MEASUREMENT OF NEUTRON CAPTURE CROSS SECTIONS OF ^{139}La, ^{152}Sm and $^{191,193}Ir$ ON FILTERED NEUTRON BEAMS OF 54 keV and 148.3 keV

V. H. TAN[1], T. T. ANH[2], N. C. HAI[2], P. N. SON[2], TOKIO FUKAHORI[3]

1) Vietnam Atomic Energy Commission

2) Dalat Nuclear Research Institute

3) Japan Atomic Energy Commission

Outline

- General information
- Neutron filter technique
- Experiments
-
- Results
- References

General information

Precise measurement of radiactive neutron capture cross sections in the keV energy region are important need for:

- Researches on fundamental nuclear physics
- Calculation and/or simulation of neutron transport
- Design of reactors
- Safety analysis
- Study on nuclear astrophysics
- Application of nuclear techniques

Neutron filters technique

Basic principles (proposed by O.D. Simpson*, L.G. Miller) :

The phenomenon of neutron filtration is conditioned by existence in the total neutron cross sections for some atomic nuclei of deep interference minimums which are the result of interference between the coherent waves of resonance and potential neutron scattering in these nuclei.

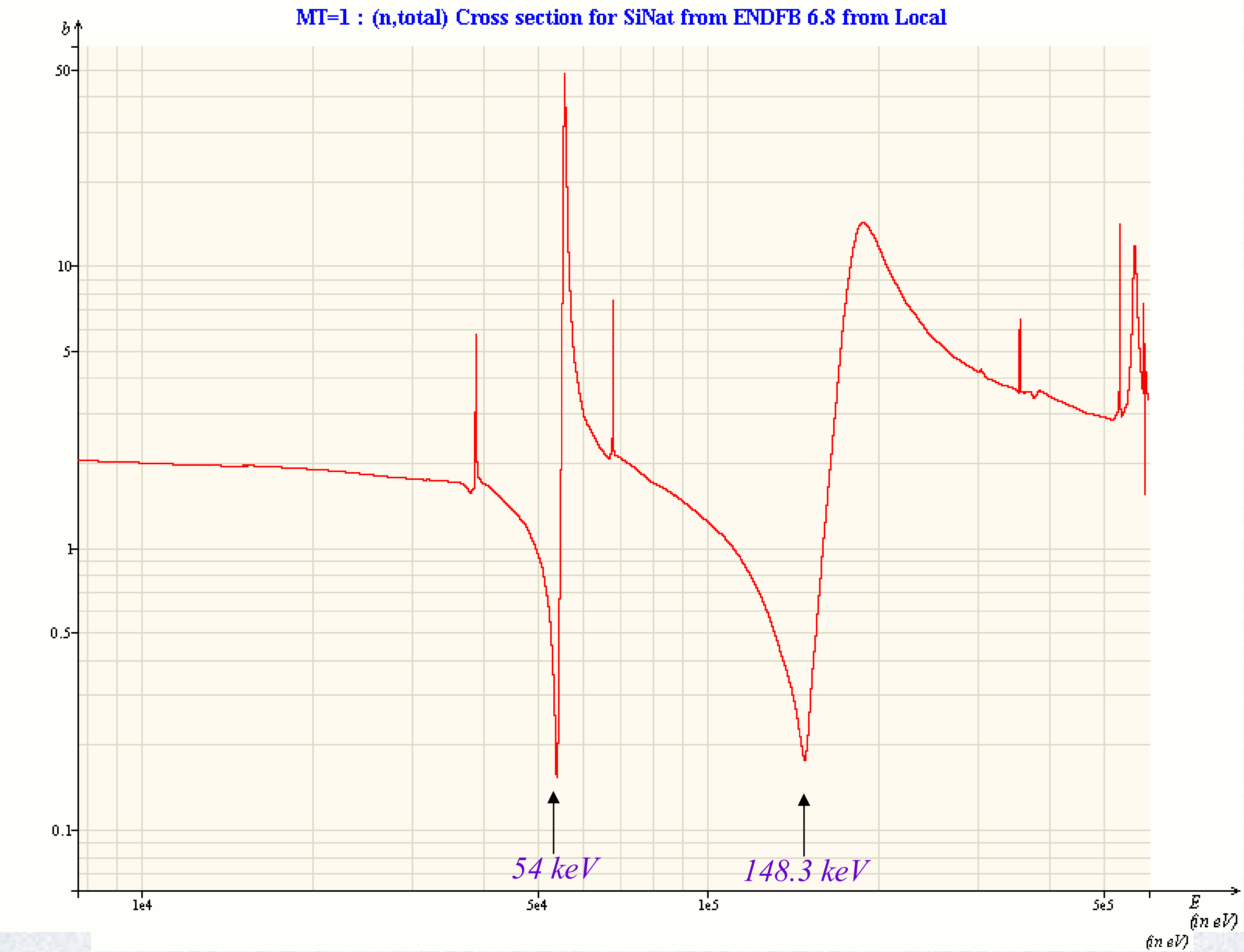
1. Transmission:

$$T(E) = \exp\{- \Sigma\, n_i \cdot \sigma_i(E)\}$$

2. Relative intensity:

$$I(E) = \frac{\int e^{-\sum n_i \sigma_i (E)} \Phi(E)dE}{\int \Phi(E)dE}$$

*Simpson O.D., Miller L.G. "A technique to measure neutron cross sections in the low keV energy region", *Nucl. Instr. Meth.*, v.61, No3, (1968).



MT=1 : (n,total) Cross section for SiNat from ENDFB 6.8 from Local
b
50
10
5
1
0.5
0.1
1e4
5e4
1e5
5e5
E
(in eV)
(in eV)
54 keV
148.3 keV

Materials for Neutron Filters

- Natural elements: Si, Al, V, Sc, S, Mn, Fe, B, Ti, Mg, Co, Ce, Rh, Cd, LiF.

- Enriched isotopes: ^{52}Cr (99.3), ^{54}Fe (99.92), ^{56}Fe (99.5), ^{57}Fe (99.1), ^{58}Ni (99.3), ^{60}Ni (92.8 - 99.8), ^{62}Ni (98.04), ^{80}Se (99.2), ^{10}B (85), ^{7}Li (90).

Basic demands to neutron filters

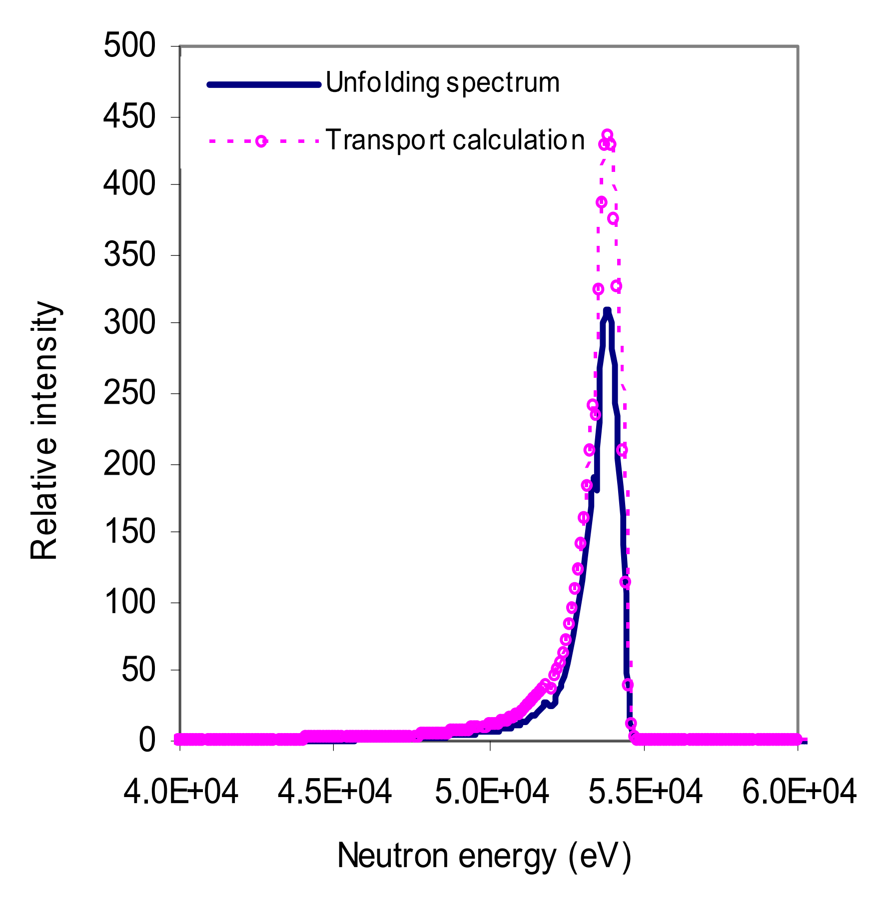
- The purity of the main energy line in neutron spectrum has to be as much close to 100 % as possible.
- Neutron intensity is to be the most possible, sufficient to obtain the necessary accuracy in experiment.
- Construction and composition have to provide the minimal possible gamma-background.
- In necessary case construction and composition have to allow to increase or to reduce the width of base line without essential worsening of filter quality.
- The amount of enriched isotopes in filter components has to be minimum necessary.
- Filter components have to provide the energy range of filtered neutrons up to 1 MeV and more.

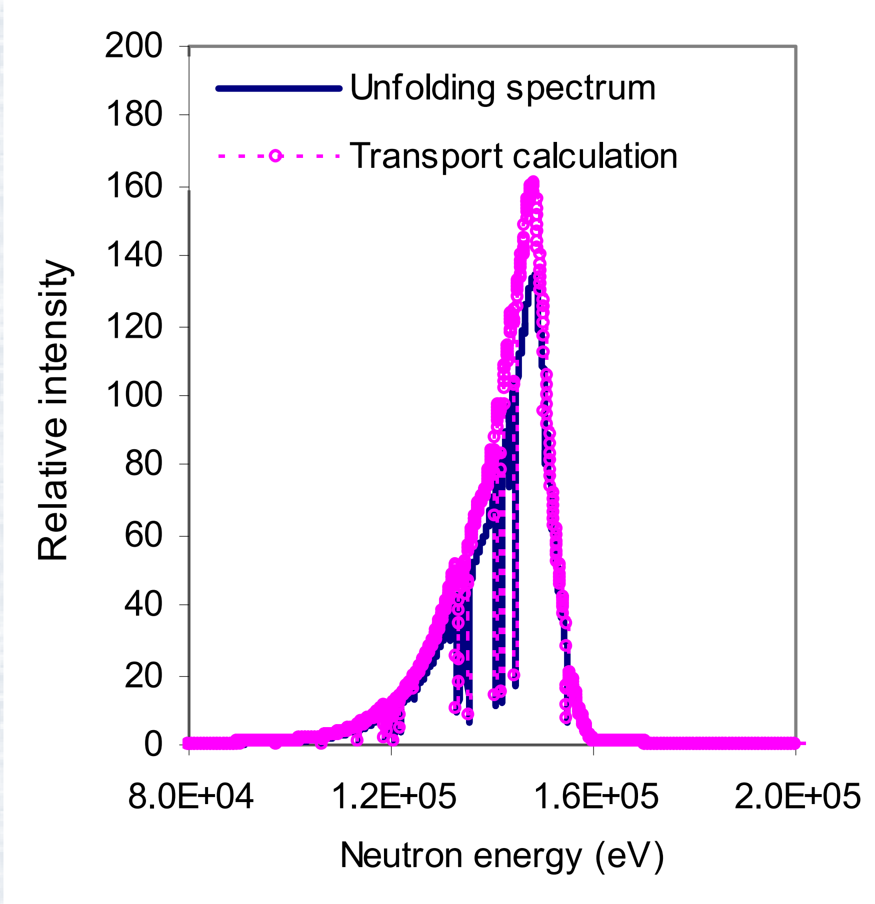
Main tasks for scientific research

- High precision measurements (0.1 – 0.01 %) of total and partial cross sections for fundamental neutron-nuclear investigations.
- Measurements of neutron capture gamma-spectra.
- Measurements of activation cross sections.
- Isomeric ratio investigations.
- Investigations of Doppler-effect.
- Research of radiation damage energy dependence in materials.
- Neutron radiography and tomography.
- Boron-Neutron Capture Therapy (BNCT).
- Prompt Gamma-ray Activation Analysis (PGAA).
- Development of standard fluxes for neutron-dosimetry purposes.
- Energy calibration of proton recoil counters.

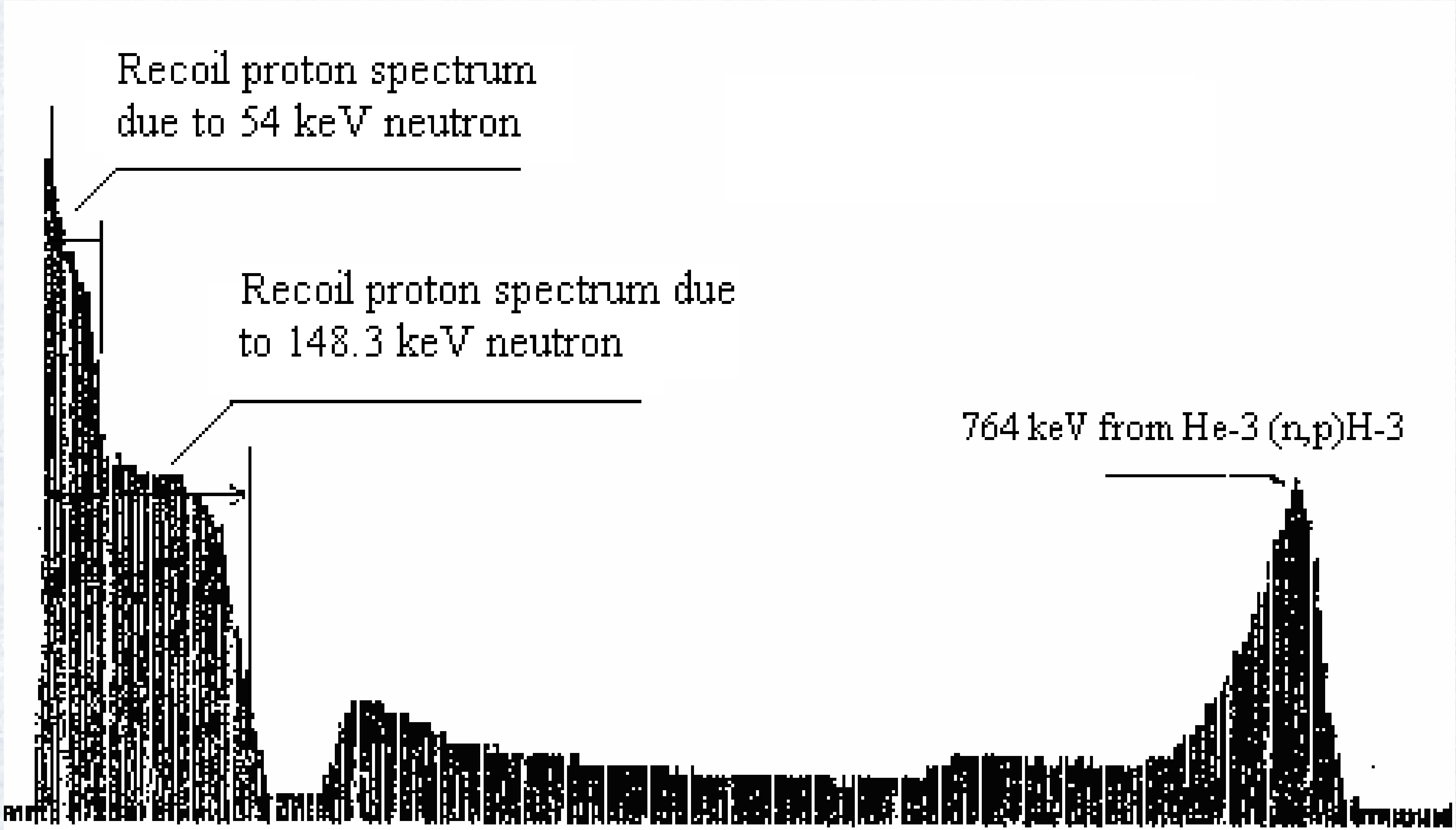
Filtered Neutron spectra calculations

- Unfolding neutron spectra of 54 keV and 148.3 keV filtered neutron beams at Dalat Research Reactor

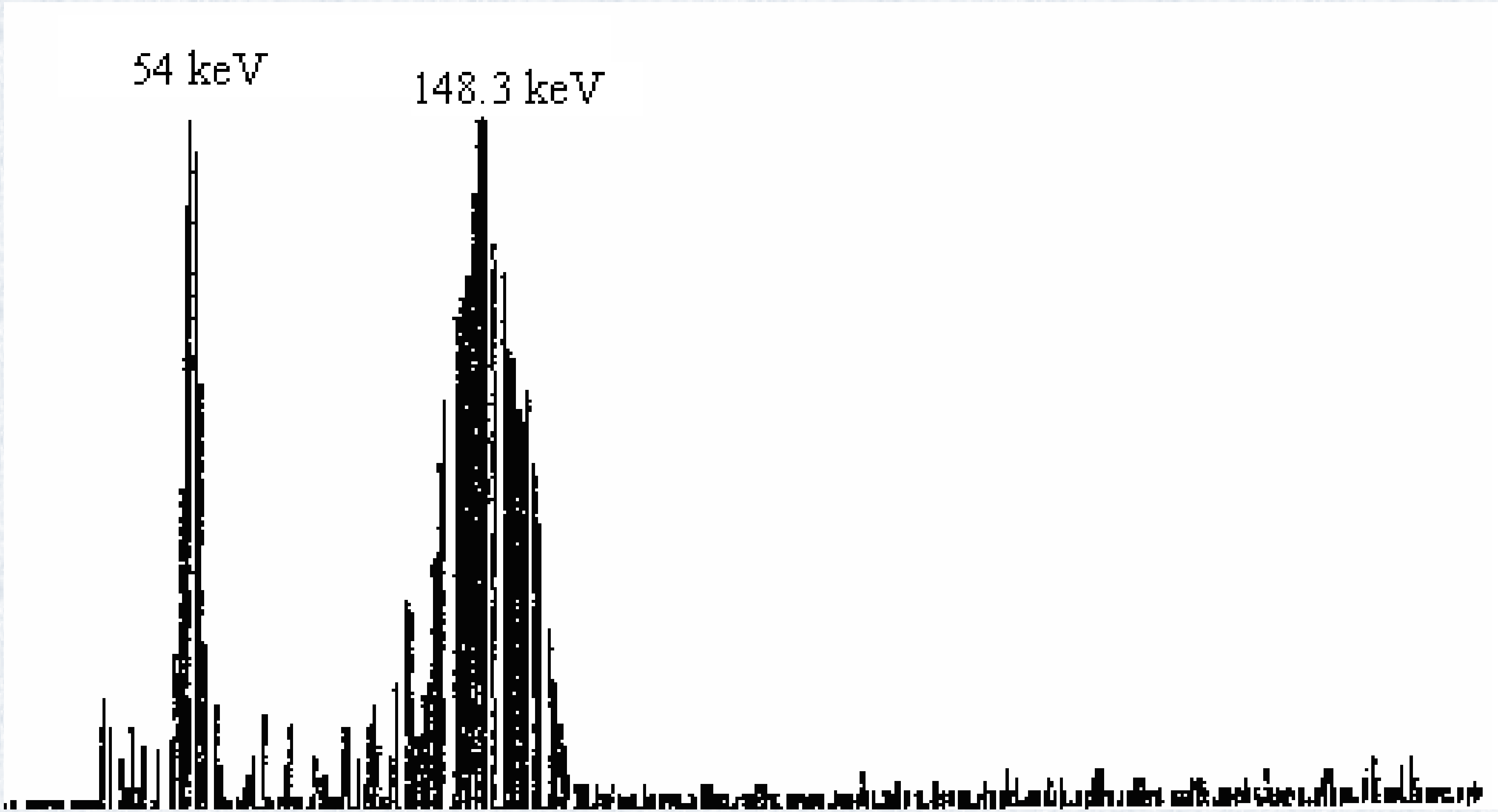




Neutron spectrum measurement



Recoil proton counter SNM-38
(90 % H_2 + 9.56 % CH_4 + 0.44 % ^3He, 3 atm)


54 keV
148.3 keV

Properties of the filtered neutron beams

Neutron energy	Filter combination	Flux density *($n.cm^{-2}.s^{-1}$)*	FWHM *(keV)*
148.3 keV	98 cm Si +1,0 cm Ti + 0,2 g/cm^2 B-10	2.14×10^6	22
54 keV	98 cm Si + 35 g/cm^2 S + 0,2 g/cm^2 B-10	5.61×10^5	8

Experiments

- Experimental arrangement

  - Samples: La_2O_3, Sm_2O_3 and IrO_2, 99.99%
  - Standard: gold foils 0.01mm in thickness
  - Cd covers with 0.5mm in thickness
  - A fast-digital gamma-ray spectroscopy in compacted with a 58% efficient HPGe detector

- The neutron capture cross sections for the reactions of:

  $^{139}La(n,\gamma)^{140}La$, $^{152}Sm(n,\gamma)^{153}Sm$,

  $^{191}Ir(n,\gamma)^{192}Ir$, $^{193}Ir(n,\gamma)^{194}Ir$, $^{197}Au(n,\gamma)^{198}Au$

Decay properties of the product nuclei

Product nucleus	Half-life	γ-ray energy (keV)	Intensity per decay (%)
^{198}Au	2.6952±0.0002(d)	411.8	95.6±0.1
^{140}La	1.6781±0.0003(d)	487.02	45.5±0.6
^{153}Sm	46.50±0.21 (h)	103.2	29.3±0.1
^{192}Ir	73.827±0.013 (d)	316.5	82.7±0.2
^{194}Ir	19.28±0.13 (h)	328.45	13.1±1.7

Data processing

- Reaction rate

$$R = N\int \phi(E)\sigma_a(E)dE$$

- The average neutron capture cross section and neutron flux

$$<\sigma_a>=\int \sigma_a(E)\phi(E)dE \,/ \int \phi(E)dE$$

$$<\phi>=\int \phi(E)dE$$

➔

$$R = N<\sigma_a><\phi>$$

The radioactivity of sample at the end of irradiation

$$A = R(1 - \exp(-\lambda t_1))$$

$$A = \frac{C f_c \lambda}{\varepsilon_\gamma I_\gamma \exp(-\lambda t_2)(1 - \exp(-\lambda t_3))}$$

- The average capture cross sections of the irradiated samples can be obtained

$$<\sigma_a>^x = \frac{C^x f(\lambda,t)^x f_c^x I_\gamma^{Au} \varepsilon_\gamma^{Au} N^{Au}}{C^{Au} f(\lambda,t)^{Au} f_c^{Au} I_\gamma^x \varepsilon_\gamma^x N^x} <\sigma_a>^{Au}$$

$$f(\lambda,t) = \frac{\lambda}{(1 - \exp(-\lambda t_1))\exp(-\lambda t_2)(1 - \exp(-\lambda t_3))}$$

Correction factors calculation

- Multi-scattering of neutron in sample
- Self-shielding effect

→ Monte Carlo Simulation
NeuCorrection code

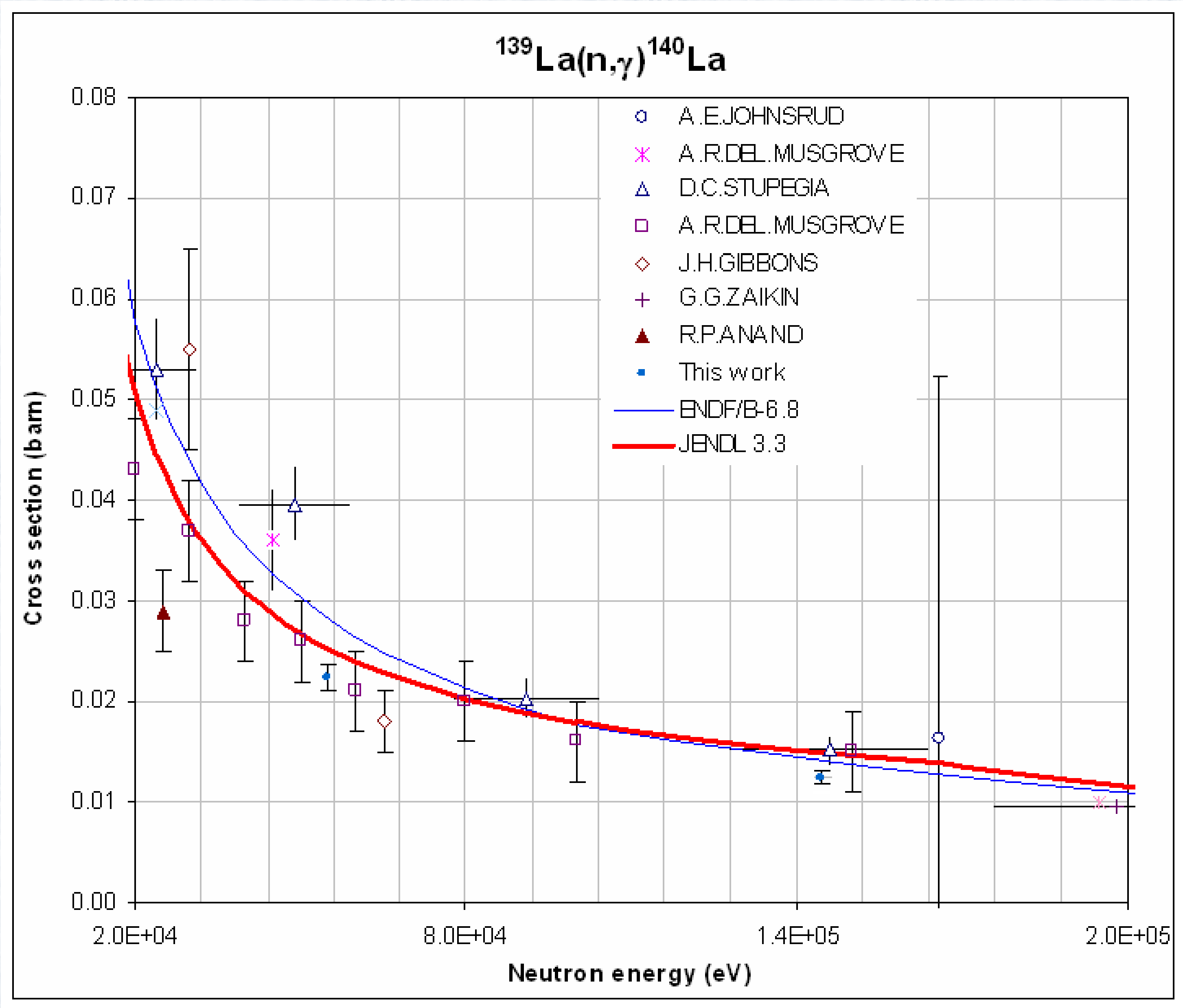
- Resonance capture with neutrons in low energy background region

→ Unfolding method
NeutronSpectrumCal Code

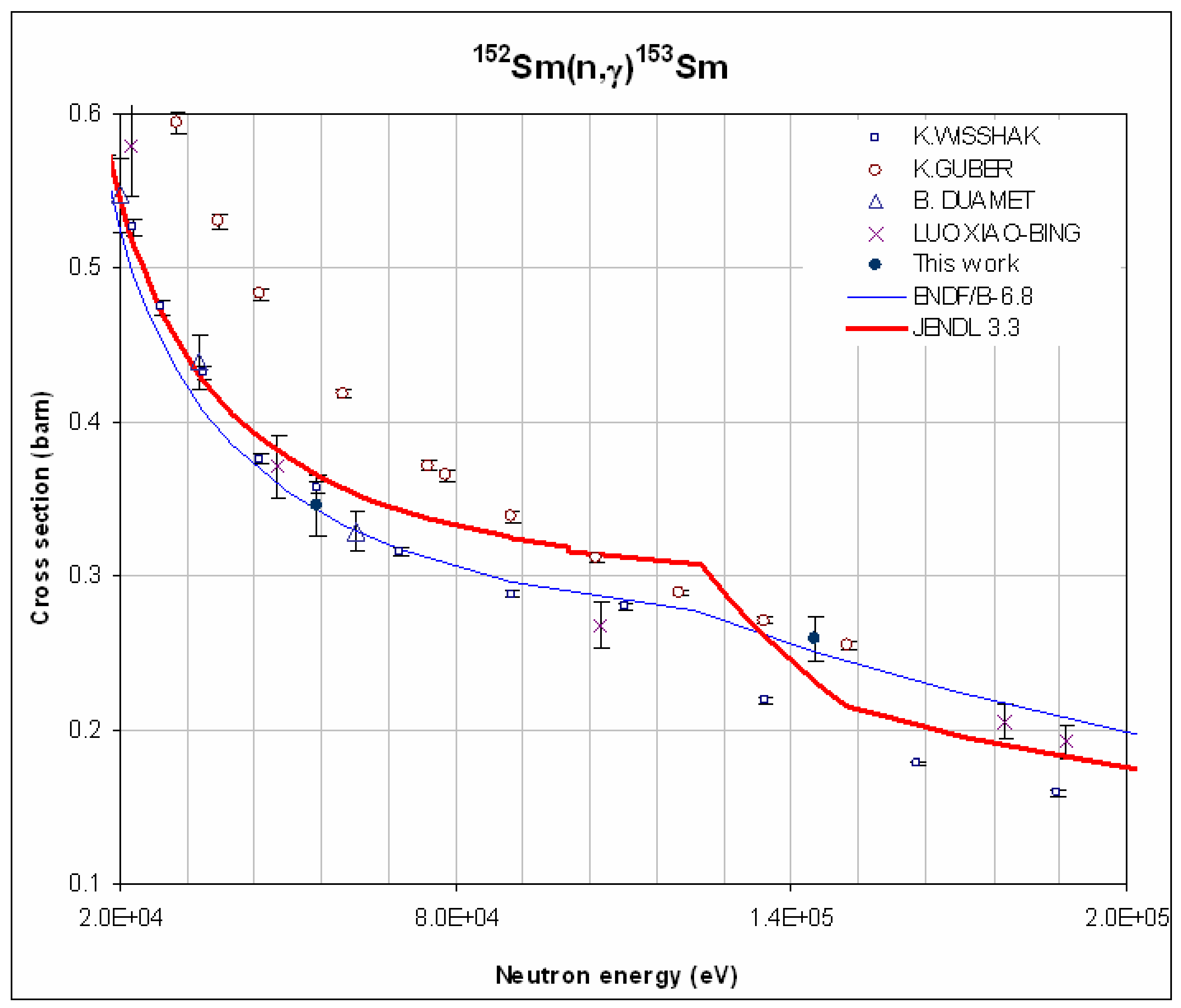
Nuclides	54keV region			148keV region		
	Self-shielding	Multi-scattering	Resonance capture	Self-shielding	Multi-scattering	Resonance capture
Au-197	0.9985	0.9901	0.4269	0.9988	0.9929	0.5338
La-139	0.9962	0.9785	0.6227	0.9986	0.982	0.7531
Sm-152	0.9988	0.9856	0.2816	0.9991	0.9917	0.4890
Ir-191	0.9959	0.9782	0.4937	0.9968	0.9828	0.6593
Ir-193	0.9959	0.9774	0.5214	0.9968	0.9826	0.6944

Experimental Results

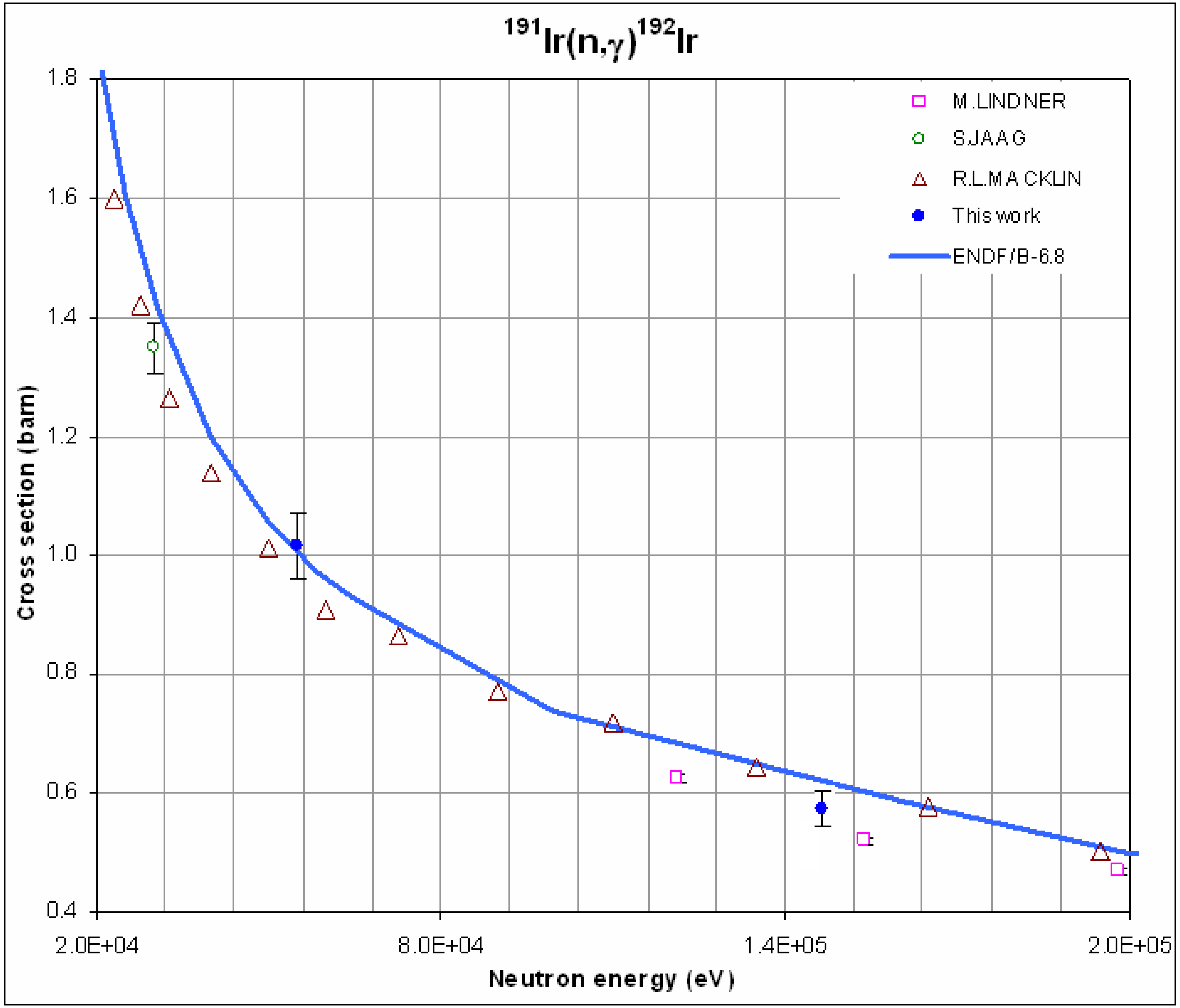
Neutron energy	$<\sigma_a>^{La-139}$ (mb)	$<\sigma_a>^{Sm-152}$ (mb)	$<\sigma_a>^{Ir-191}$ (mb)	$<\sigma_a>^{Ir-193}$ (mb)
54 keV	22.4 ± 0.55	345.5 ± 8.2	1016.5 ± 21.1	566.7 ± 14.9
148.3 keV	12.01 ± 0.2	258.7 ± 5.2	514 ± 11.7	404.5 ± 9.8



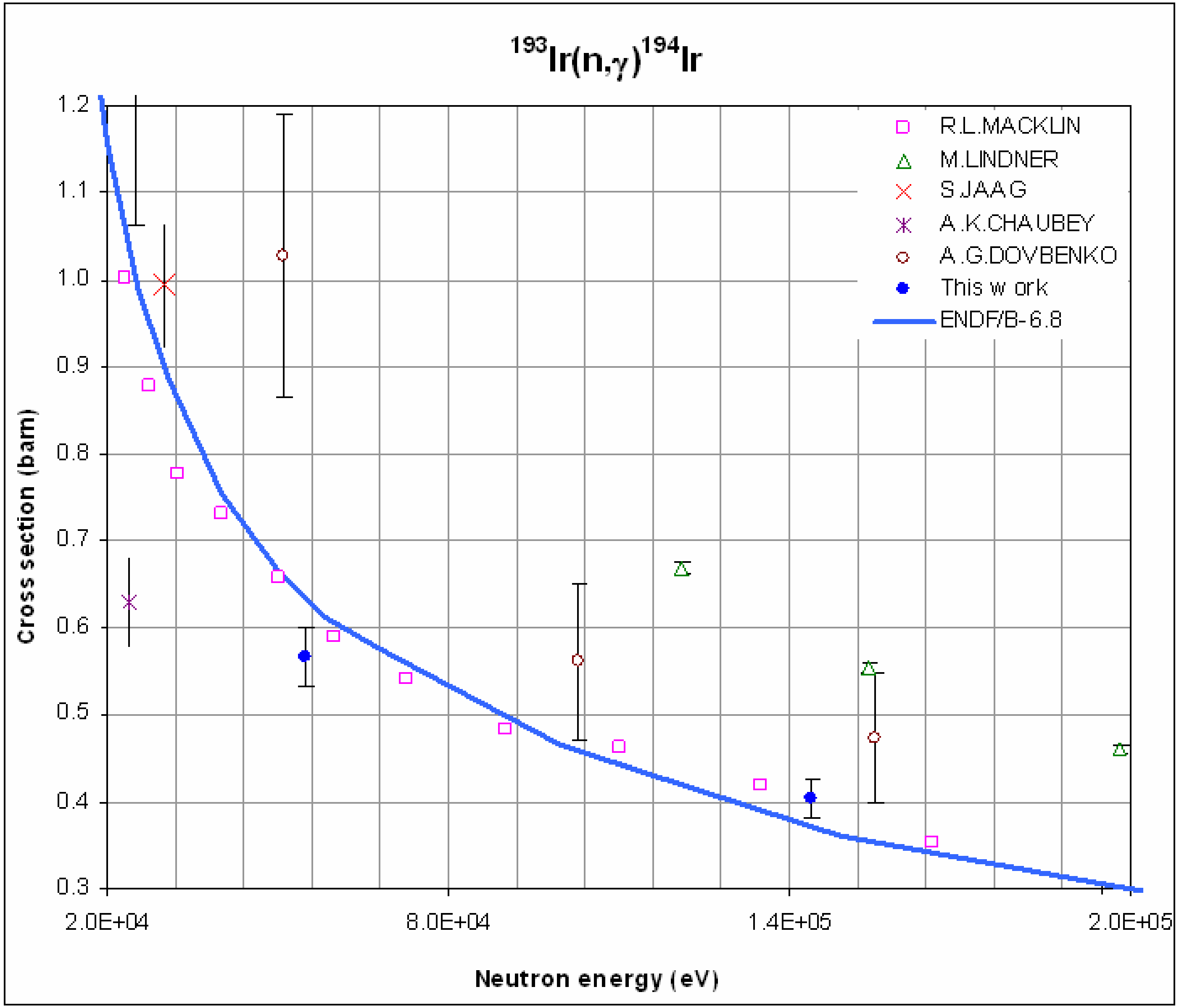
$^{139}La(n,\gamma)^{140}La$
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Cross section (barn)
2.0E+04
8.0E+04
1.4E+05
2.0E+05
Neutron energy (eV)
A.E.JOHNSRUD
A.R.DEL.MUSGROVE
D.C.STUPEGIA
A.R.DEL.MUSGROVE
J.H.GIBBONS
G.G.ZAIKIN
R.P.ANAND
This work
ENDF/B-6.8
JENDL 3.3



152Sm(n,γ)153Sm
Cross section (barn)
Neutron energy (eV)
0.6
0.5
0.4
0.3
0.2
0.1
2.0E+04
8.0E+04
1.4E+05
2.0E+05
K.WISSHAK
K.GUBER
B. DUAMET
LUO XIAO-BING
This work
ENDF/B-6.8
JENDL 3.3



$^{191}Ir(n,\gamma)^{192}Ir$
Cross section (barn)
Neutron energy (eV)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
2.0E+04
8.0E+04
1.4E+05
2.0E+05
M.LINDNER
S.JAAG
R.L.MACKLIN
This work
ENDF/B-6.8



193Ir(n,γ)194Ir
Cross section (barn)
Neutron energy (eV)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2.0E+04
8.0E+04
1.4E+05
2.0E+05
R.L.MACKLIN
M.LINDNER
S.JAAG
A.K.CHAUBEY
A.G.DOVBENKO
This w ork
ENDF/B-6.8

Publication

CINDA Like Entry
for Proceedings of 2006 Symposium on Nuclear Data

An index to the nuclear reaction data presented in SND2006 is given in this text. The format is that od the Computer Index to Nuclear Reaction Data (CINDA)[1)], which is available from nuclear data centers world-wide. The format is as follows:

Element S	Element A	Quantity Reaction	Quantity Type	Energy Min	Energy Max	Lab.	Type	Documentation Ref&Page	Documentation 1st Author
C		(n,xa)	DADE	1.40E+7		JPNOSA	Expt	SND2006-V.03-1	K. Kondo
Fe		(n,xn)	DADE	1.40E+8	1.60E+8	JPNKYU	Expt	SND2006-V.05-1	H. Arakawa
Zr		(n,2n)	SIG	1.40E+7		JPNOSA	Expt	SND2006-V.04-1	K. Shiken
Zr		(n,2n)	DA	1.40E+7		JPNOSA	Expt	SND2006-V.04-1	K. Shiken
Zr		(n,2n)	DADE	1.40E+7		JPNOSA	Expt	SND2006-V.04-1	K. Shiken
La	139	(n,g)	SIG	5.50E+4	1.44E+5	VN DAL	Expt	SND2006-V.02-1	Vuong Huu Tan
Sm	152	(n,g)	SIG	5.50E+4	1.44E+5	VN DAL	Expt	SND2006-V.02-1	Vuong Huu Tan
Ir	191	(n,g)	SIG	5.50E+4	1.44E+5	VN DAL	Expt	SND2006-V.02-1	Vuong Huu Tan
Ir	193	(n,g)	SIG	5.50E+4	1.44E+5	VN DAL	Expt	SND2006-V.02-1	Vuong Huu Tan
Pb	206	MANY		2.00E+7	2.00E+8	JPNKYU	Eval	SND2006-V.08-1	T. Kajimoto
U	235	(n,f)	FY	therm		JPNJAE	Theo	SND2006-V.06-1	M. Ohta

V. H. Tan, T. T. Anh, N. C. Hai, P. N. Son and T. Fukahori, *Measurement of Neutron Capture Cross Section of ^{139}La, ^{152}Sm and ^{191,193}Ir at 55keV and 144keV*, SND2006-V.02-1, Proceeding of 2006 Symposium on Nuclear Data, Jan. 25-26, 2007, RICOTTI, Tokai, Ibaraki, Japan, ISBN978-4-89047-138-6, [CD], 2007.

Conclusions

- The neutron capture cross sections of ^{139}La, ^{152}Sm and $^{191,193}Ir$ within the uncertainties of about 3-6% have been measured at energies of 54 keV and 148.3 keV by the activation foil method.

- The neutron filtered beams of 54 keV and 148.3 keV are available and useful for measurement of nuclear data at these energies.

- In the next term, we are planning to produce for new filtered compositions of 24.3 keV, 58.8 keV and 133.3 keV in order to expand the potentiality of nuclear data measurement in other energy regions at Dalat Nuclear Research Institute.

References

[1] K. H. Guber, et al., Neutron Cross Section Measurements at the Spallation Neutron Source, Int. Conf. on Nuclear Data for Science and Technology, Tsukuba (JP), 7-12, P. 281, Oct. 2001.

[2] Stefano Marrone, Measurement of the $^{139}La(n,\gamma)$ Cross Section at n_TOF, 12th Conference on Capture Gamma-Ray Spectroscopy and Related Topics, CGS12, 4-9 (2005).

[3] S. O'Brien et al., Neutron capture cross section of ^{139}La, Phy. Rev. C68, 035801 (2003).

[4] Z. Y. Bao, H. Beer, F. Kappeler, F. Voss, And K. Wisshak, Neutron Cross Sections for Nucleosynthesis Studies, Atomic Data and Nuclear Data Tables 76, 70–154 (2000).

[5] Kazuya OHGAMA, et al., Measurement of keV-Neutron Capture Cross Sections and Capture Gamma-Ray Spectra of $^{91,92}Zr$, J. Nuclear Science and Technology, Vol. 42, P. 333 (April 2005).

[6] P. Z. Hien, V. H. Tan, N. C. Hai. Radiactive capture cross section measurements for U-238 on the 54 keV and 148.3 keV filtered neutron beams, KC-09-08, Dalat (1995), P. 117.

[7] V. P. Vertebnyj, et al., Filtered Medium and Thermal Neutron Beams and Their Use, "Properties of Neutro Sources", IAEA-TECDOC-401, (1986).

[8] O. O. Gritzay, et al., Neutron Filters at Kyiv Research Reactor, KIRN-01-6 (2001).

[9] K. Senoo, Y. Nagai, T. Shima, T. Ohsaki, A Monte Carlo code for multiple neutron scattering events in a thick sample for (n, γ) experiments, Nucl. Instr. and Meth. A339 (1994) 556-563.

[10] Motoharu Mizumoto and Masayoshi Sugimoto, The Influence of Water Absorption in Samples for Neutron Capture Cross Section Measurements, Nucl. Instr. and Meth., A282 (1989) 324.

[11] Nudat 2.2 Database, http://www.nndc.bnl.gov/nudat2/

[12] Oleg Shcherbakov and Hideo Harada, Resonance Self-Shielding Corrections for Activation Cross Section Measurements, J. Nucl. Sci. Tech., Vol. 39, No. 5, P. 548 (2002).

[13] K. Shibata, T. Kawano, T. Nakagawa, O. Iwamoto, J. Katakura, T. Fukahori, S. Chiba, A. Hasegawa, T. Murata,H. Matsunobu, T. Ohsawa, Y. Nakajima, T. Yoshida, A. Zukeran, M. Kawai, M. Baba, M. Ishikawa, T. Asami, T. Watanabe, Y. Watanabe, M. Igashira, N. Yamamuro, H. Kitazawa, N. Yamano and H. Takano: "Japanese Evaluated Nuclear Data Library Version 3 Revision-3: JENDL-3.3," J. Nucl. Sci. Technol. 39, 1125 (2002).

[14] V. McLane and Members of the Cross Section Evaluation Working Group, "ENDF/B-VI Summary Documentation (ENDF-201)", BNL-NCS-17541, Brookhaven National Laboratory (1996).

[15] A. R. de L. Musgrove, B. J. Allen, R. L. Macklin, Resonance Neutron Capture in ^{139}La, Aust. J. Phys., 30, 599-604 (1977).

[16] K. Wisshak, et al., Neutron Capture in ^{148,150}Sm: A Sensitive Probe of the s-Process Neutron Density, Phy. Rev. C48, 3, (1993).

[17] B. Duamet, et al. Measurement of keV-Neutron Capture Cross Sections and Capture Gamma-Ray Spectra of ^{147,148,149,150,152,154}Sm, J. Nucl. Sci. Tech., Vol. 36, p. 865-876 1999).

[18] R. L. Macklin, D. M. Darke and J. J. Malanify, Fast Neutron Capture Cross Section of ^{169}Tm, ^{191}Ir, ^{193}Ir, ^{175}Lu for E_n from 3-2000 keV, LA-7479-MS, Aug. 1978.

THANK YOU