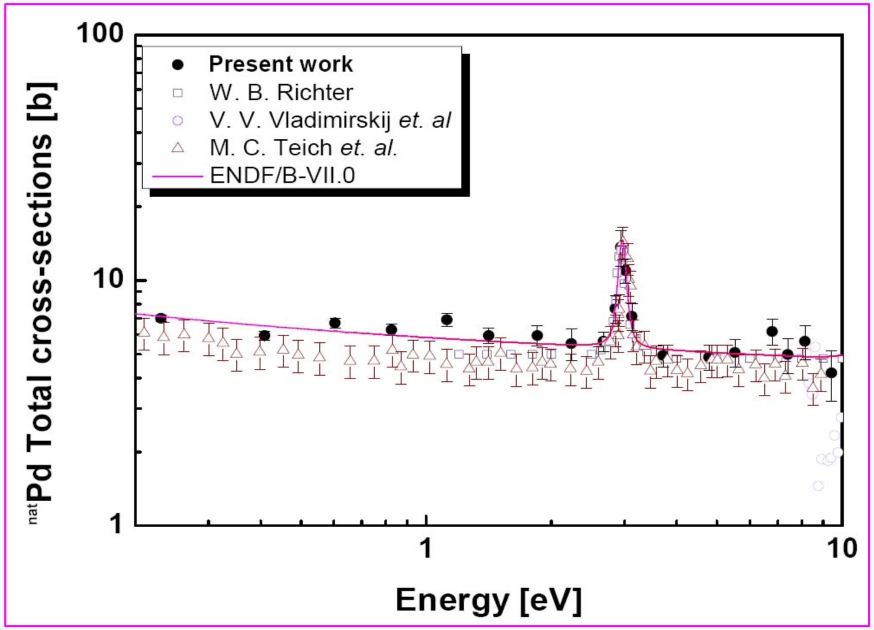
$$\sigma_T = -\frac{1}{n}\ln(T)$$

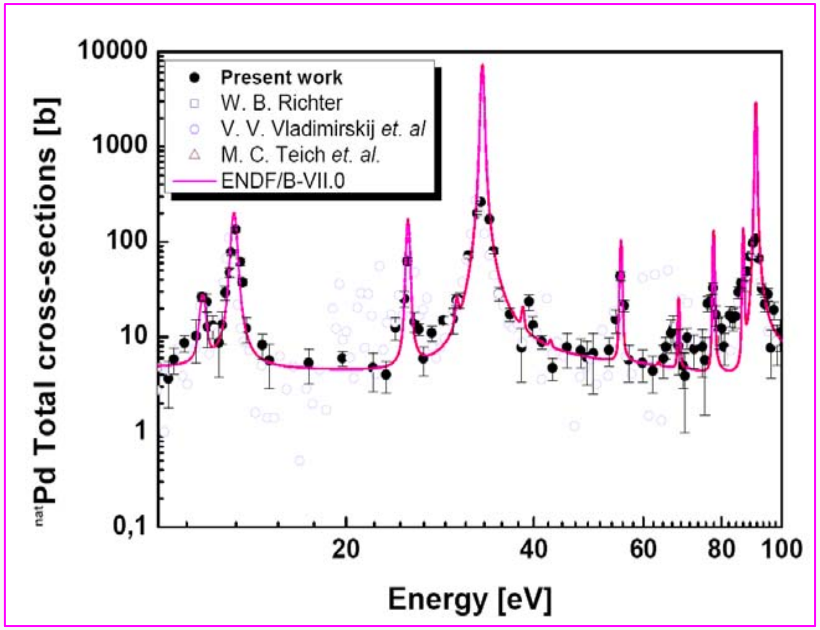
$$n[atoms/barn] = \frac{0.623 \times t(cm) \times \rho(g/cm^3)}{M(u)}$$

References:

1. M. Adib, A. Abdel-Kawy, R. M. Maayouf, M. Mostafa, M. Fayek, I. Hamouda, "*The total cross-section of Nb-93 below 2 eV at different temperature* ", Egyptian report to the I.N.D.C., No.2, p. 4,1981
2. W. Dilg, " *Neutron total cross-sections at 18.8 eV*, Zeitschrift fuer Naturforschung, Section A, Vol.29,1750, 1974
3. M. R. Serpa, "*Total neutron cross section on Nb*", Idaho Nuclear Corp. USA, Reports No.1407, p. 143, 1970
4. J. B. Garg, J. Rainwater, W. W. Havens Jr, "*Neutron Resonance Spectroscopy Nb, Ag, I and Cs*", Phy Rev,137, B547,1965
5. K. K. Seth, D. J. Hughes, R. L. Zimmerman, R. C. Garth, *Nuclear Radii by Scattering of Low-Energy Neutrons*. Phy Rev, 110, 692, 1958
6. V. E. Pilcher, R. L. Zimmerman, EXFOR No. 3619, http://www-nds.iaea.org/exfor/exfor.htm
7. Evaluated Nuclear Data File, B/VII.0

Pd Cross-sections





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1. W. Biel Richter, "*Total cross section of Pd*", J Atomkernenergie, **9**, 307, 1965
2. V. V. Vladimirskij, I. A.Radkevich, V.V.Sokolovskij, 1st UN Conf. Peaceful Uses Atomic Energy, Geneva 1955 Vol.4, p.22, 1955
3. M. C. Teich, P. J.Schweitzer, C. A. Anderson, T. J. Thompson, " *The total neutron cross-sections of Palladium from 0.005 to 10 eV*" Nuclear Sci & Eng., **30**, 145, 1967
4. ENDF/B-VII.0

SAMMY: Resonance Analysis Code from ORNL

SAMMY† offers the RM approximation, SLBW, and MLBW formalisms

It deals with Doppler broadening, resolution broadening, point wise data

Using Bayes' theorem, different energy ranges of the same/different data set can be be analyzed

It may reproduce the exact theoretical data depending on the proper experimental conditions

$$\sigma_T = \frac{2\pi}{k^2} g\{1 - \cos 2\phi (1 - \frac{\Gamma_1 \Gamma}{2d}) - \sin 2\phi \frac{\Gamma_1 (E_\lambda - E)}{d}\}$$

$$d = \{(E_\lambda - E)^2 + (\frac{\Gamma}{2})^2\}$$

$$g = \frac{(2J+1)}{2(2I+1)}$$

$$R_{GE}(E, E') = \frac{1}{\Delta_E \Delta_G \sqrt{\pi}} \int_{E-\Delta E_S}^{\infty} dE^0 \exp\left\{-\frac{\left(E^0 - \left(E - \Delta E_S\right)\right)}{\Delta_E}\right\} \exp\left\{-\frac{\left(E' - E^0\right)^2}{\Delta_G^2}\right\}$$

$$\Delta_G = E[aE + b]^{1/2}$$

$$\Delta_E = c(\sqrt{E})^3$$

† N. M. Larson, "RSICC Peripheral Shielding Routine Collection SAMMY-M2a: A Code System for Multilevel R-Matrix Fits to Neutron Data Using Bayes' Equations (PSR-158, SAMMY-M2a)", Oak Ridge National Laboratory, 2001

RSAP: Code for Display Data

- RSAP [†] is a computer code for display of neutron cross section data and selected SAMMY output.
- RSAP, which runs on the Digital Unix Alpha platform, reads ORELA Data Files (ODF) created by SAMMY and uses graphics routines from the PLPLOT package.
- In addition, RSAP can read data and/or computed values from ASCII files with a format specified by the user.

[†] *Sayer R A, ORNL/TM-2001/15*

SAMMY Fitting Procedure

Preparations of required files:
INPut File, PARameter File, and DATa File

↓

Non Bayes' Analysis
(Manually adjust the parameters as gradually Neutron width and / or Gamma width, and / or Energy & Plot By RSAP Code)

↓

Bayes' Analysis
(Tune all resonance's parameters within the energy region & Plot By RSAP Code)

↓

Bayes' Analysis
(To Generate Covariance Matrix)

↓

Repeat The Bayes' Analysis With Covariance Matrix
(To get the advantage of Bayes' fitting over least square fitting)

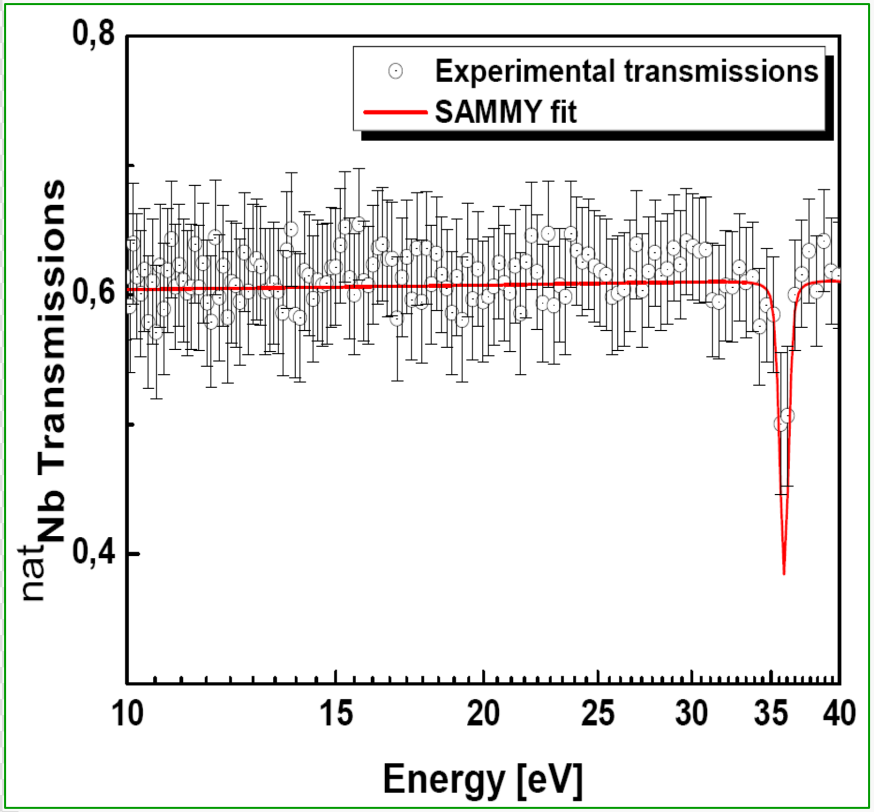
↓

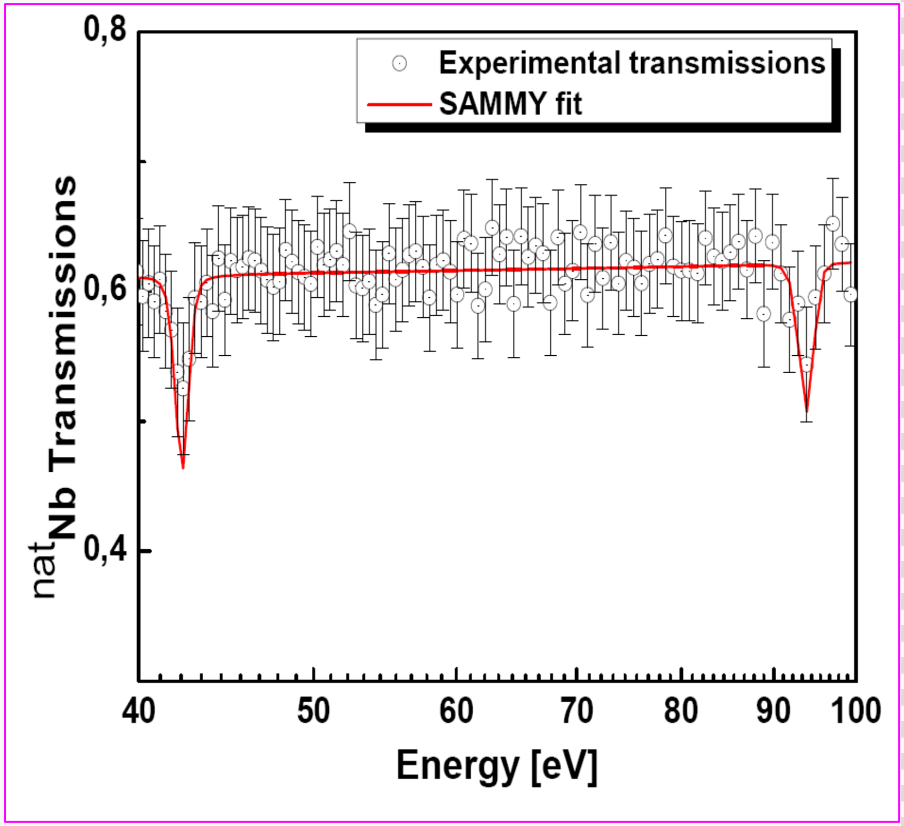
Final Bayes' Analysis With Generated Covariance Matrix
(Plot By RSAP Code)

↓

Final Non Bayes' Analysis With Generated Covariance Matrix
(Plot By RSAP Code)

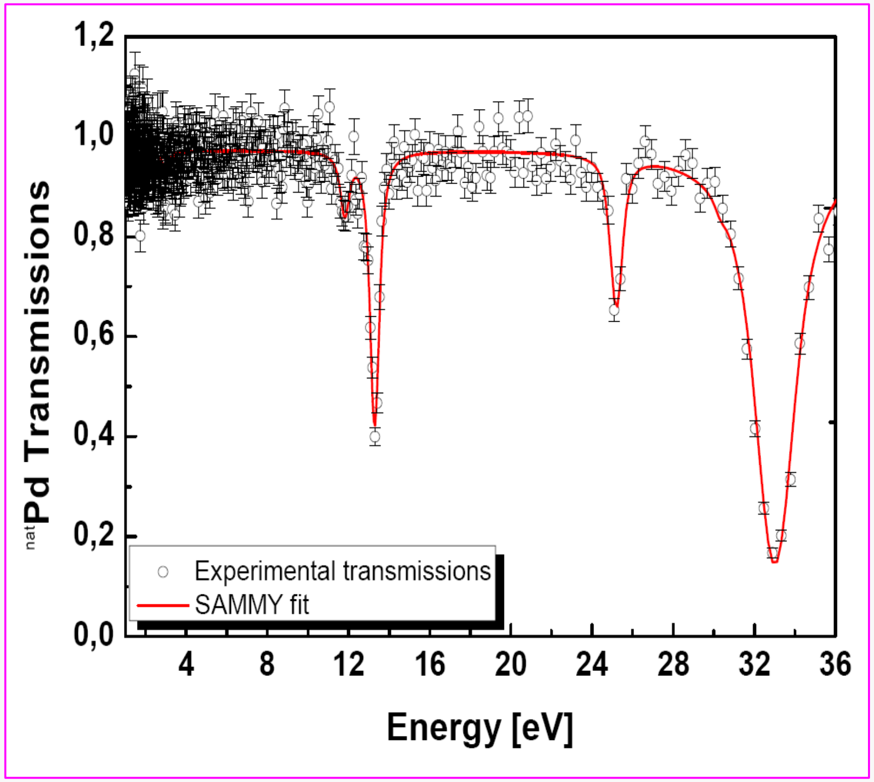
Experimental Transmissions & SAMMY Fit : Nb

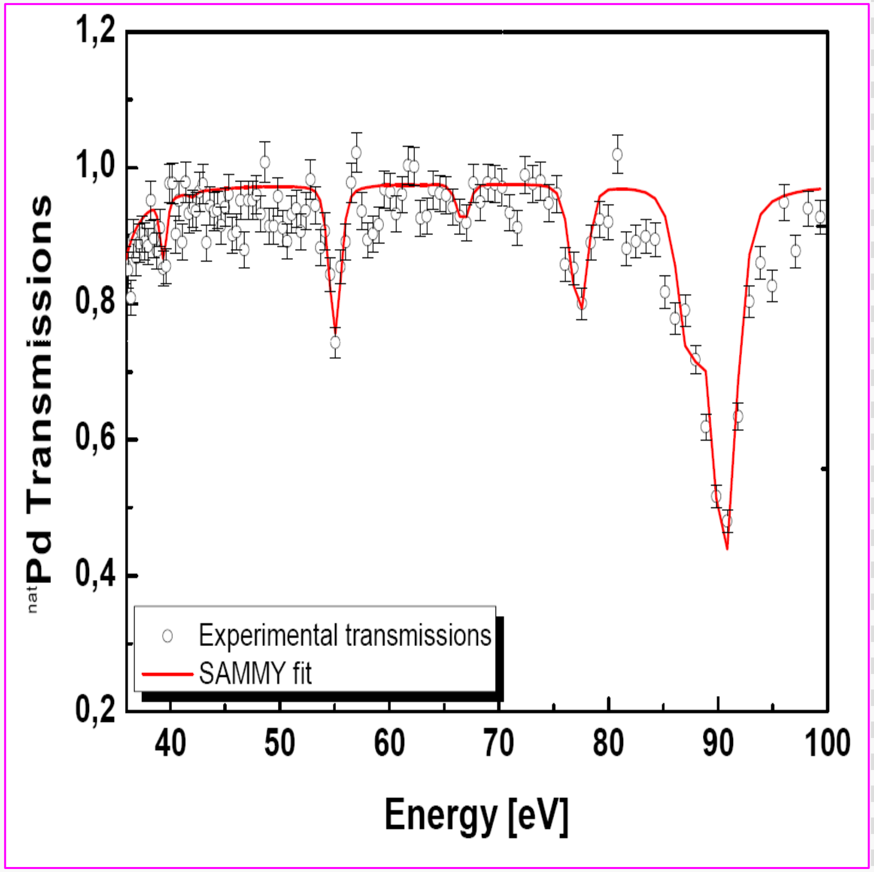




Chi-sq/N-dat=1.05

Experimental Transmissions & SAMMY Fit : Pd





Chi-sq/N-dat=1.51

Resonance Parameters of Nb-93

J/l	E_λ [eV]		Γ_γ [meV]	Γ_n [meV]
5/1	**Present**	**35.9220 ± 0.0202**	**215.57 ± 17.98**	**0.078 ± 0.041**
	Saplakoglu *et. al.*	35.90	205 ± 51	0.079 ± 0.006
	Jackson	35.9	215 ± 40	0.056 ± 0.005
	Mughabghab	35.9 ± 0.1	209 ± 80	0.056 ± 0.005
	ENDF/B-VII.0	35.90	209	0.101
4/1	**Present**	**42.2878 ± 0.0642**	**228.47 ± 22.32**	**0.079 ± 0.007**
	Saplakoglu *et. al.*	42.2	256 ± 84	0.065 ± 0.006
	Jackson	42.2	260 ± 20	0.055 ± 0.006
	Mughabghab	42.3 ± 0.1	222 ± 40	0.053 ± 0.003
	ENDF/B-VII.0	42.30	222	0.096

•A. Saplakoglu, L. M. Boolinger, and R. E. Cote, "*Properties of s-Wave and p-Wave neutron resonances in Niobium*, Phy Rev **109**, 1258, 1958
•H. E. Jackson, "*Total radiation with for s-Wave and p-Wave neutron capture in Nb*" Phy Rev, **11**, 378, 1963.
•S. F. Mughabghab, *Atlas of Neutron Resonances: Resonance Parameters and Thermal cross sections, Z = 1-100*, Elsevier, 5th Edition, 2006

Resonance Parameters of Pd Isotopes#

Nuclide	J/l	E_λ [eV]		Γ_γ [meV]	Γ_n [meV]
105Pd	3/0	**Present**	**11.8221 ± 0.0250**	**226.29 ± 10.33**	**0.331 ± 0.015**
		Smith *et. al.*	11.780 ± 0.007	150 ± 2	0.1800± 0.0017
		Satveloz *et. al*	11.790 ± 0.02	151.1± 2.1	0.21± 0.01
		ENDF/B-VII.0	11.79	151.40	0.180
106Pd	1.5/1	**Present**	**63.2466 ± 0.0356**	**106.54 ± 10.68**	**0.0069 ± 0.0007**
		Smith *et. al.*	63.47 ± 0.03	107± 12	0.0066± 0.0003
		ENDF/B-VII.0	63.42	107	0.0065
108Pd	1.5/1	**Present**	**2.9636 ± 0.0008**	**323.79 ± 2.30**	**0.0051 ± 0.0001**
		Smith *et. al.*	-	-	-
		Coceva *et. al*	2.96 ± 0.01	90 ± 2	0.0054 ± 0.0005
		ENDF/B-VII.0	2.96	91.80	0.0025

 # Pd-102(Abn. 0.0102),104(0.1114),105(0.02233),106(0.2733),108(0.2646),110(0.1172)

•D. A. Smith, J. D. Bowman, B. E. Crawford, C. A. Grossmann, T. Haseyama, A. Masaike Y. Matsuda, G. E. Mitchell, S. I. Penttila, N. R. Roberson, S. J. Seestrom, E. I. Sharapov, S. L. Stephenson, A. M. Sukhovoj, and V. W. Yuan, *Neutron resonance spectroscopy of ^{104}Pd, ^{105}Pd, and ^{110}Pd,* Phy Rev C, **65**, 024607(2002)

•C. Coceva, F.Corvi, P.Giacobbe, M.Stefanon, "*Low energy neutron resonances of palladium*", Phys Lett 16, 59 (1965)

P. Satveloz, E. Cornelis, L. Mewissen, F. Poortmans, G. Rohr, R. Shelley, T. Van Der Veen, *Neutron Resonance parameters for Palladium isotopes" Report from CEC-countries and CEC to NEANDC* No. 209L.,Belgium, p 53, 1979.

Conclusions

- **We presented total cross-sections of Niobium, and Palladium**
- **The data shapes are good agreement with the existing measurements as well as the evaluated data in ENDF/B-VII.0!**
- **Though the experimental data and SAMMY fittings are good, but there are some discrepancies with our RP & others**
- **We only used total cross-sections data for RP but we need to carry out capture cross-sections measurements, and we ‘ll do it at the PNF, Korea in near future.**

Greetings

Thanks a lot