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FUNDAMETAL RESEARCH BASED ON NEUTRON BEAMS AT DALAT NUCLEAR RESEARCH REACTOR

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Content

1. General information

2. Fundamental research and applications using neutron beams at the Dalat nuclear research reactor (DNRR):

-Neutron beams development using the filtered technique;

-Nuclear physics research:

+ Neutron cross-section measurement (capture cross-section, total cross-section);

+ Gamma two-steps cascade measurement (decay schema, level density and gamma strength function);

-Neutron activation analysis (INAA, CNAA, PGNAA, CINAA). - Manufacture of radiation measurement equipment using DSP and FPGA.

3. Aspect of education

1. General information

NUCLEAR PHYSICS AND ELECTRONICS DEPARTMENT

PRINCIPAL MISSIONS:
To exploit DNRR for fundamental research, application and nuclear human resource development

MANPOWER

- Official members: 15
- Scientific collaborators:5 (senior researchers: 7)

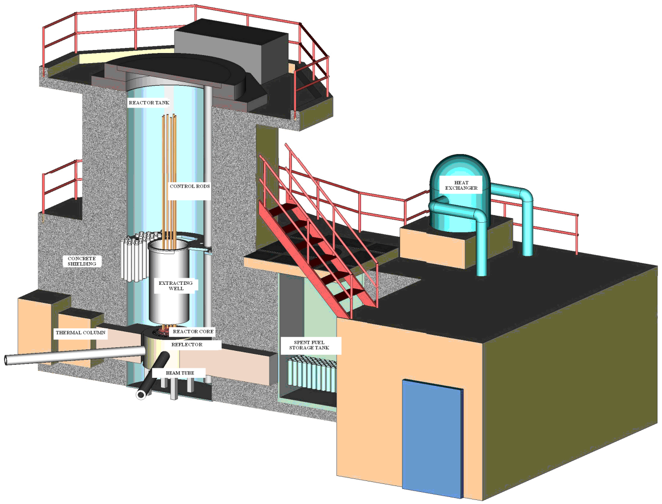
FACILITIES AND EQUIPEMENT

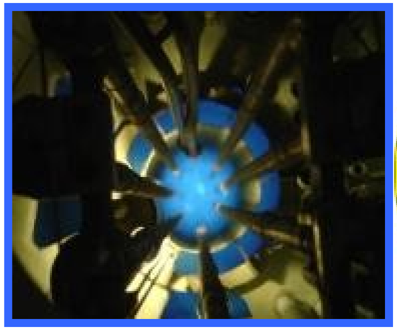
- Dalat research reactor (DNRR);
- Mono-energetic neutron beams;
- Spectroscopy system (Gamma, neutron, Compton suppression, gamma-gamma coincidence spectroscopies)

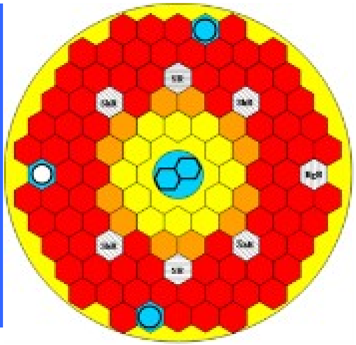
ACTIVITIES

- Development of mono-energetic neutron beams using the filtered technique;
- Nuclear data measurement (neutron capture, total cross section, gamma decay schema, level density,...);
- Development and application of neutron activation analytical techniques (INAA, PGNAA, CNAA, CoinINAA, hydro index,...);
- Design and manufacture of radiation measurement systems

Main characteristics of DNRR





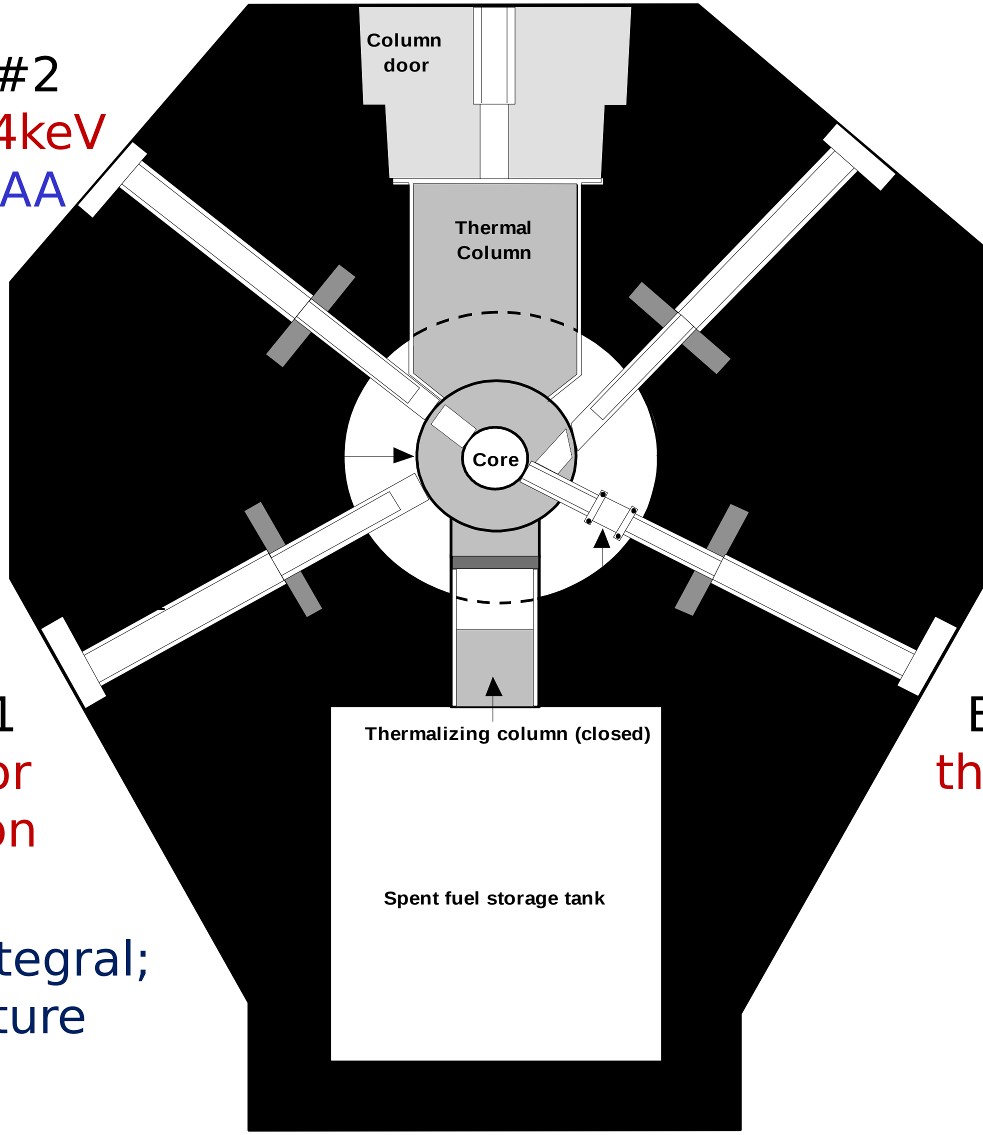


- **Reactor type:** Pool type (TRIGA Mark II, modified to Russian type of IVV-9)
- **Nominal power:** 500 kW
- **Maximum thermal neutron flux in the core:** 2.1×10^{13} $n.cm^{-2}.s^{-1}$
- **Coolant and moderator:** Light water
- **Reflector:** Beryllium and graphite
- **Core cooling mechanism:** Natural convection
- **Fuel type:** Russian type, VVR-M2, UO2+Al, 19.75% enrichment
- **Control rods:**
  - 2 safety rods: B_4C
  - 4 shim rods: B_4C; 1 fine rod
- **Vertical irradiation channels:** 4 holes in core and 40 holes at the rotary rack
- **Horizontal beam-ports**: 4 (1 tangential - No #3 and 3 radial - No #1, #2, #4)
- **Thermal column:** 1

Neutron beam channels of DNRR and applications

Beam port #2
thermal, 2, 24keV
NC, RI, PGNAA

Beam port #3
thermal
Level density,
gamma transitions



Horizontal section view of DNRR

Beam port #1
will be used for
new application

Beam port #4
thermal, 54, 59,
133,148keV
NC, TC

RI: Resonance Integral;
NC: Neutron capture measurement;
TC: Transmission measurement.

Spectroscopy systems

Neutron spectroscopy

Gamma-gamma coincidence spectroscopy

Low background gamma spectroscopy

Compton suppression spectroscopy

ATIVITIES

1. Development of mono-energetic neutron beams using the filtered technique;

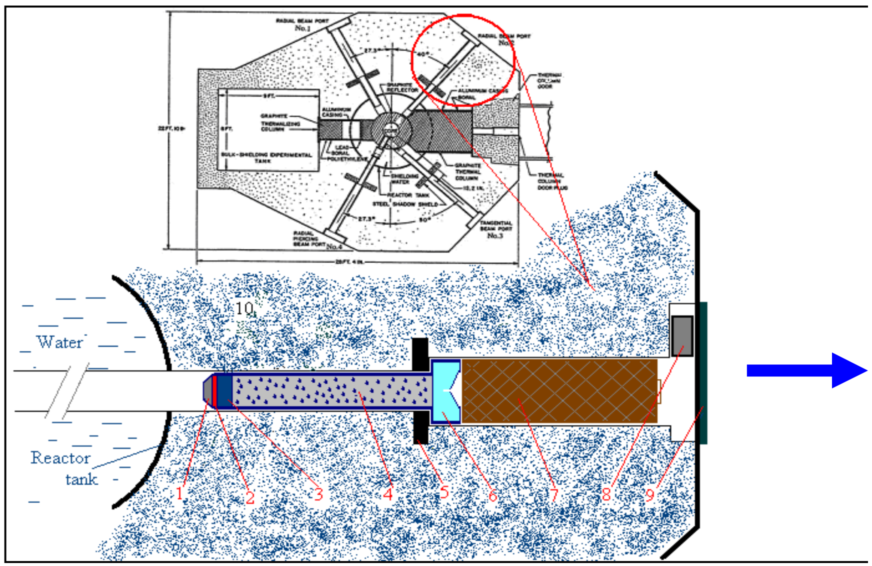
2. Nuclear data measurement (neutron radiative capture, neutron total cross sections, gamma decay schema, level density and gamma strength function);

3. Development and Application of neutron activation analytical techniques (INAA, PGNAA, CNAA, CoinINAA);

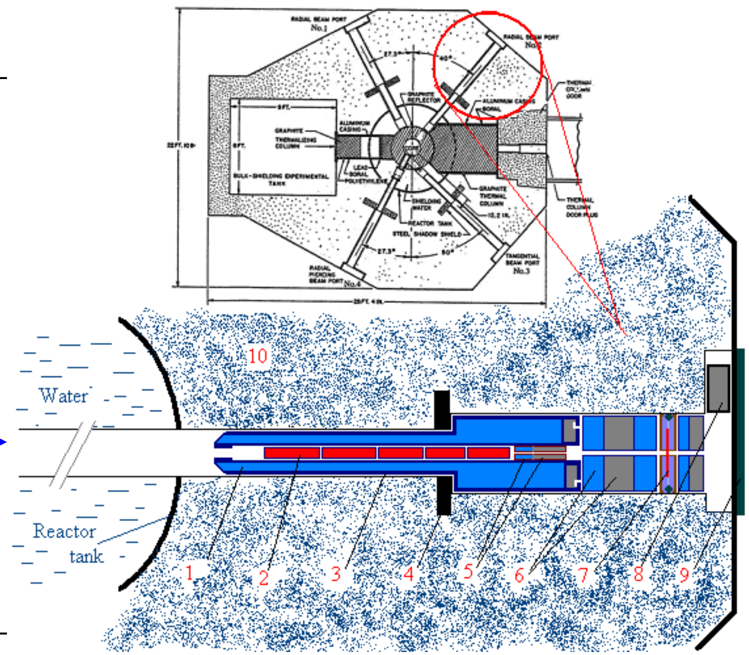
4. Design and manufacture of radiation measurement systems;

Development of filtered neutron beams

Design and constructions of neutron filter plugs at Dalat research reactor

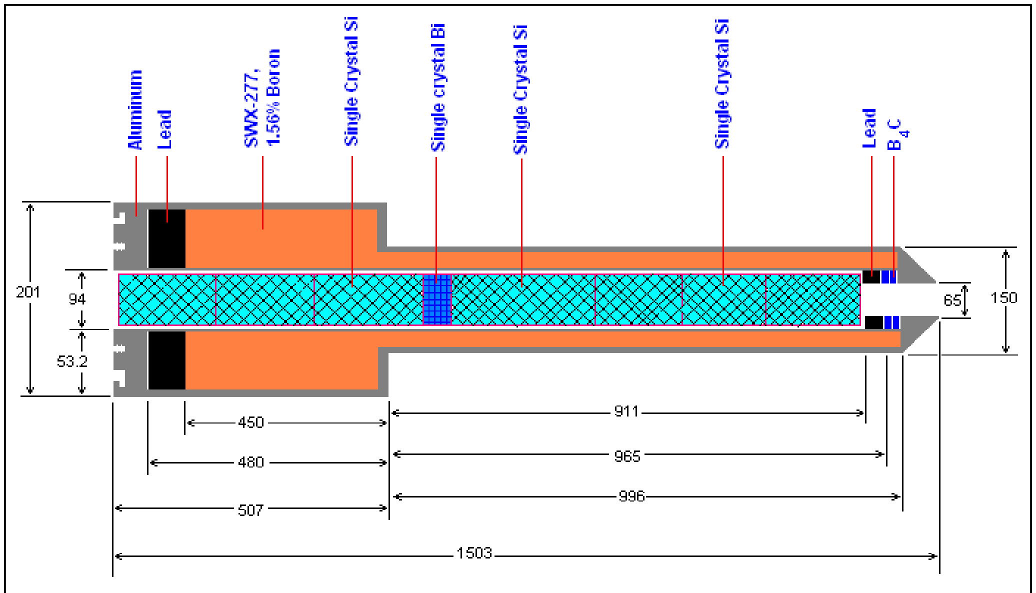


Before beam development
(the channel is closed)



After beam development
(the channel is being used)

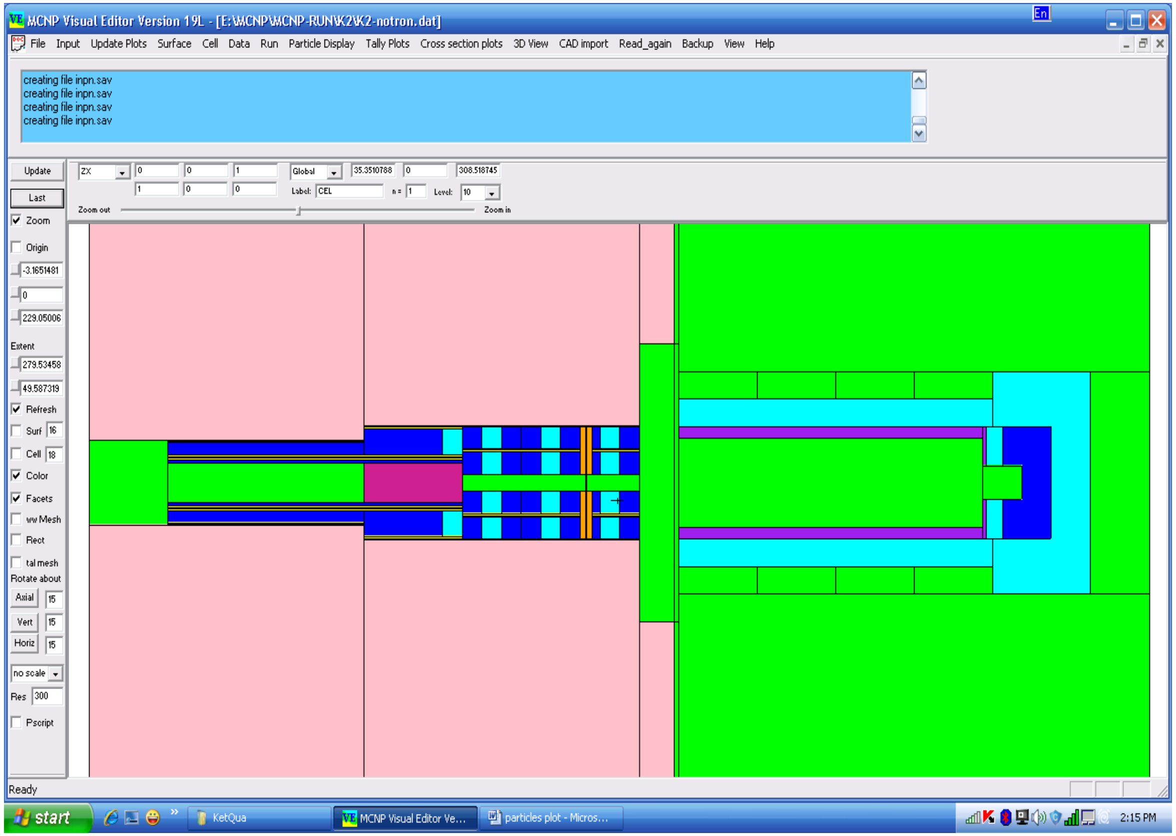
Development of filtered neutron beams



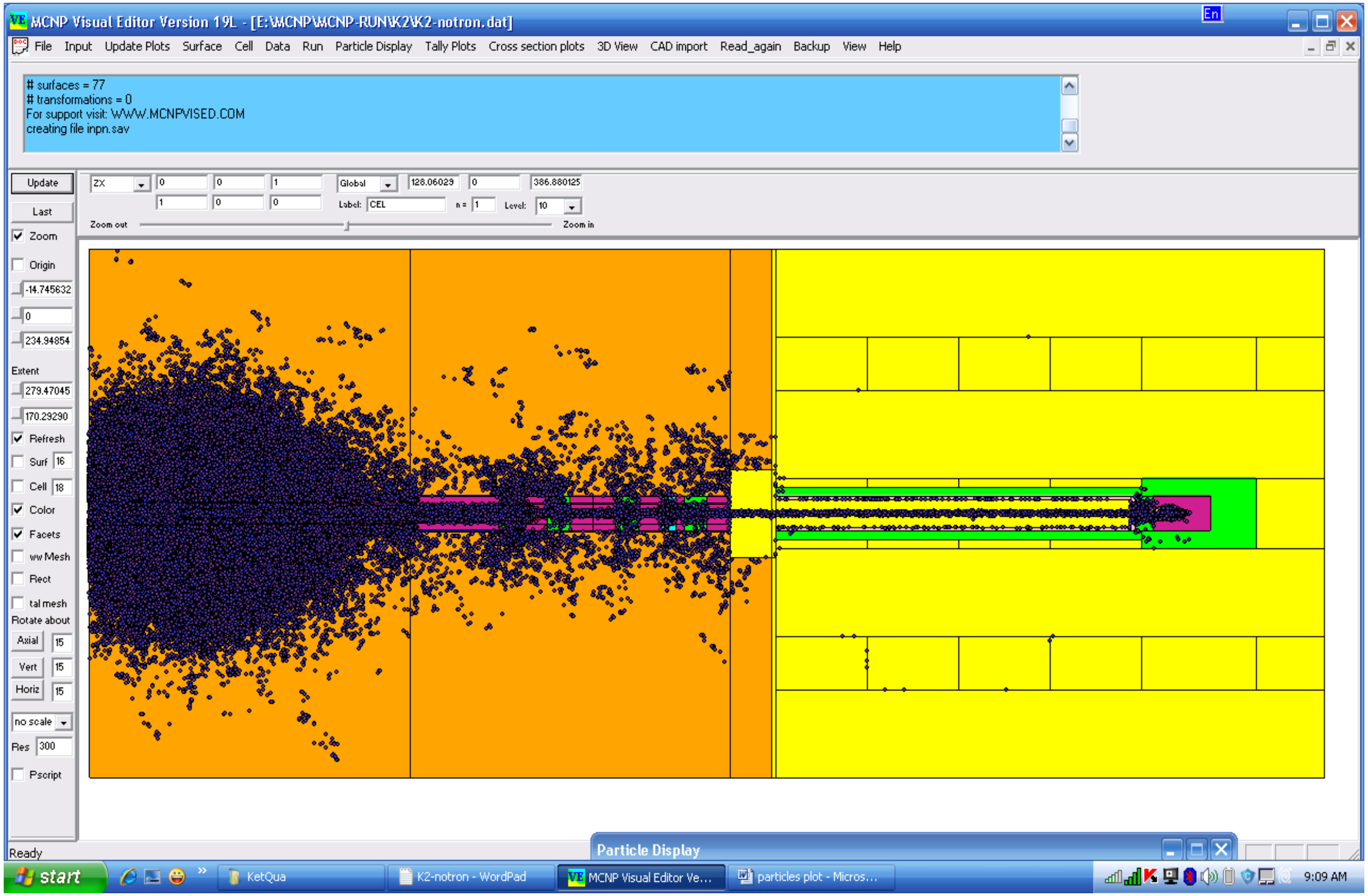
Filtered neutron facility at the horizontal channel of Dalat reactor (unit: mm)

Design and constructions of neutron filter plug

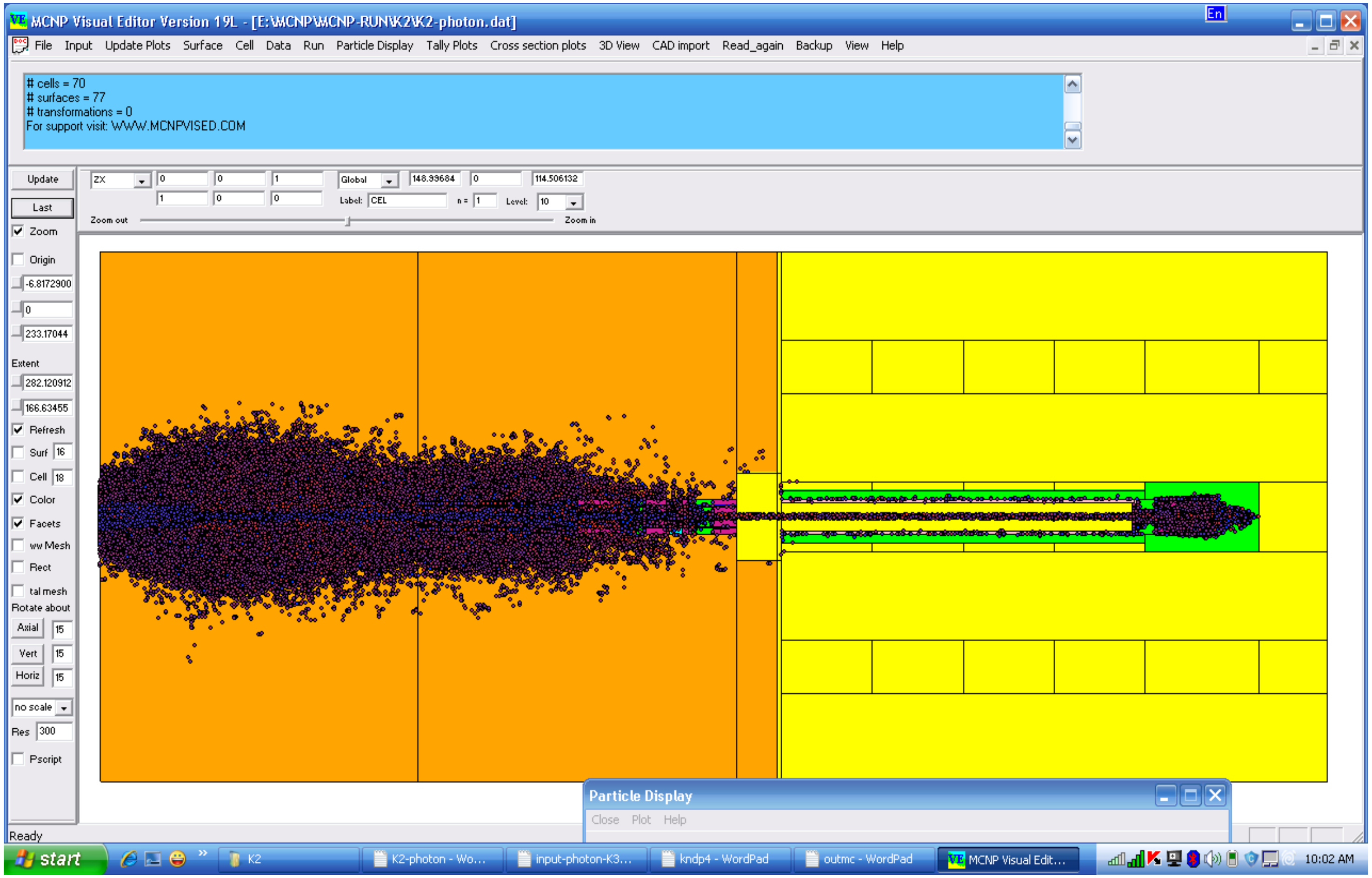
Development of filtered neutron beams



Monte-Carlo simulation and design for filtered thermal neutron beams at Dalat research reactor

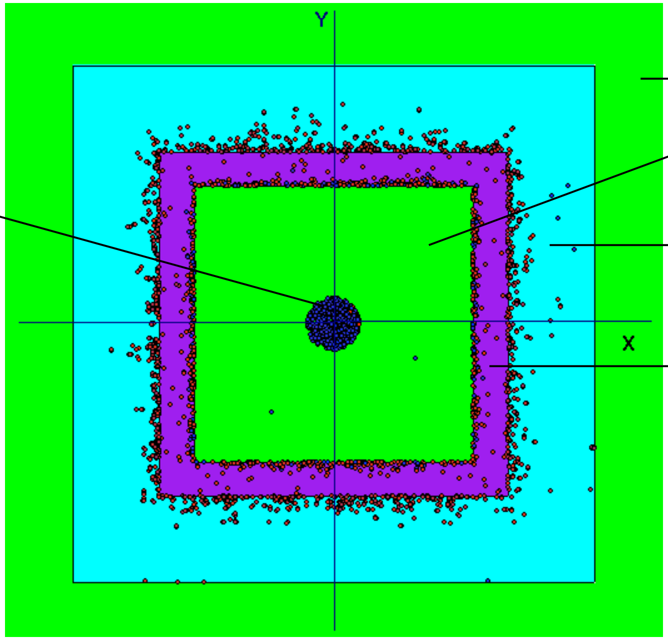


Monte-Carlo simulation of neutron radiation for filtered thermal neutron beams at Dalat research reactor



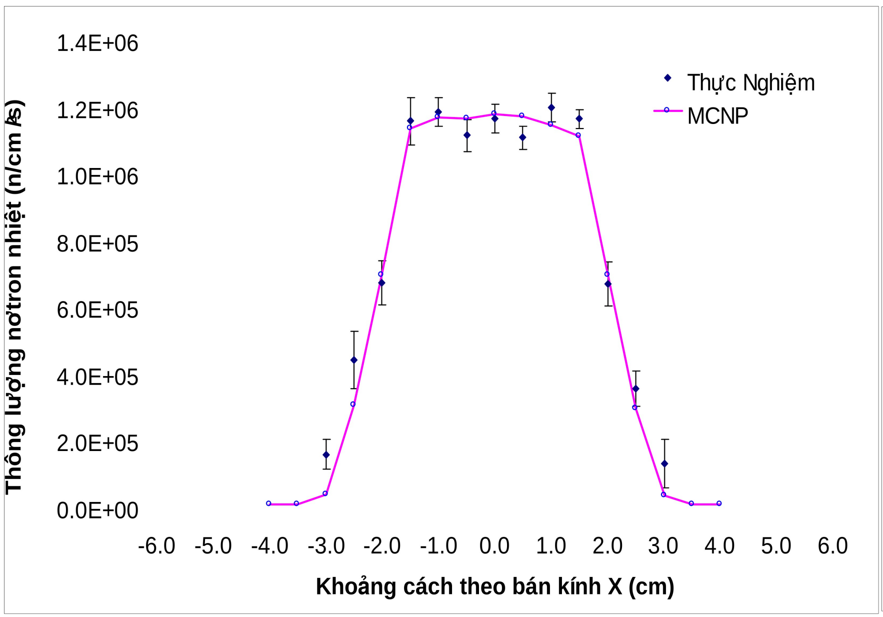
Monte-Carlo simulation of gamma radiation for filtered thermal neutron beams at Dalat research reactor

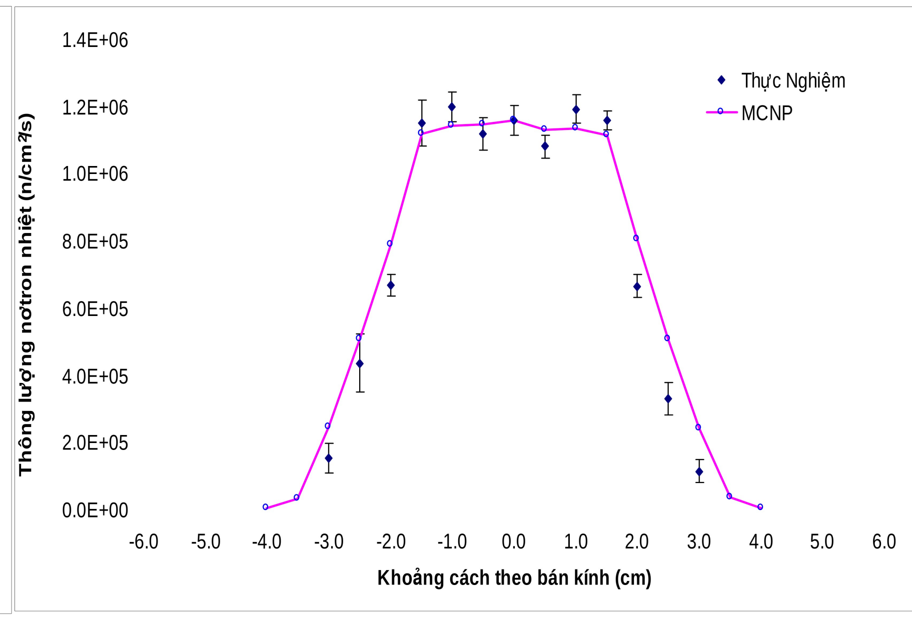
Development of filtered neutron beams



Monte-Carlo simulation for filtered neutron beam at Dalat research reactor

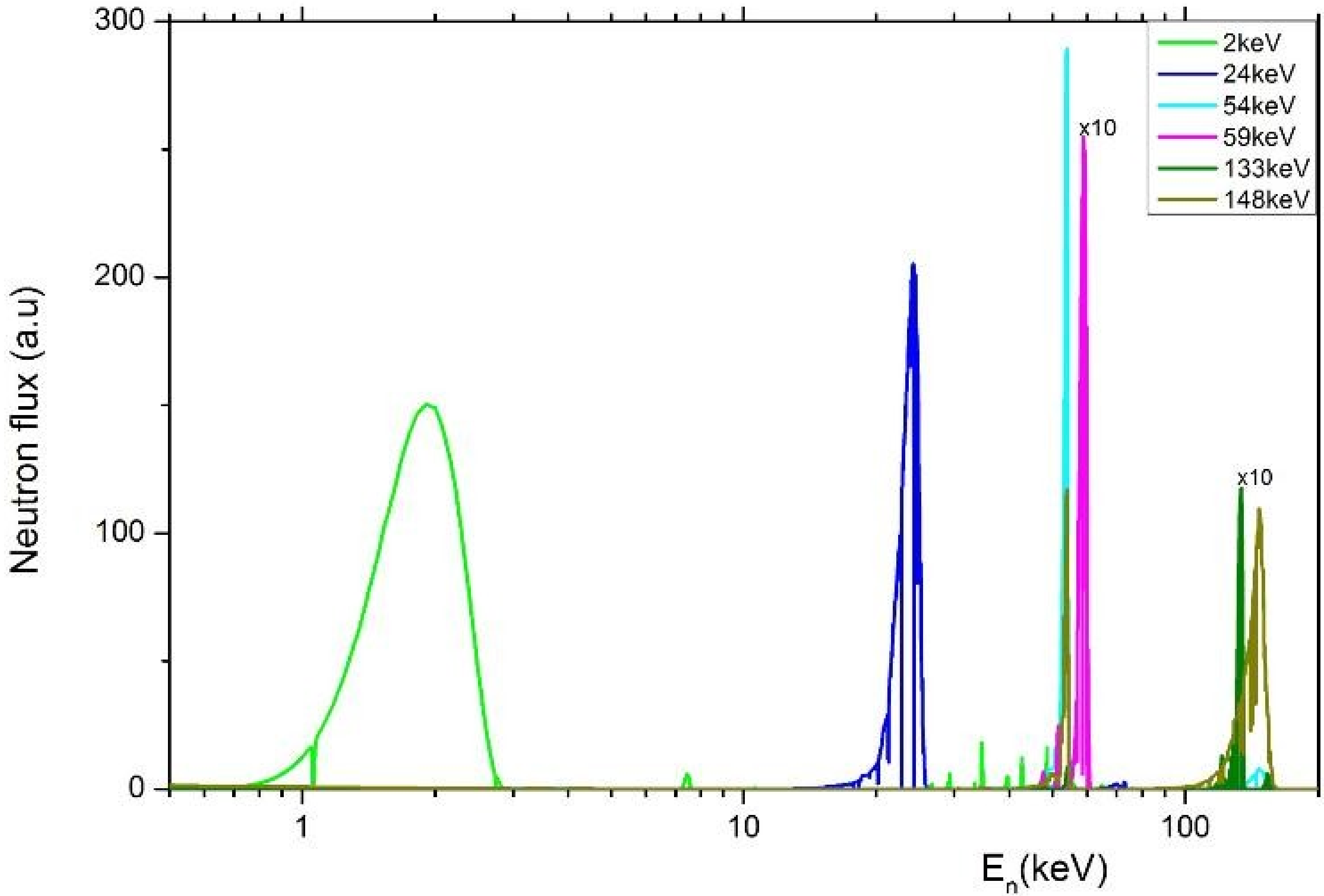
Development of filtered neutron beams



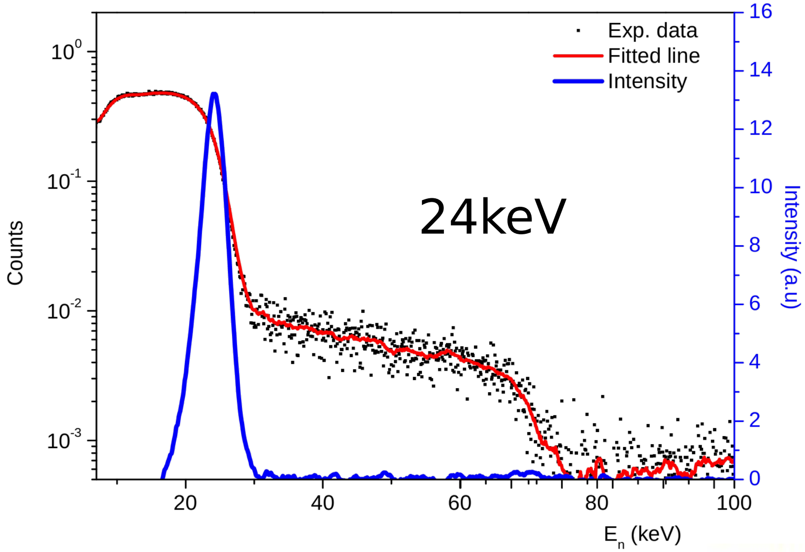


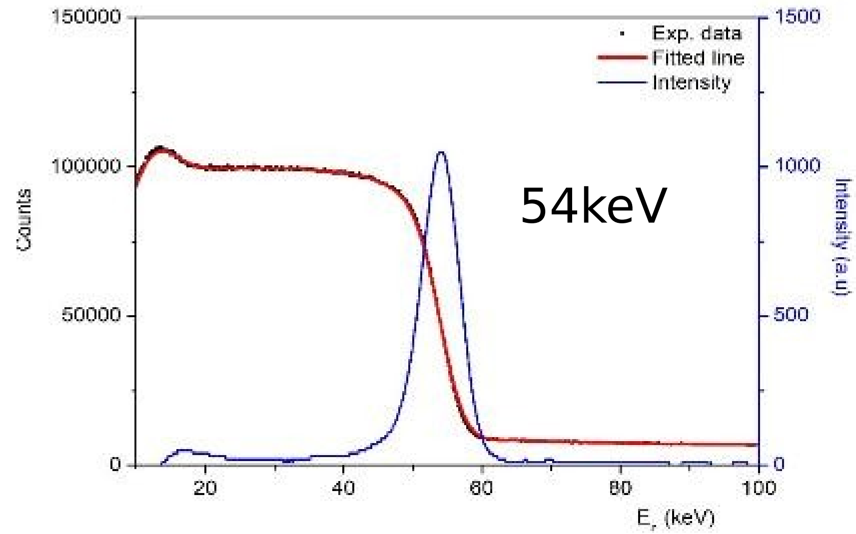
Monte-Carlo simulation and experiments for radial distribution of thermal neutron fluxes

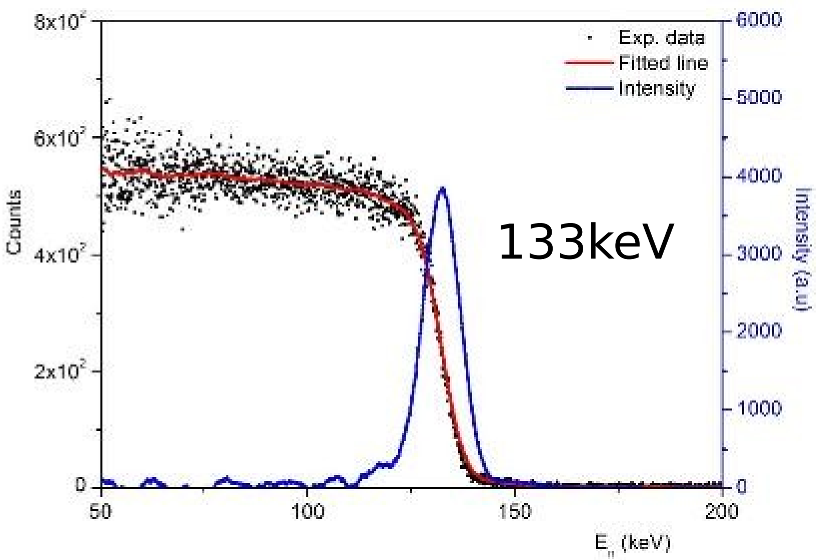
keV- filtered neutron spectra (cal.)

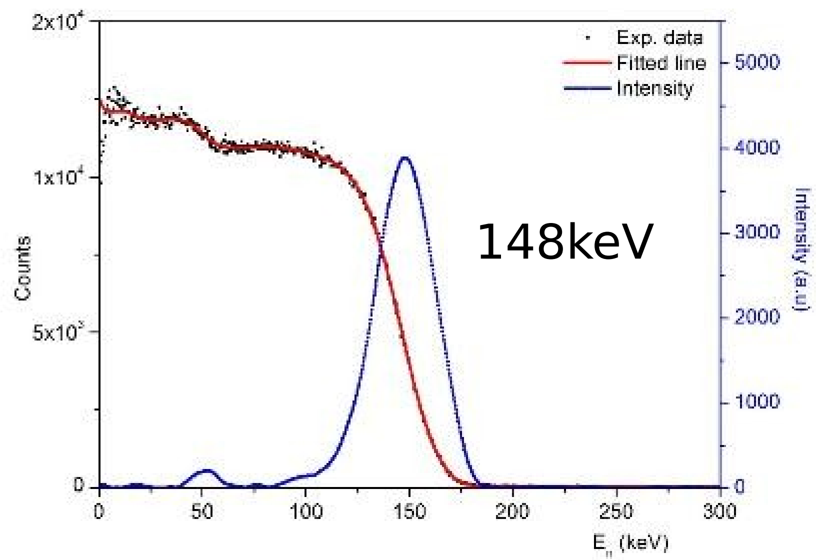


keV- filtered neutron spectra (exp.)

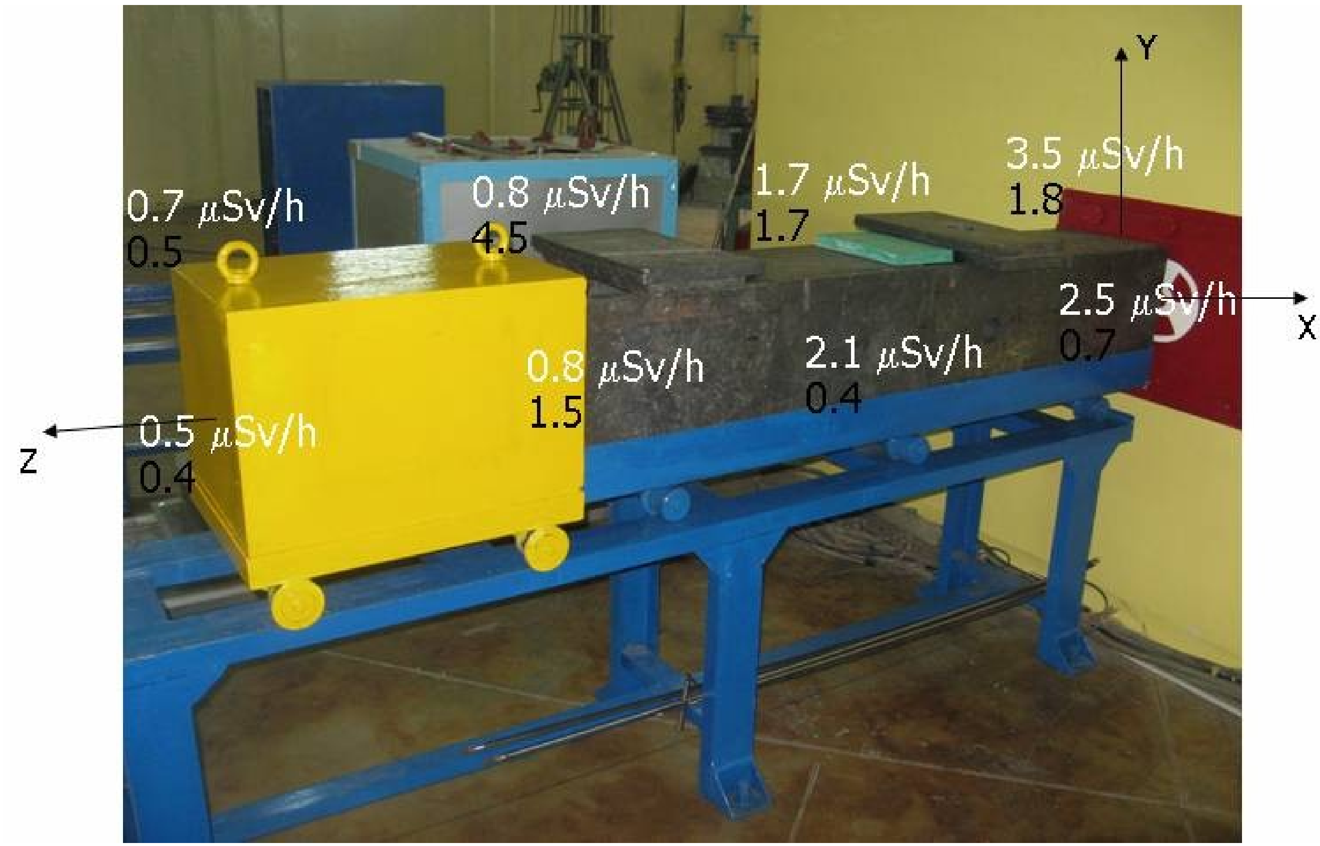








Development of filtered neutron beams



An outside view of filtered neutron beam at the channel No.2 of Dalat research reactor with radiation dose rate information (white color for neutron and black color for gamma)

Development of filtered neutron beams

Neutron beam characteristics:

Neutron energy	**24keV**	**59keV**	**133keV**
Neutron flux (n/cm^2.s)	$6.1x10^5$	$5.3x10^5$	$3.2x10^5$
Energy resolution (keV)	1.8	2.7	3.0
Peak relative intensity (%)	96.72	92.28	92.89
Beam collimated diameter	3 cm	3 cm	3 cm
Filter compositions	B 0.2g/cm^2 Fe 20cm Al 30cm S 35g/cm^2	B 0.2g/cm^2 Ni 10cm V 15cm Al 5cm S 35g/cm^2	B 0.2g/cm^2 Cr 50g/cm^2 Ni 10cm Si 60cm

Development of filtered neutron beams

Neutron beam characteristics:

Neutron energy	0.025 (eV)	54keV	148keV
Neutron flux (n/cm^2.s)	1.6×10^6	6.7×10^5	3.9×10^6
Energy resolution (keV)		1.5	14.8
Peak relative intensity (%)	Rcd = 420	78.05	95.78
Beam collimated diameter	3 cm	3 cm	3 cm
Filter compositions	Si 80 cm Bi 6 cm (single crystals)	B 0.2g/cm^2 Si 98cm S 35g/cm^2	B 0.2g/cm^2 Si 98cm Ti 1cm

Development of filtered thermal neutron beams

Neutron beam characteristics:

	Filters	Thermal Φ_{th} (n/cm^2/s)	Epithermal Φ_{epi} (n/cm^2/s)	R_{Cd} ratio	Collimators
1	120 cm Si (Single Crystal)	8.08×10^5 ± 0.15%	2.41×10^2 ± 3.03%	205	Cylinder Φ = 3cm
2	80cm Si + 3cm Bi (Single Crystal)	1.02×10^6 ± 0.14%	2.82×10^2 ± 0.96%	230	Cylinder Φ = 3cm
3	40cm Si + 9cm Bi (Single Crystal)	1.51×10^6 ± 1.57%	4.85×10^2 ± 1.45%	128	Cone Φ_1 = 5.0cm Φ_2 = 4.5cm Φ_3 = 4.0cm
4	**80cm Si + 6cm Bi (Single Crystal)**	**0.95×10^6 ± 1.25%**	**0.92×10^2 ± 2.85%**	**420**	**Cone Φ_1 = 5.0cm Φ_2 = 4.5cm Φ_3 = 4.0cm**

Nuclear data measurement

1. Measurements of neutron reaction cross-sections:

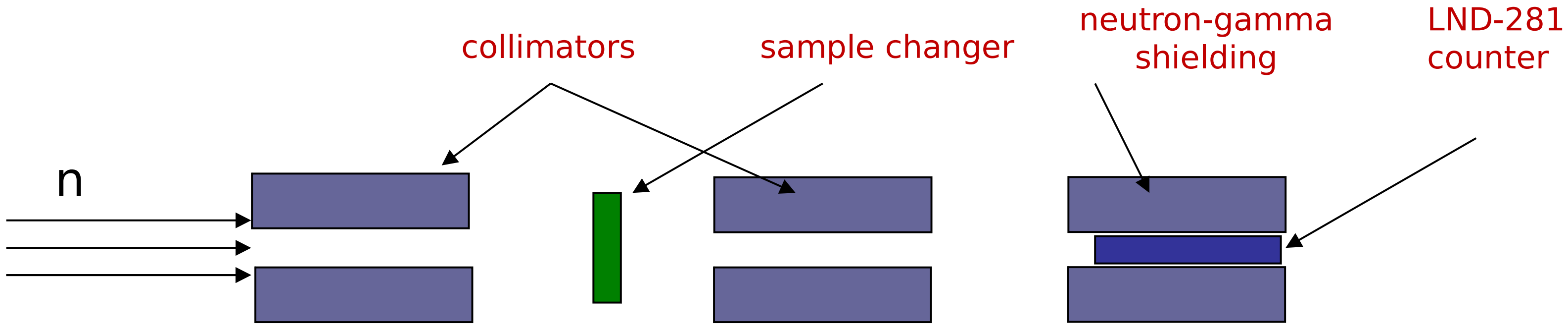
- Total neutron cross-section;
- Neutron capture cross-section.

2. Gamma decay schema, level density: using of gamma-gamma coincidence spectroscopy and gamma two-step cascade method.

Measurements of neutron reaction cross-sections

Total neutron cross sections

- Experimental arrangement



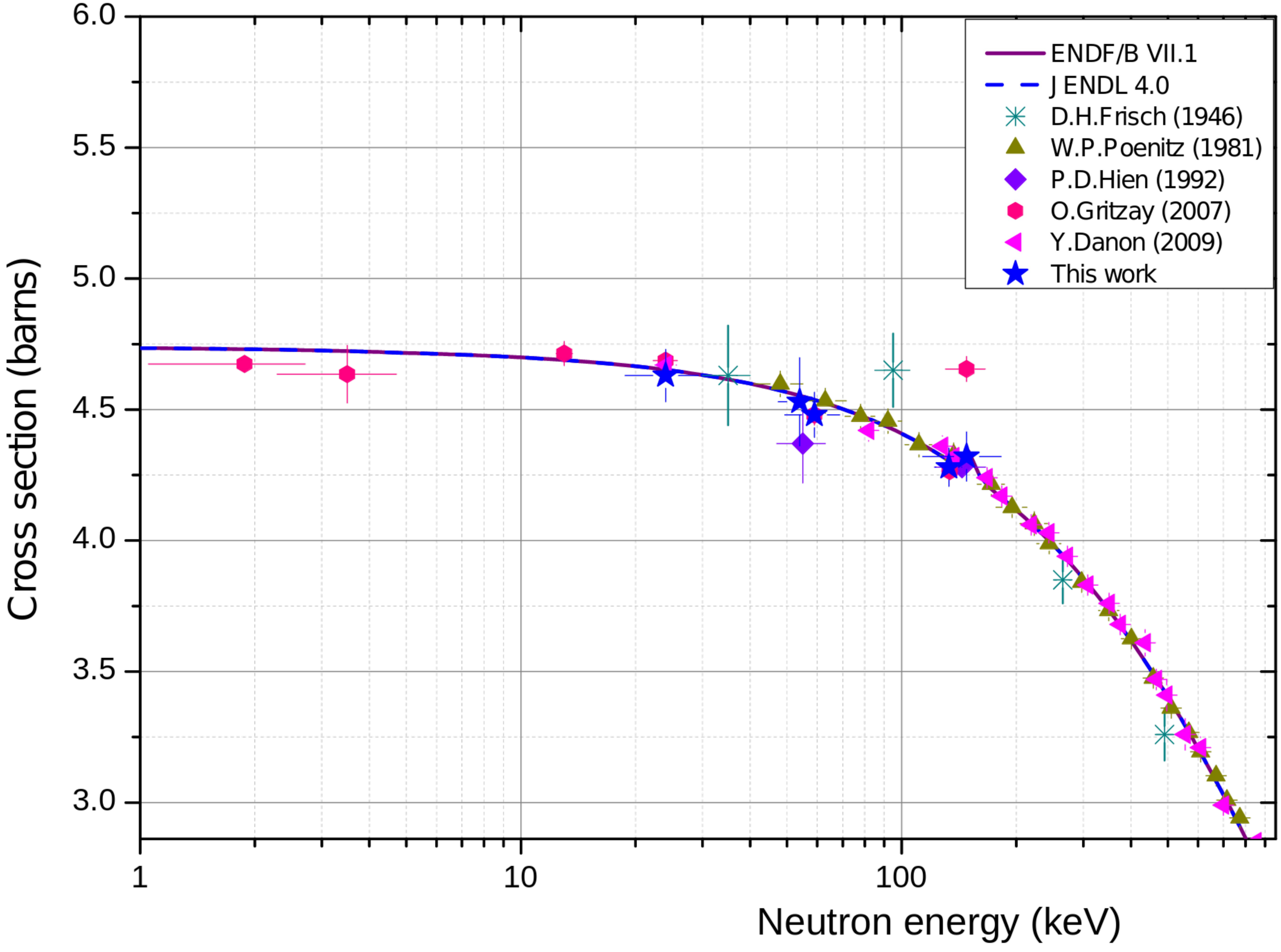
- Total neutron cross section

$$\sigma_t = \frac{1}{\rho x} \ln \frac{1}{T}$$

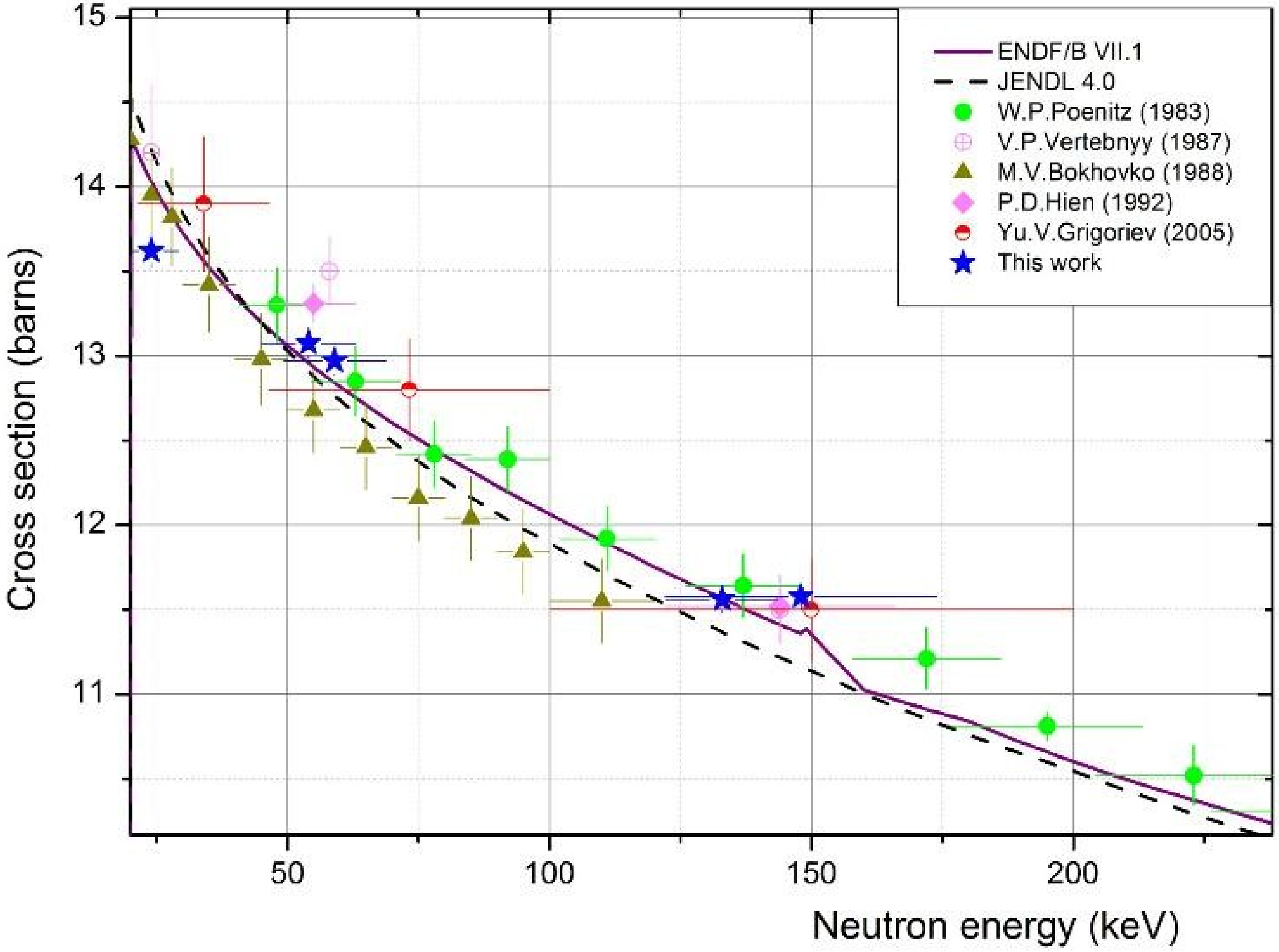
- Neutron transmission ratio

$$T = \frac{a - a^b}{a_0 - a_0^b}$$

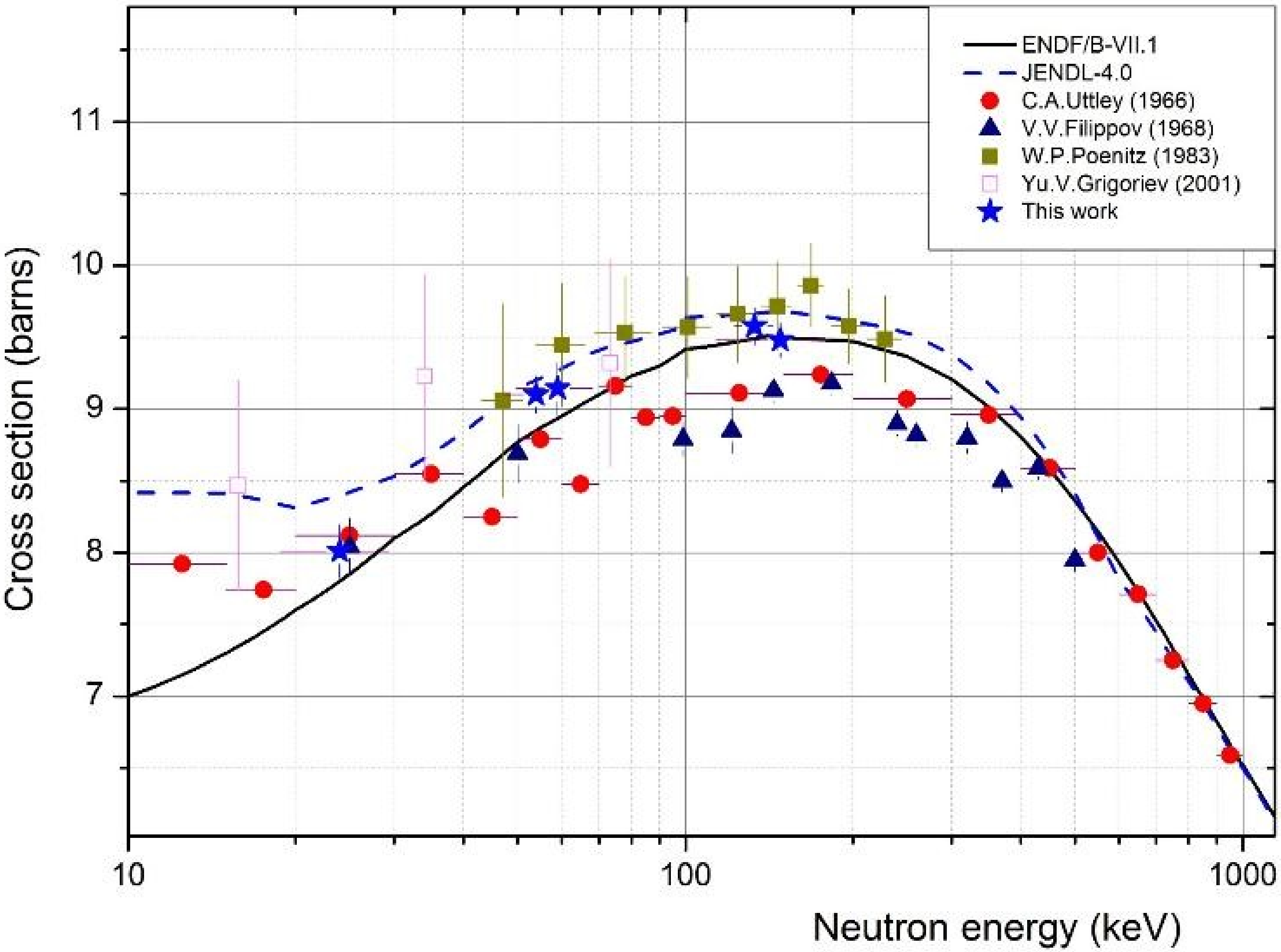
^{12}C (n,tot); En=24, 54, 59, 133 and 148 keV



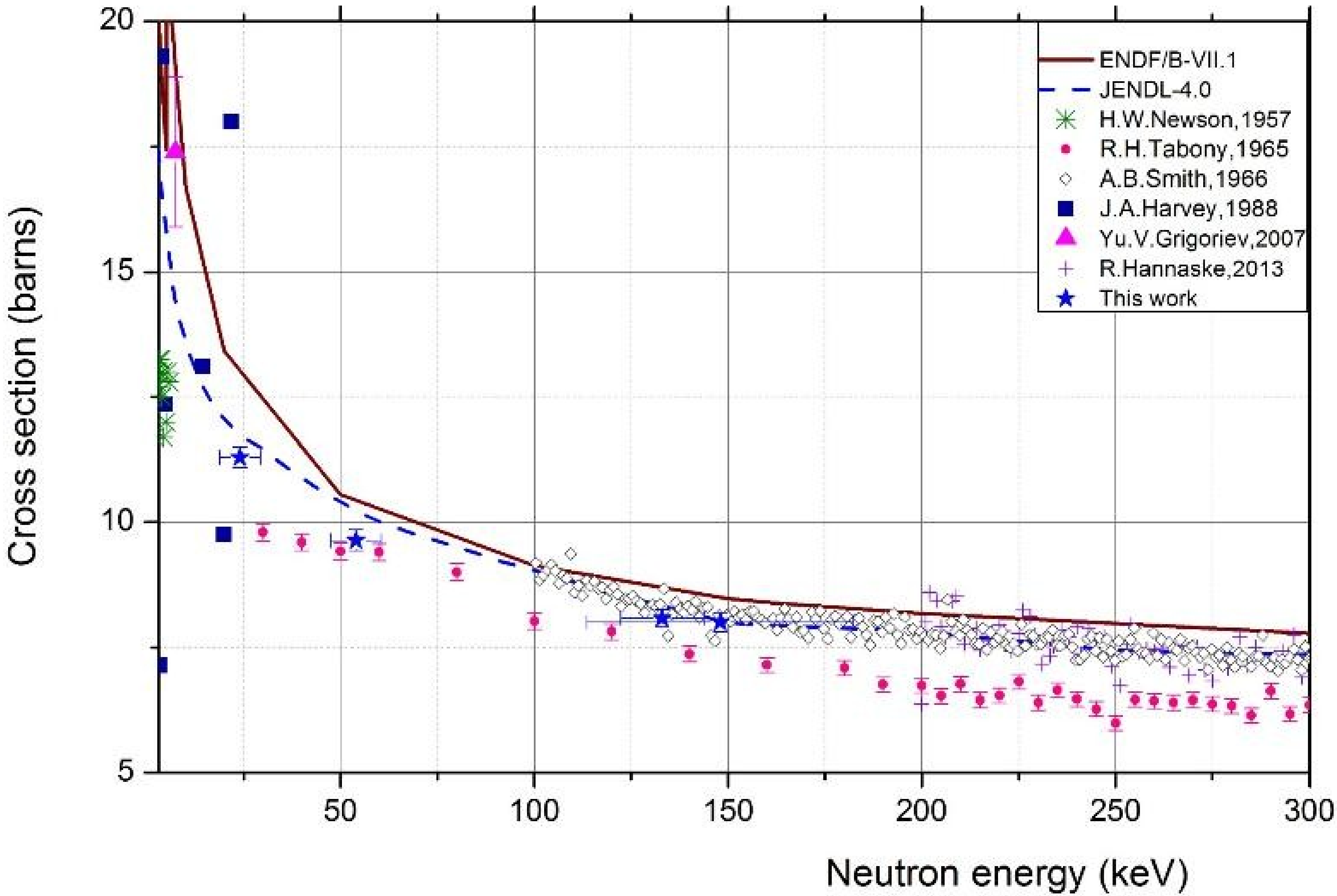
^{238}U (n,tot); En=24, 54, 59, 133 and 148 keV



^{93}Nb (n,tot); En=24, 54, 59, 133 and 148 keV



^{181}Ta (n,tot)



Cross section (barns)
Neutron energy (keV)
20
15
10
5
50
100
150
200
250
300
ENDF/B-VII.1
JENDL-4.0
H.W.Newson,1957
R.H.Tabony,1965
A.B.Smith,1966
J.A.Harvey,1988
Yu.V.Grigoriev,2007
R.Hannaske,2013
This work

Measurements of neutron reaction cross-sections

Neutron capture cross sections

The measurement of neutron capture cross sections have been carried out on the filtered neutron beams at the Dalat research reactor.

The measured neutron capture cross sections were obtained relative to the standard capture cross sections of the $^{197}Au(n,g)^{198}Au$ reaction by the activation method.

The corrections for multiple scattering, self-shielding are taken into account by Monte Carlo method.

Measurements of neutron reaction cross-sections

Neutron capture cross sections

During irradiation in a neutron beam with energy spectrum $\phi(E)$, the capture reaction rate R, Activity A of samples are defined as following expressions:

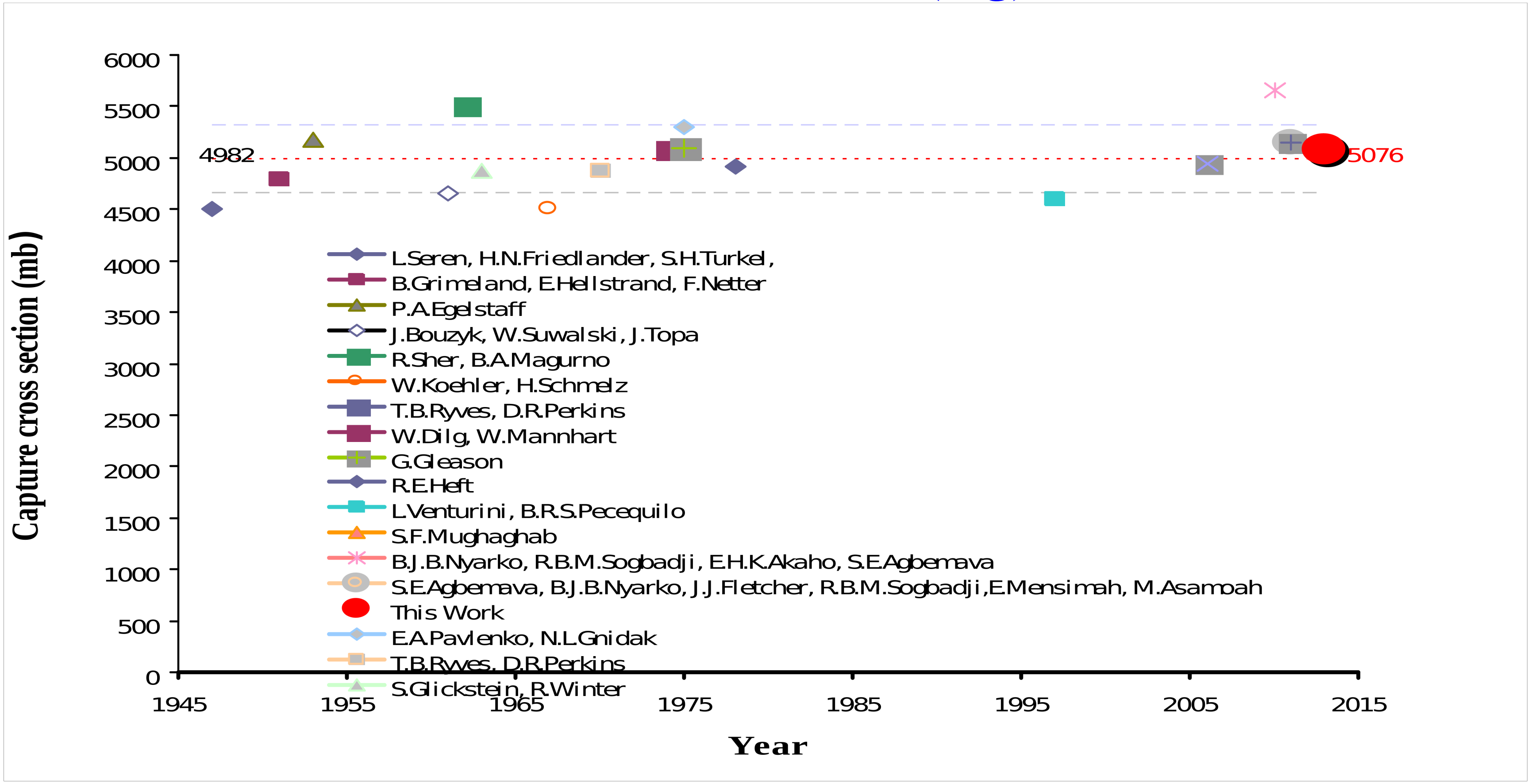
$$R = N\int \phi(E)\sigma_a(E)dE\ , \quad <\sigma_a> = \frac{\int \sigma_a(E)\phi(E)dE}{\int \phi(E)dE}; <\Phi> = \int \phi(E)dE.$$

$$R = N<\sigma_a><\Phi>. \qquad A = R(1-e^{-\lambda t_1}), \qquad A = \frac{Cf_c\lambda}{\varepsilon_\gamma I_\gamma e^{-\lambda t_2}(1-e^{-\lambda t_3})},$$

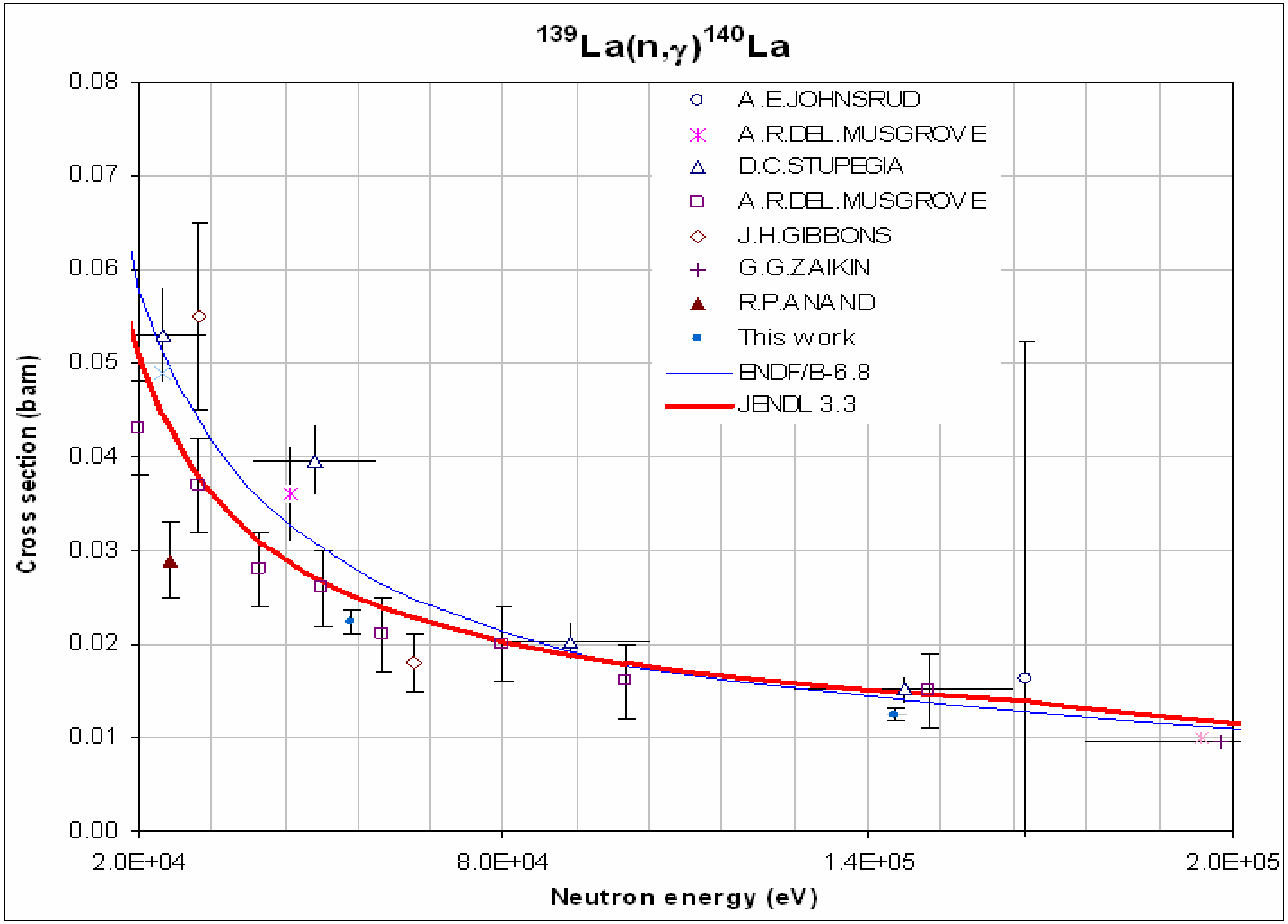
Measurements of neutron reaction cross-sections

Neutron capture cross sections

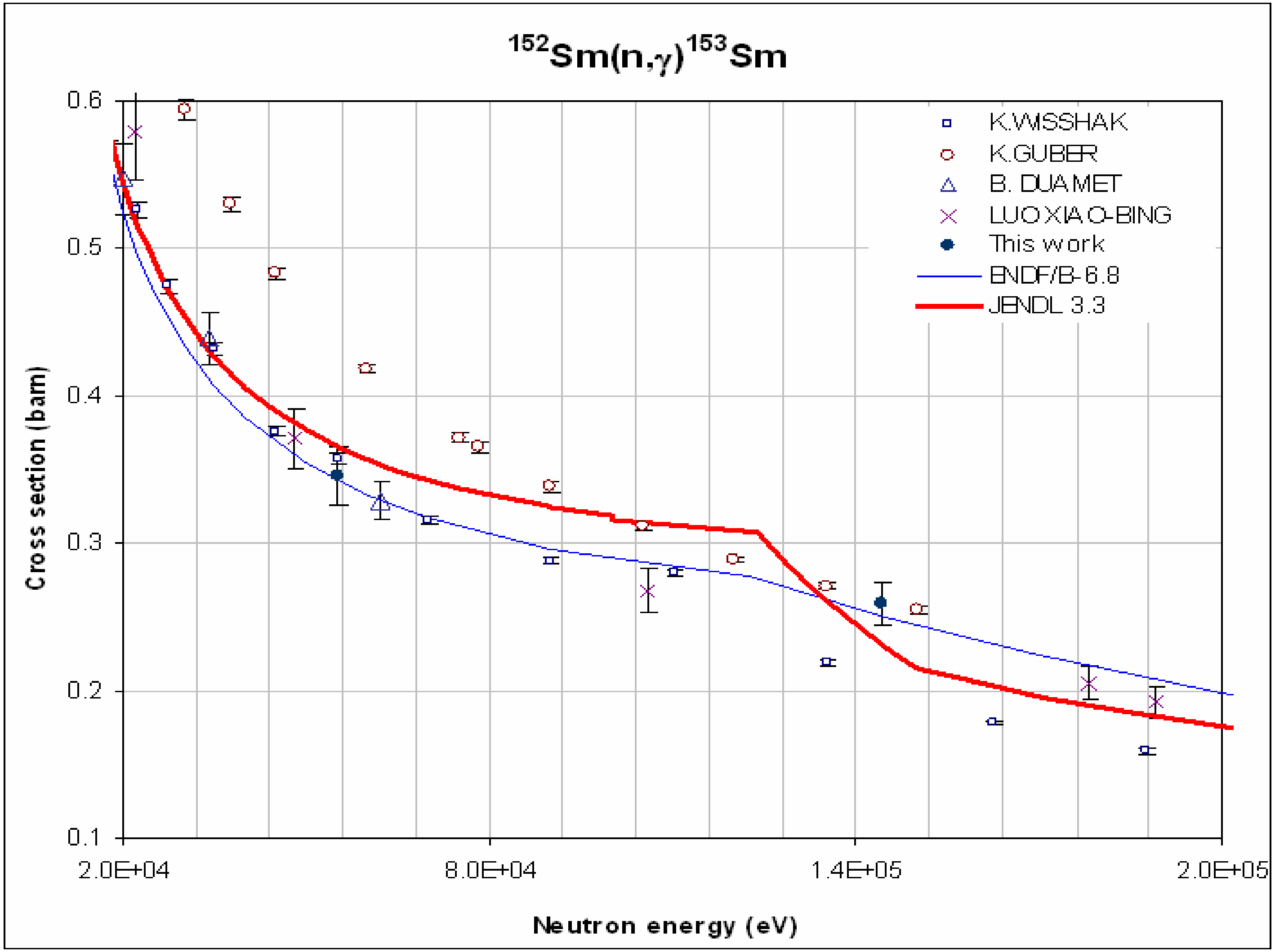
The result of measurement for $^{51}V(n,g)^{52}V$ reaction



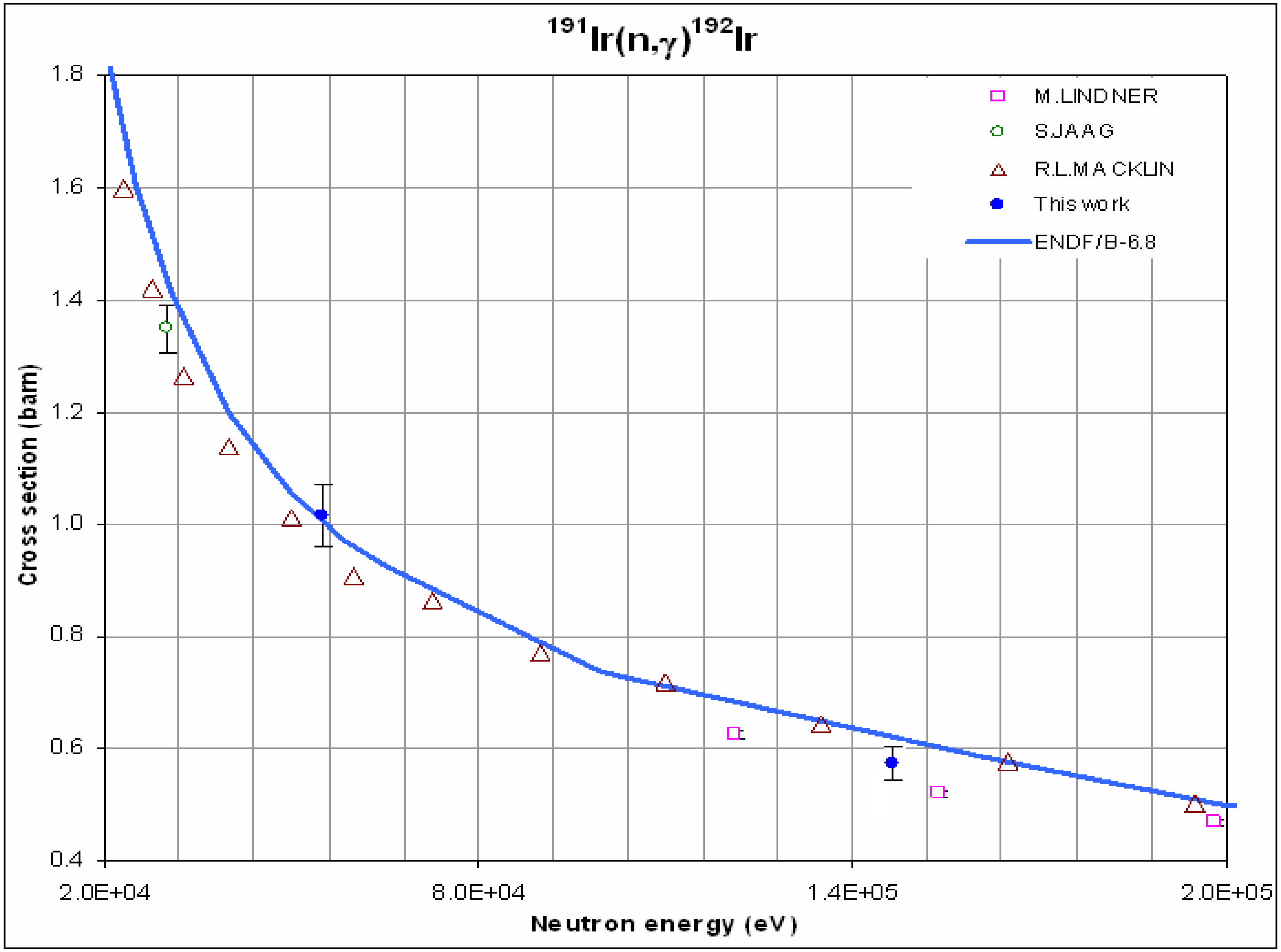
$^{139}La(n,\gamma)^{140}La$; E_n= 54 and 148 keV



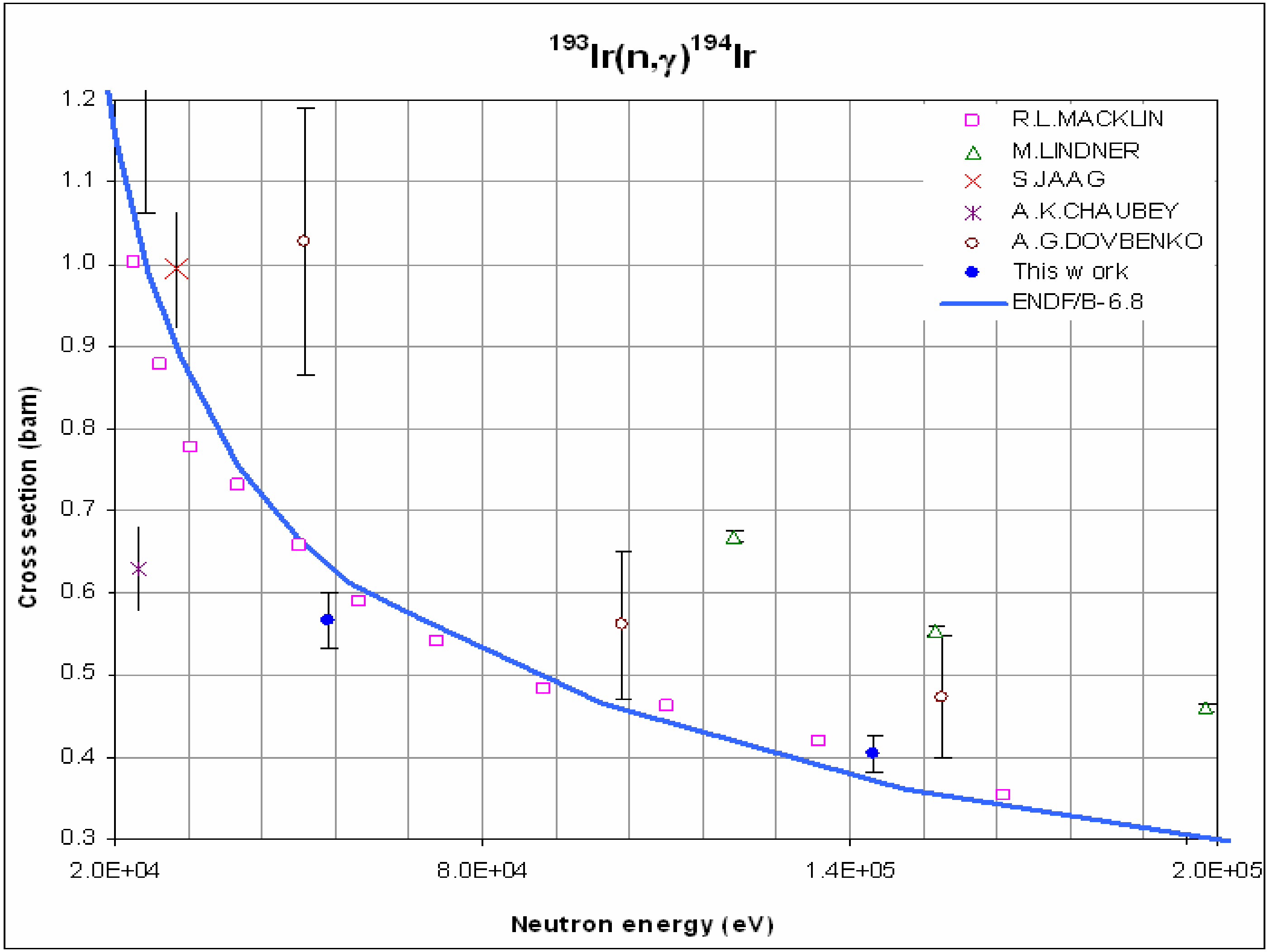
$^{152}Sm(n,\gamma)^{153}Sm$; E_n= 54 and 148 keV



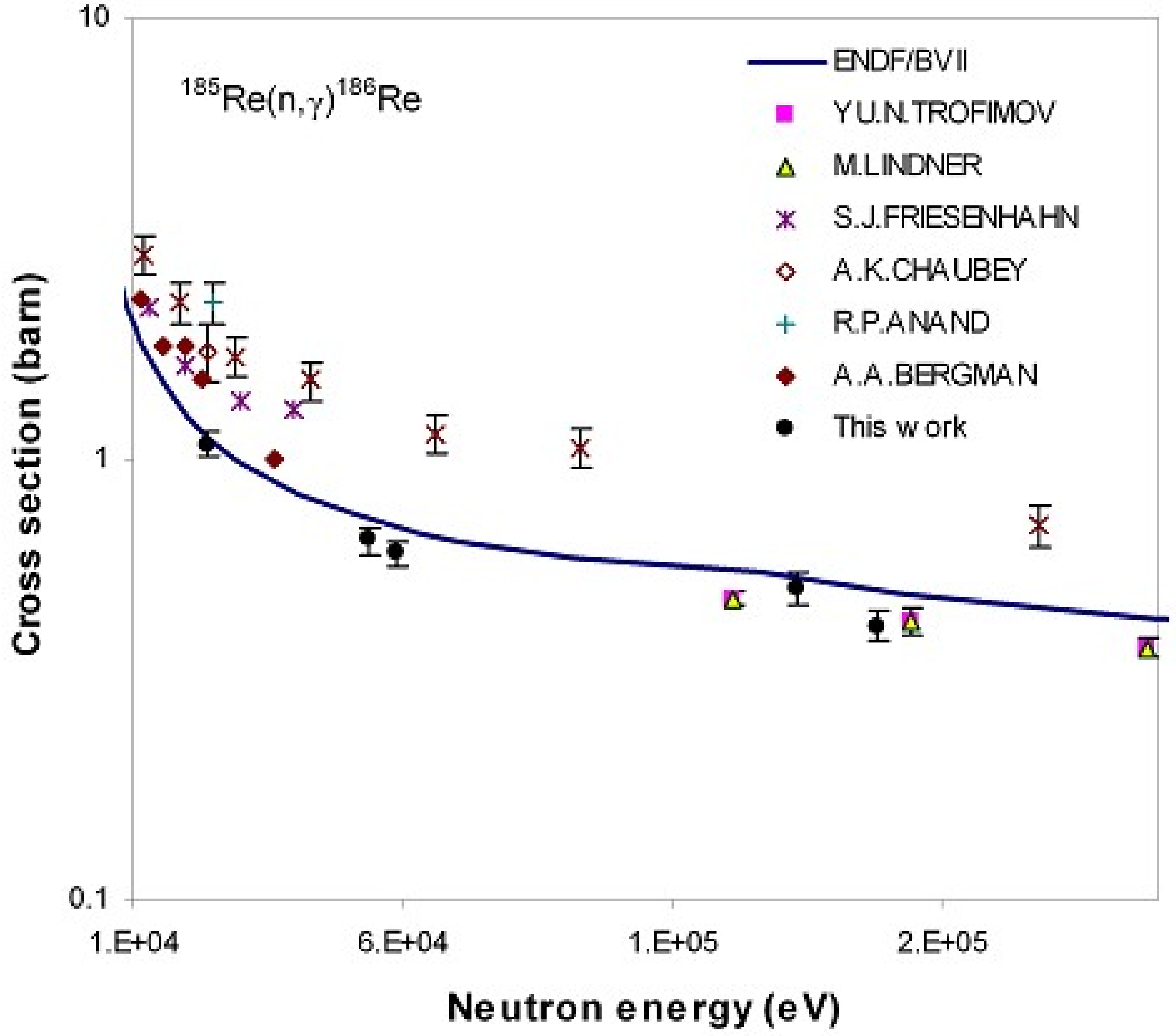
$^{191}Ir(n,\gamma)^{192}Ir$; E_n= 54 and 148 keV



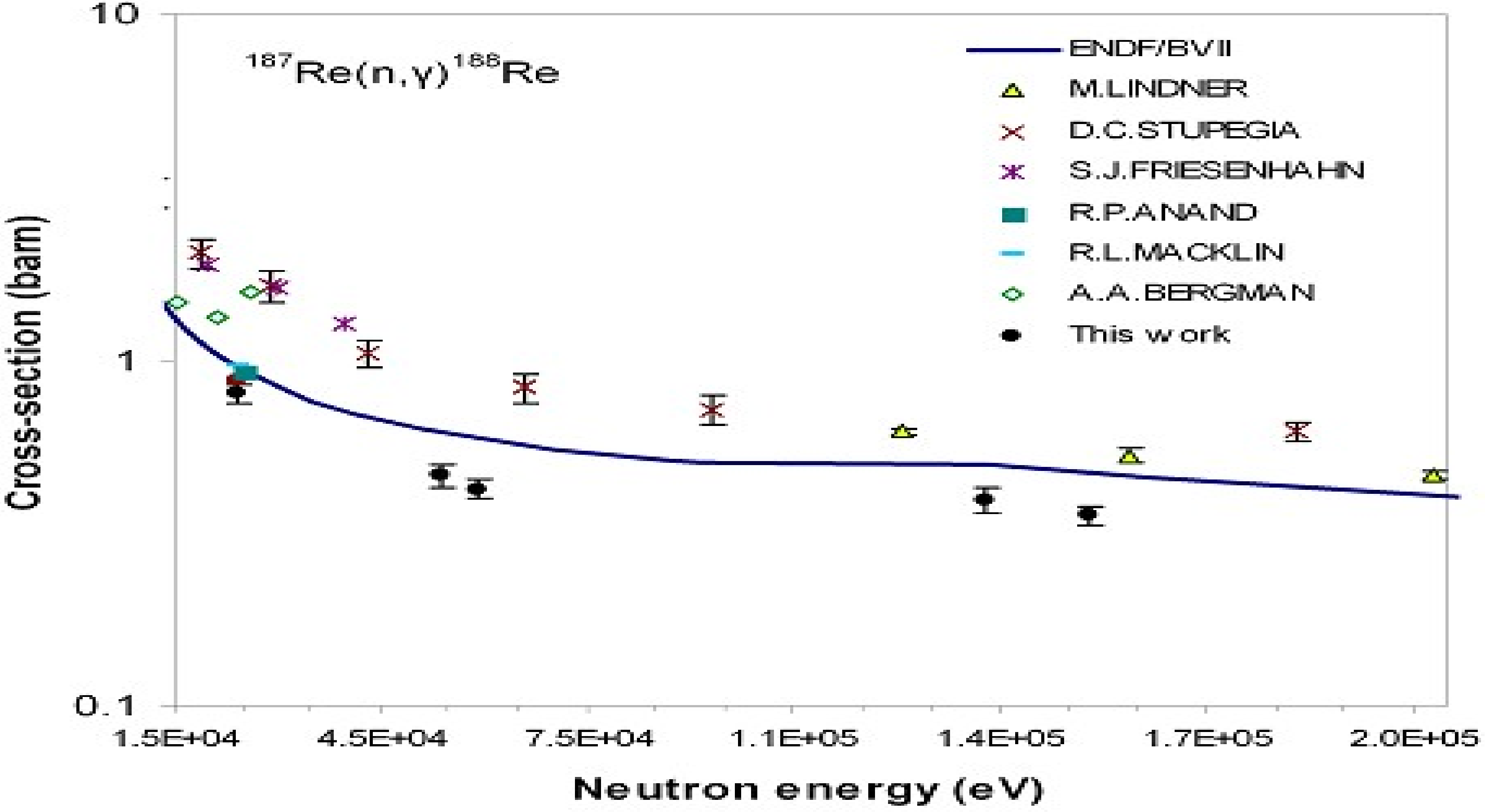
$^{193}Ir(n,\gamma)^{194}Ir_{;}\ E_n = 54$ and 148 keV



$^{185}Re(n,\gamma)^{186}Re$; En=24, 54, 59, 133 and 148 keV



$^{187}Re(n,\gamma)^{188}Re$, En=24, 54, 59, 133 and 148 keV

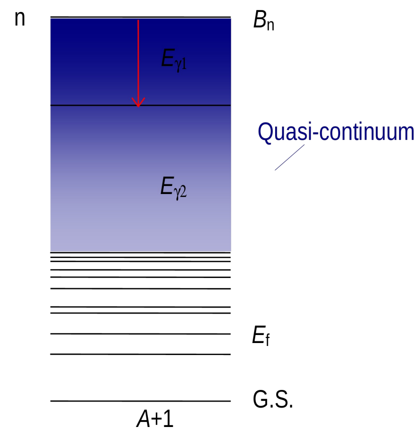


Measurements of gamma decay schema and level density

Gamma – gamma coincidence method

Reaction: $^{A}X(n,\gamma)^{A+1}X$

^{A+1}X in compound state emits gamma to go back to ground state.



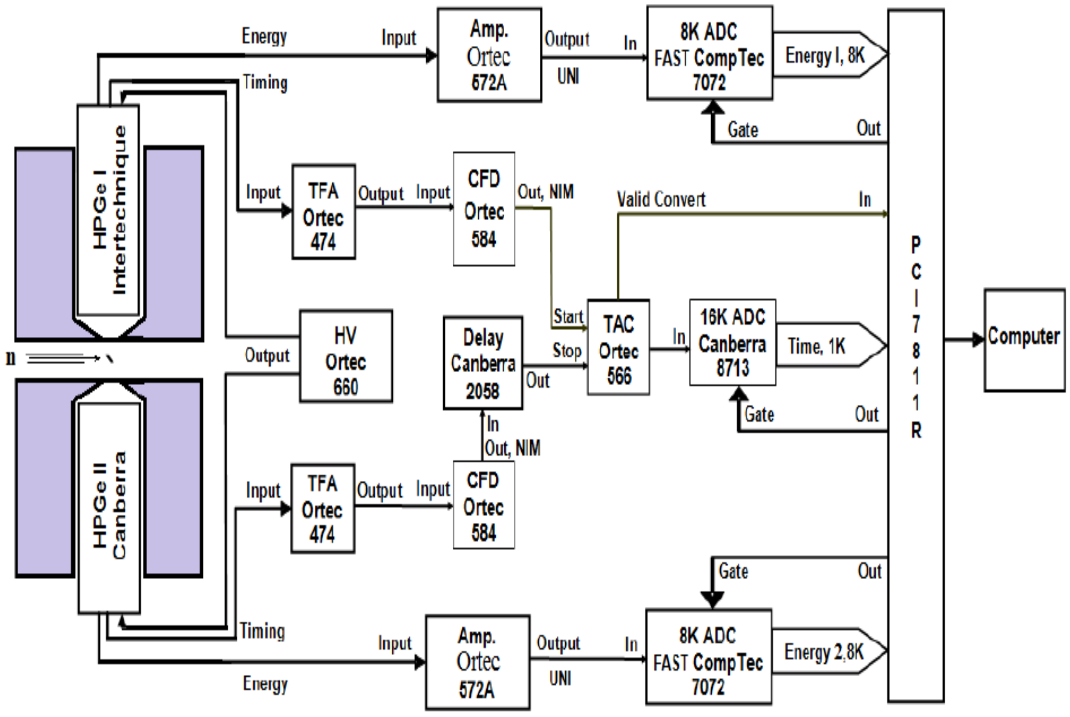
Gamma – gamma coincidence spectrometer measured only gamma in cascade (Ex: red transition in Figure).

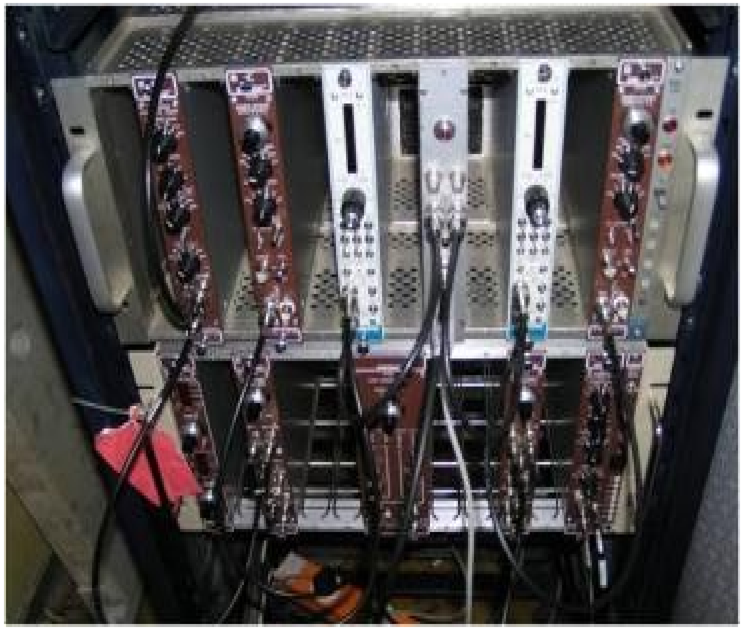
Therefore, provides information to determine intermediate levels.

Obtained data:

- Partial level scheme;
- Gamma cascade transition intensity;
- Level density and Gamma Strength function, extracted from gamma cascade transition intensity

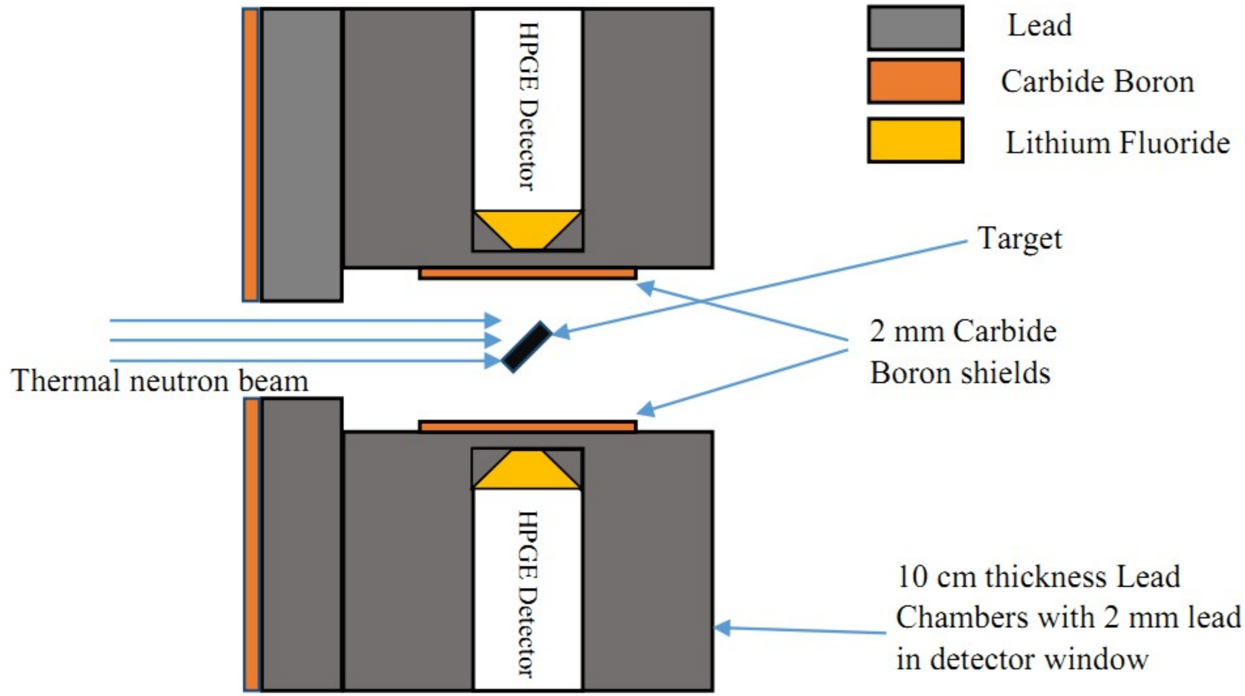
Gamma – gamma coincidence spectrometer at DNRI





Energy nominal resolution: ~1.9 keV at 1332 keV measured with Co-60;
Timing resolution: ~12 ns measured with Co-60.

Experiment setup

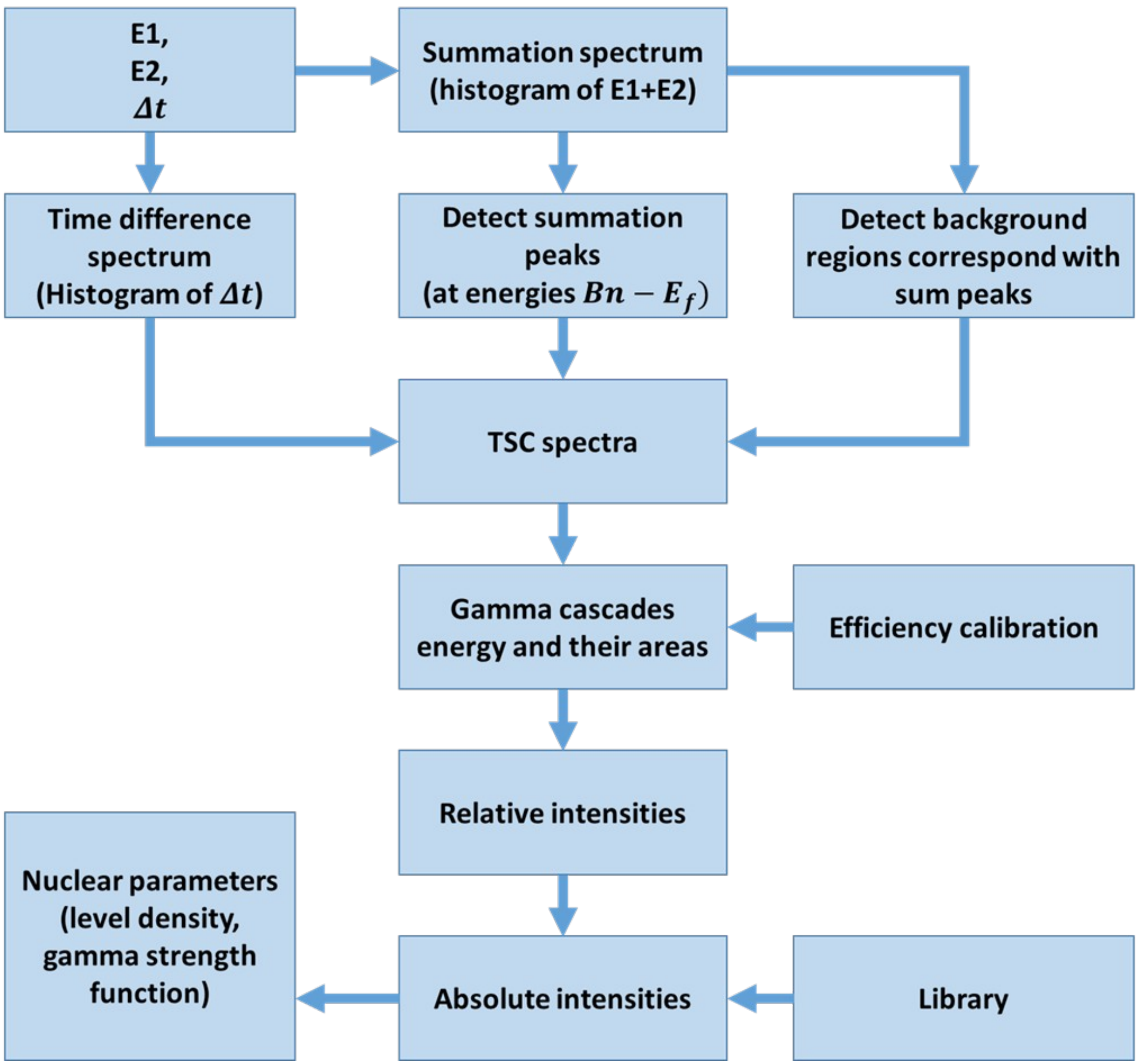


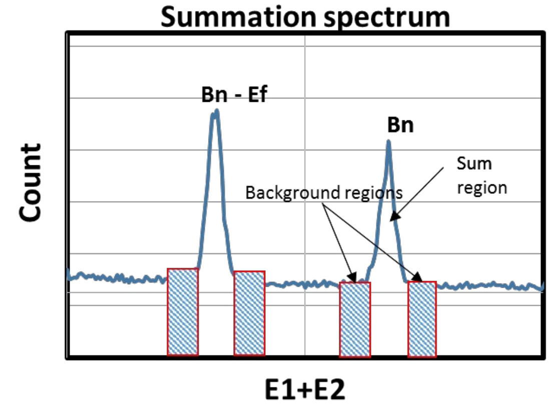
Neutron flux at target position = 1.7×10^5 $n.cm^{-2}.s^{-1}$

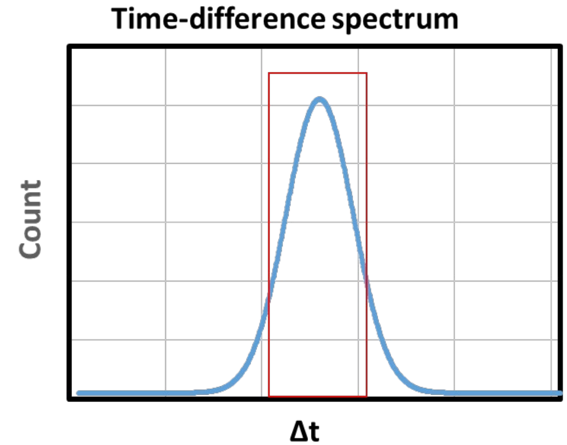
R(Cd/Au) = 230

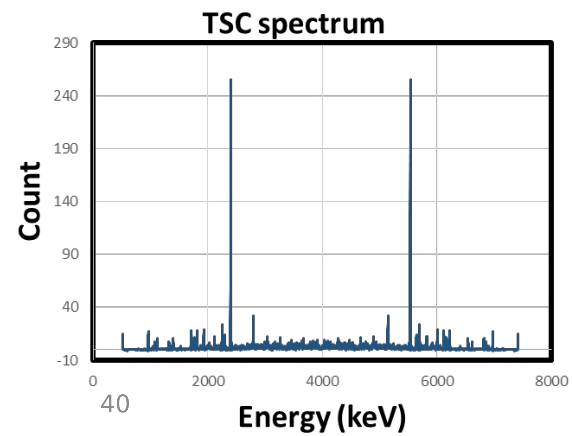
Distance from target to detector windows = 5 cm

Data analysis

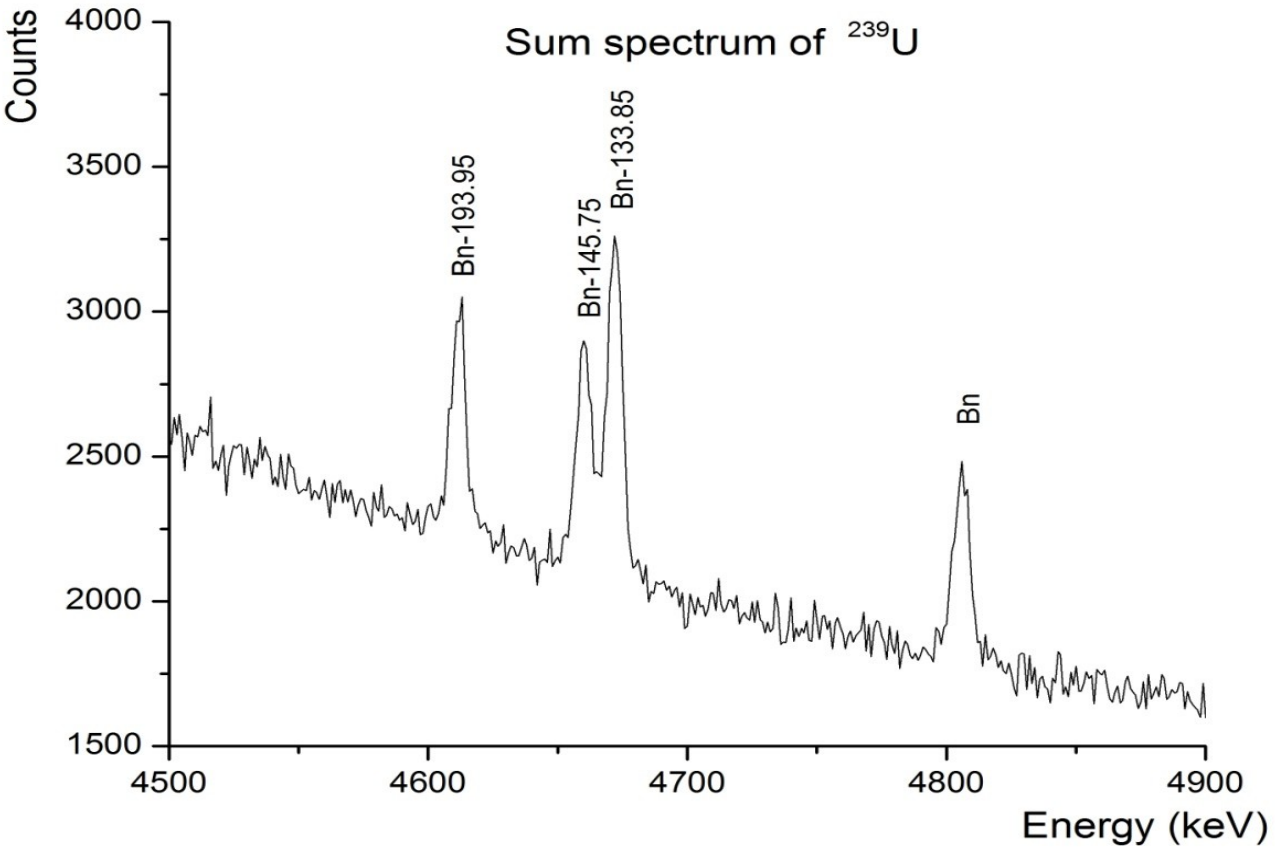








Some obtained results at DNRI



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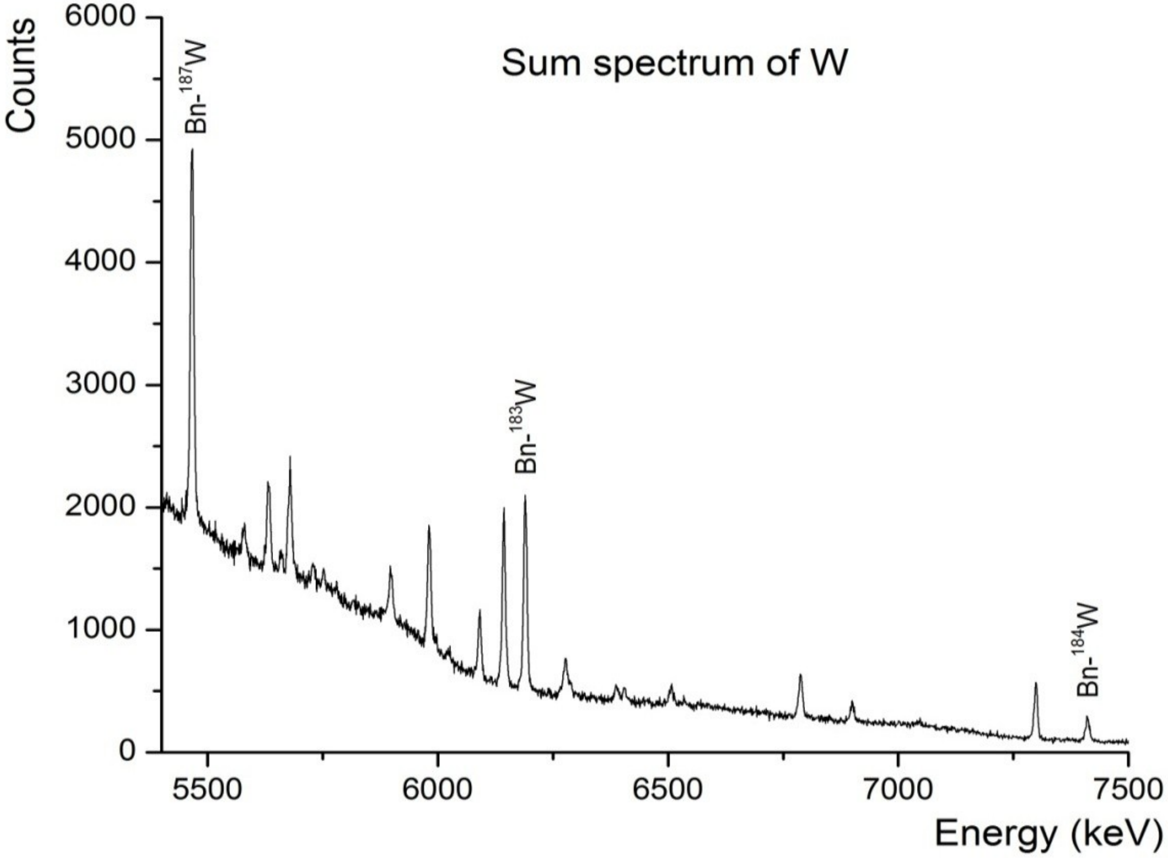
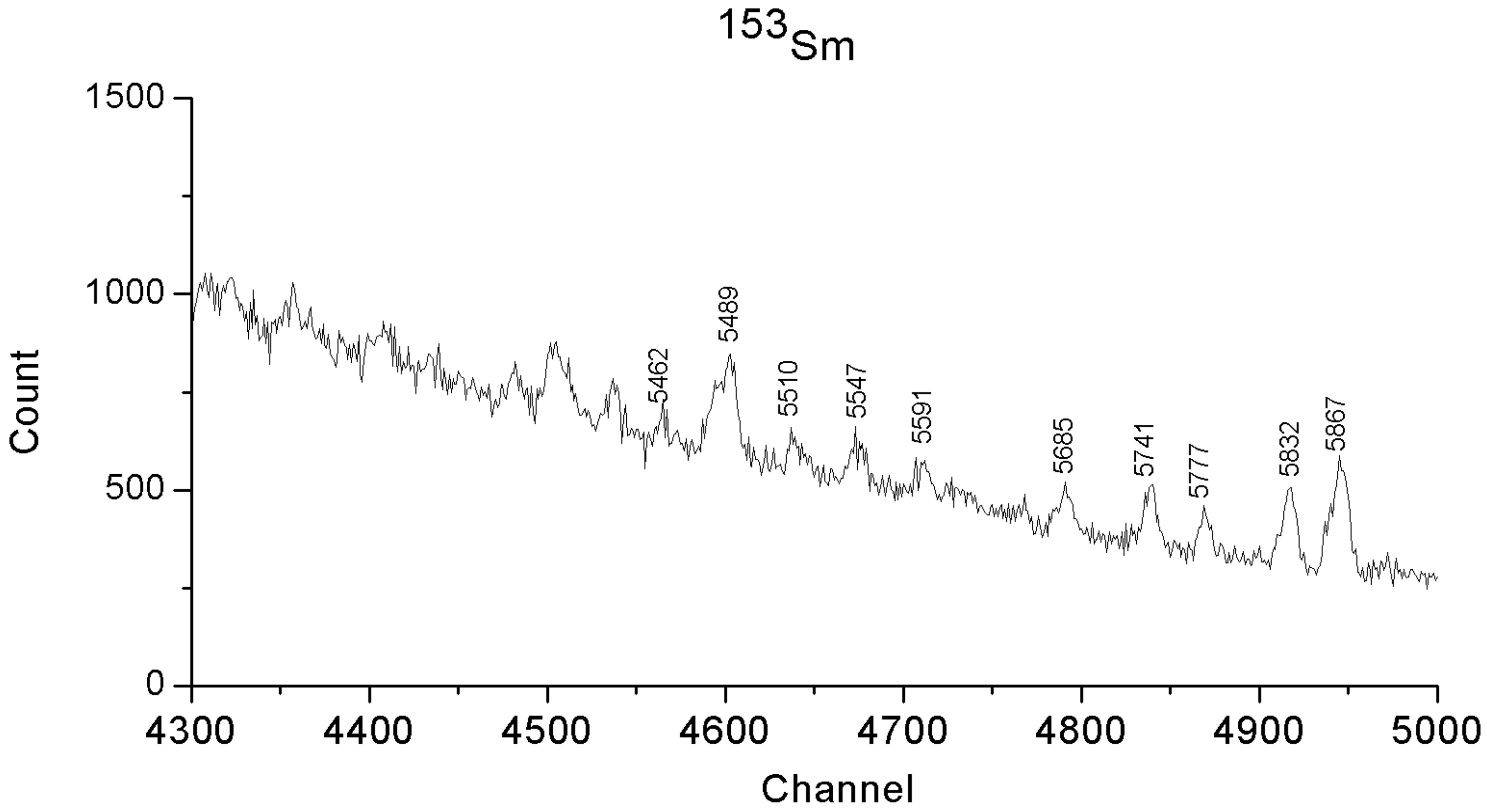
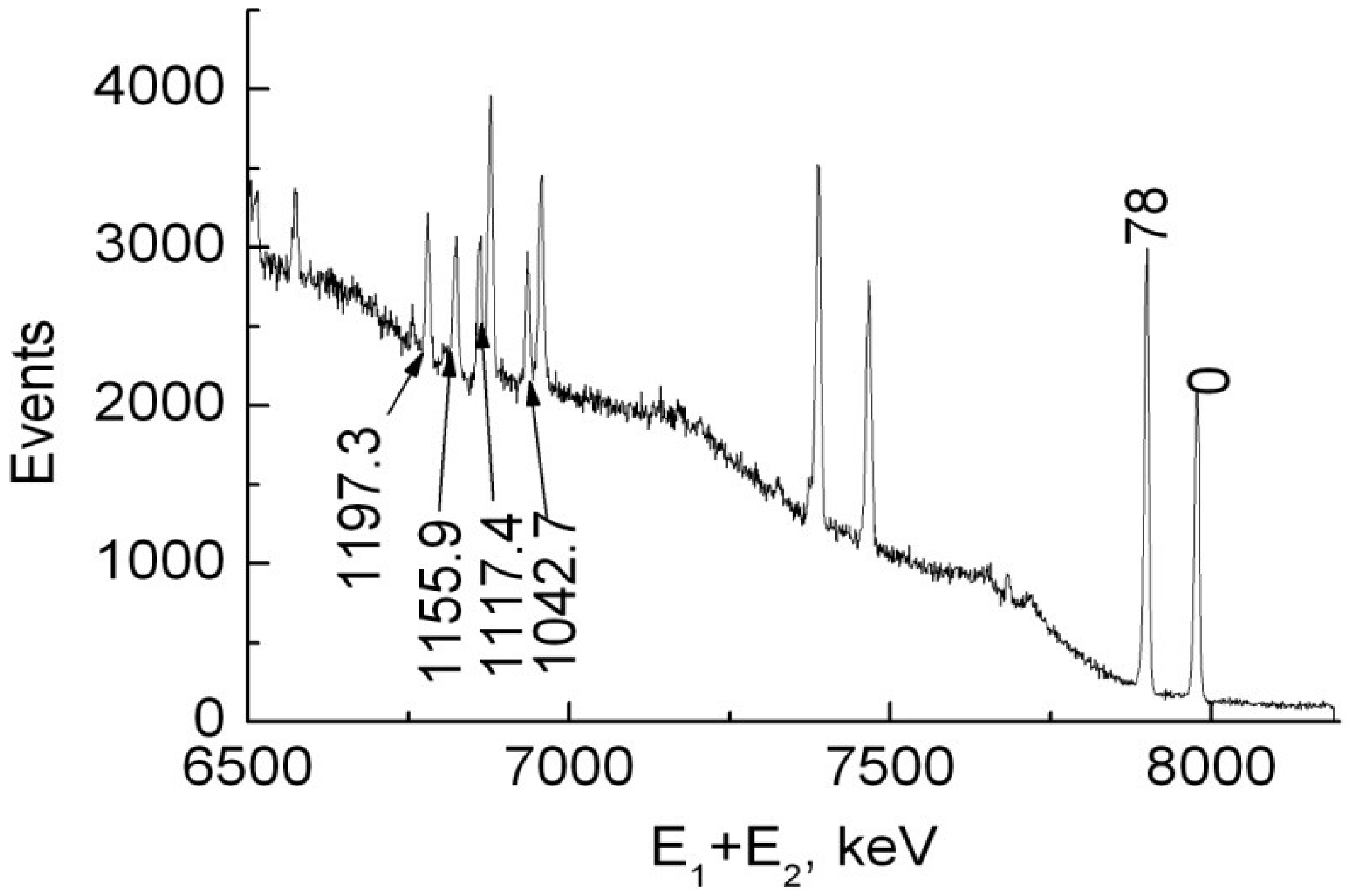


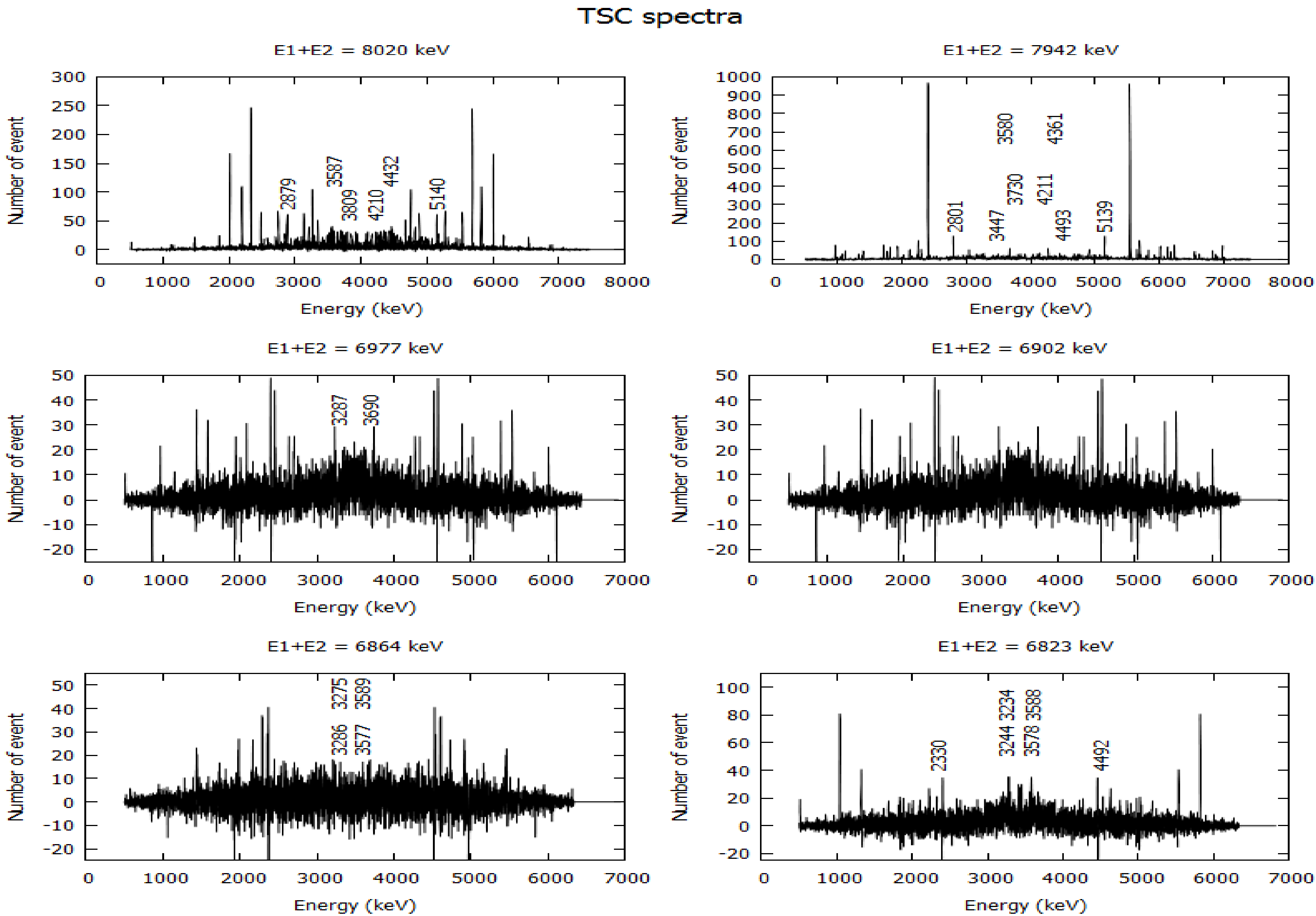
Sum spectrum of W
Counts
Energy (keV)
Bn-187W
Bn-183W
Bn-184W
0
1000
2000
3000
4000
5000
6000
5500
6000
6500
7000
7500

Summation spectrum of Sm-153

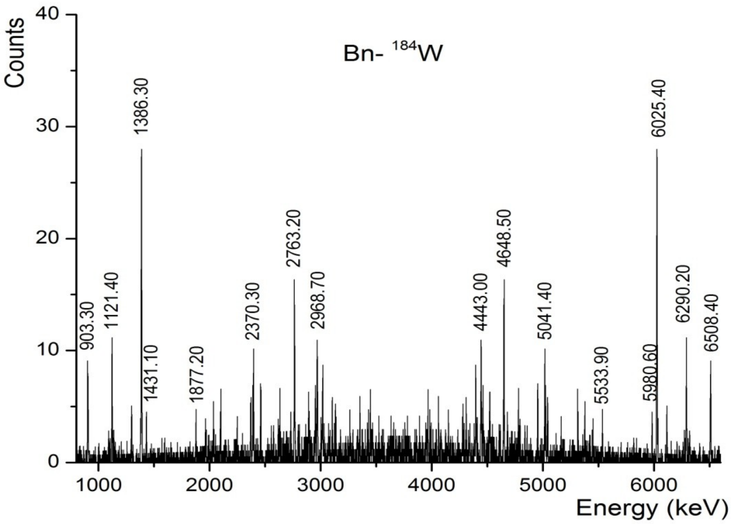


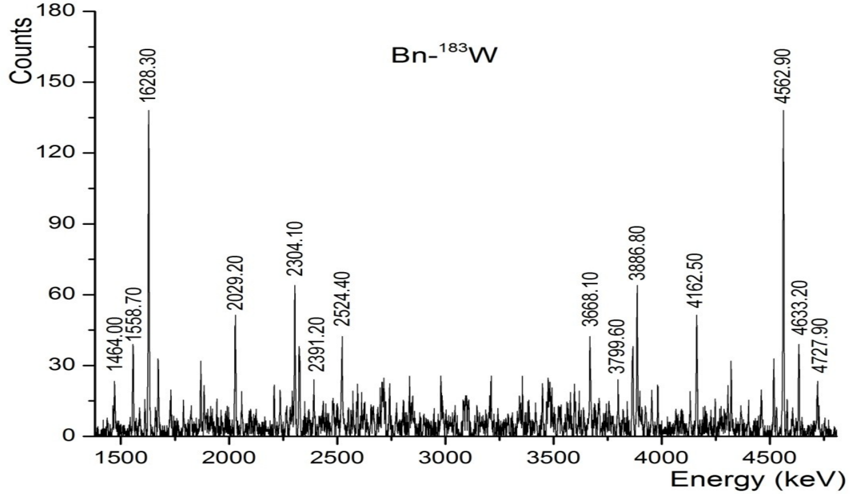
Summation spectrum of Yb-172



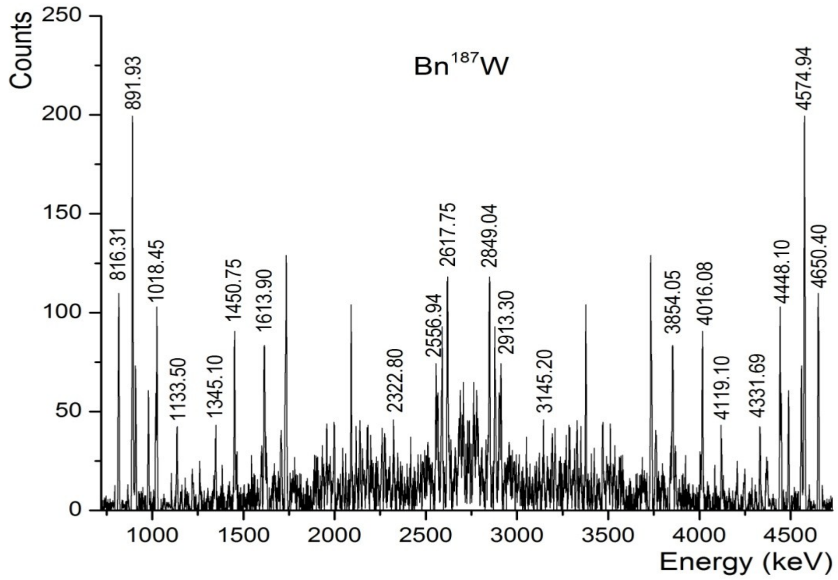


Two-step gamma spectrum of Yb-172



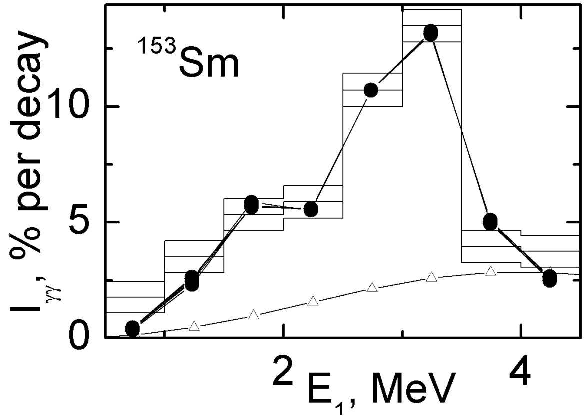


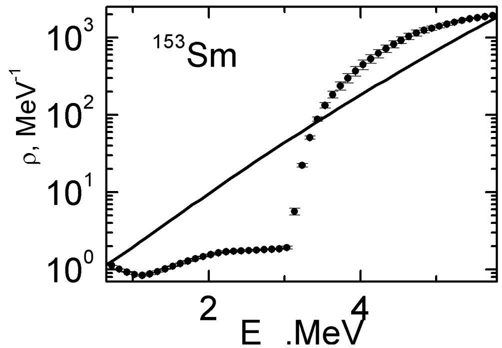
TSC spectrum to ground state of W-183, W-184 and W-187

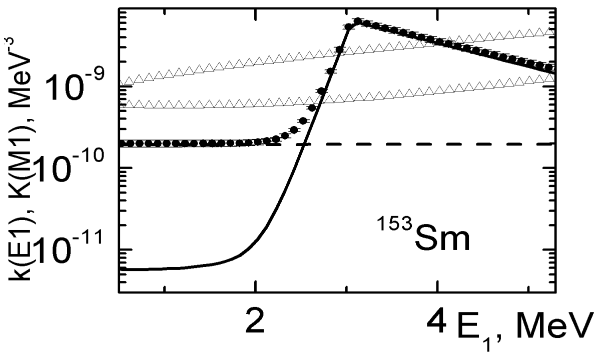


Cascade intensity, level density and gamma strength function

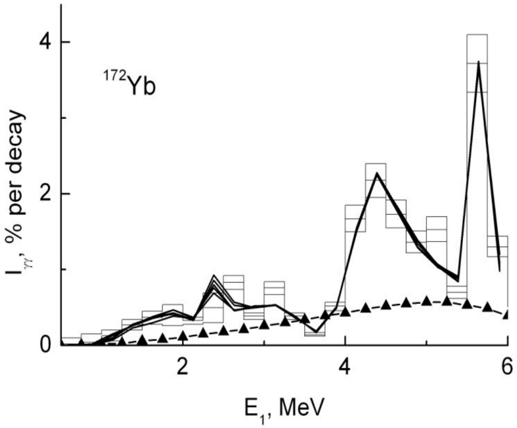
Igg, level density and RSF of Sm-153

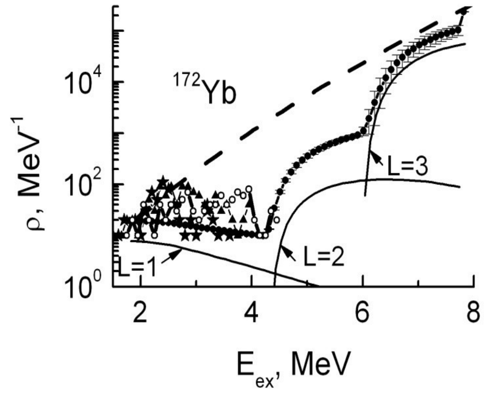


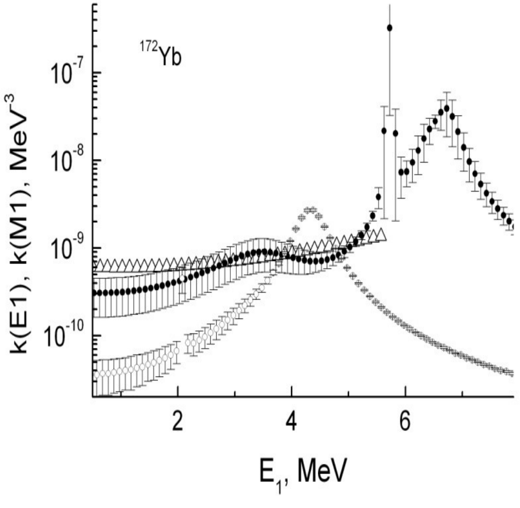




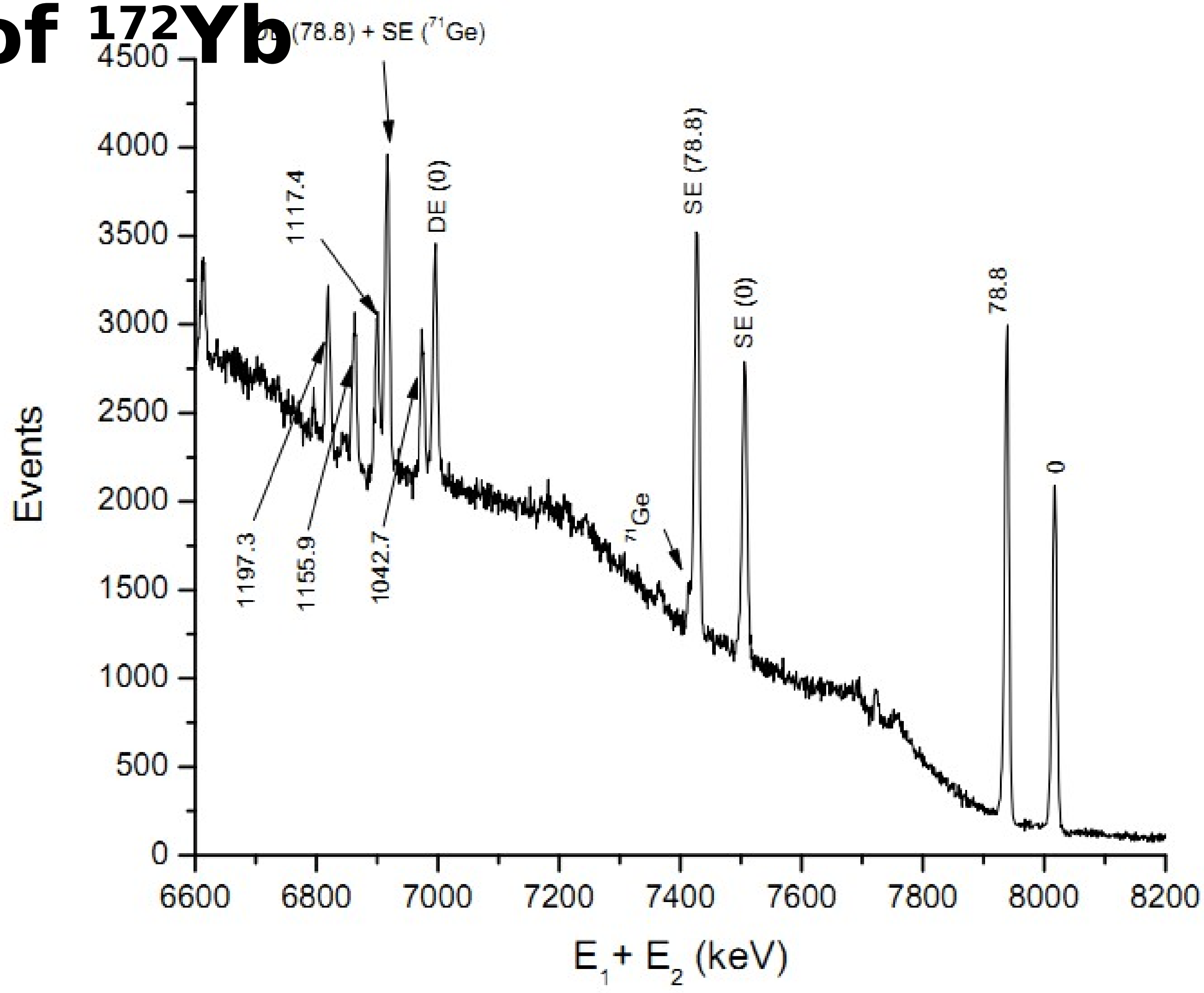
Igg, level density and RSF of Yb-172



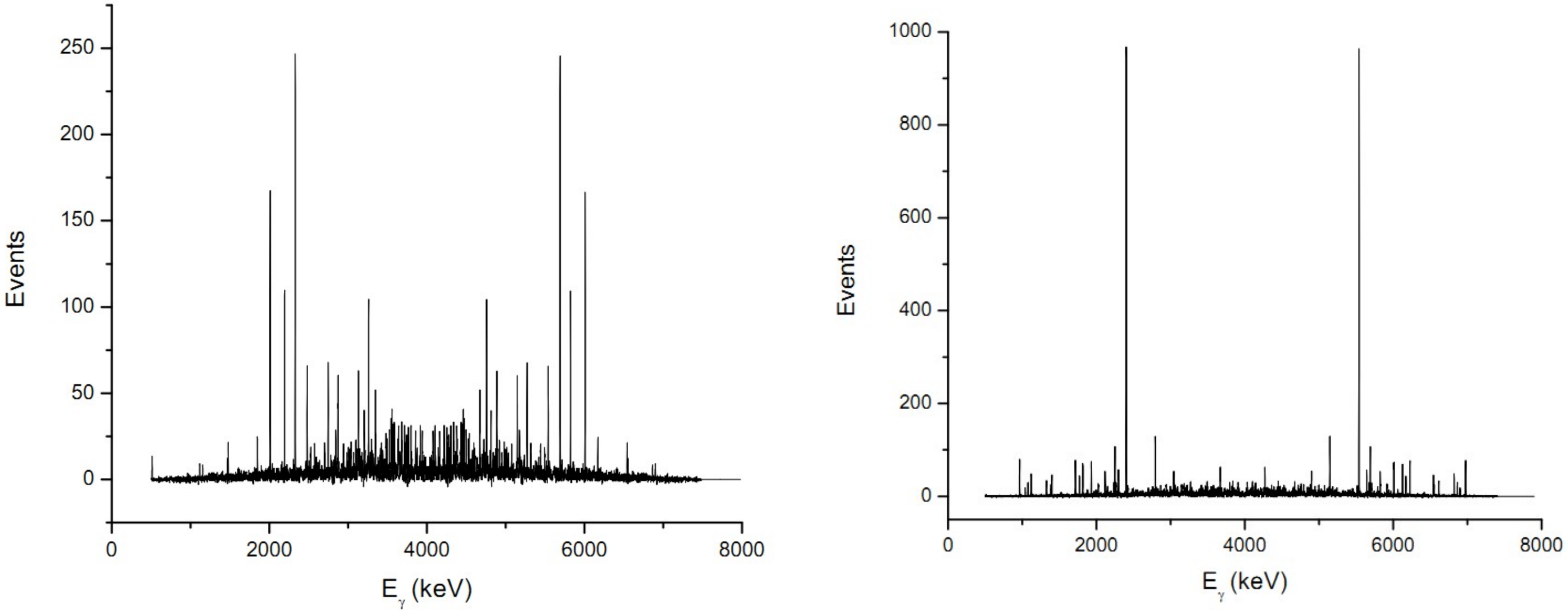




The newest result of ^{172}Yb



Summation spectrum of coincidence pulses for ^{172}Yb(n,2γ) reaction.



Two-step cascade spectrum corresponding to the ground state (left panel) and the final level with energy level Ef = 78.8 keV (right panel).

- The part of resolved peaks in TSC spectrum are 70% (to ground state) and 67% (to $E_f = 78.8\ keV$).
- Spin range of intermediate levels is 0 to 2 $\hbar$.

- The part of resolved peaks in TSC spectrum are 70% (to ground state) and 67% (to .
- Spin range of intermediate levels is 0 to 2

New gamma transitions and levels

- Measured for approximately 830 hours
- 479 cascades were determined, whereas 128 cascades had statistical count higher than 50 count.
- 61 primary gamma transition and 19 secondary gamma transitions were found to be the same as ENSDF data.
- 18 primary gamma transition and their corresponding energy levels plus 109 secondary gamma transitions are not found to currently exist in ENSDF, therefore considered as the new data

Development and applications of Neutron Activation Analytical Techniques: INAA, CNAA, PGNAA, CoinINAA)

* Equipment:

- Gamma spectroscopy;

- Coincidence spectroscopy;

- Compton suppression spectroscopy;

- Irradiation pneumatic sample transfer system;

- Automatic measurement sample changer system.

* Method:

- Delay gamma neutron activation analysis;

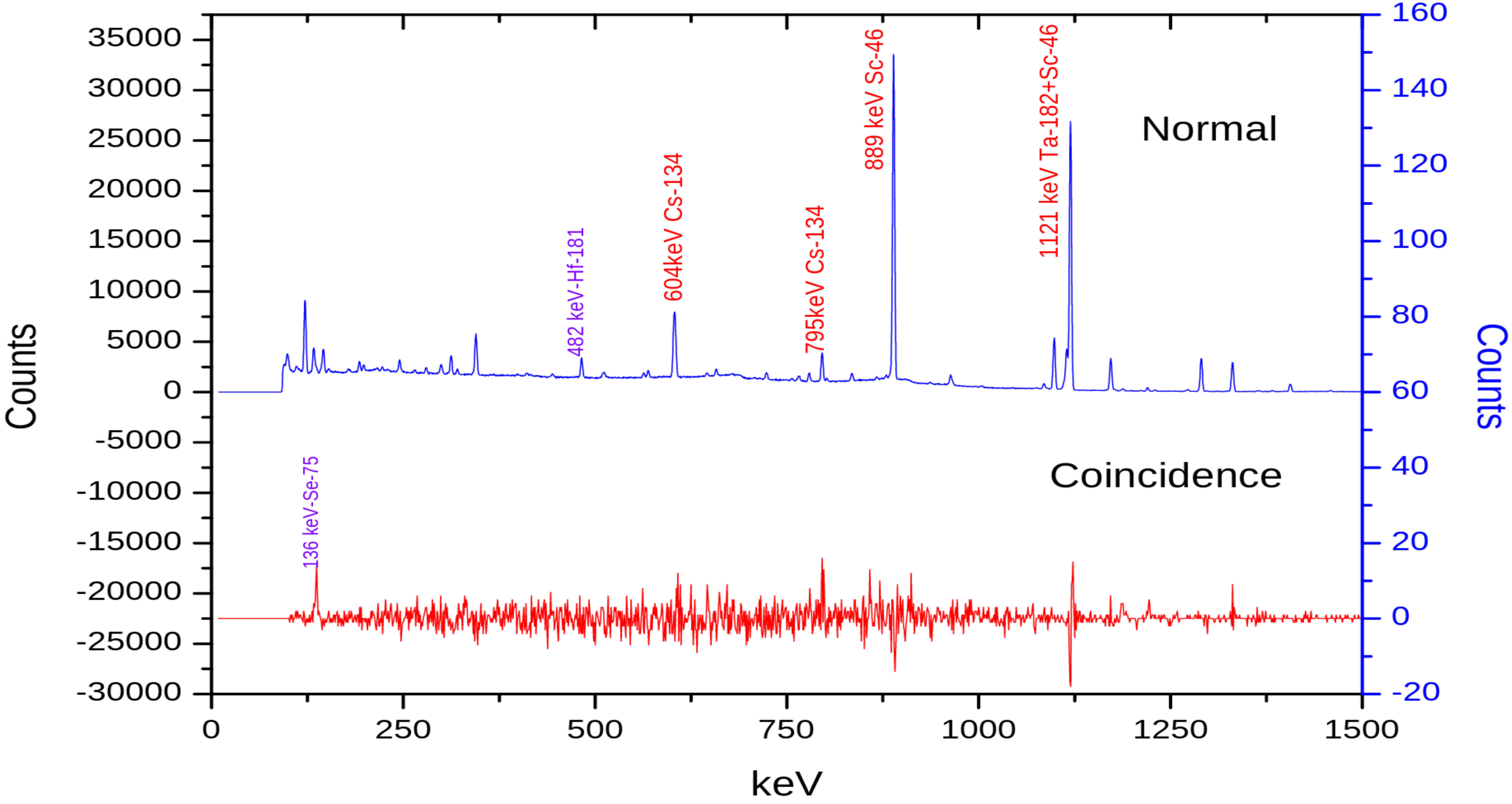
- Prompt gamma neutron activation analysis;

- Cyclic neutron activation analysis;

- Coincidence gamma neutron activation analysis.

* Application: Industrials, environment, geological, archeology,…

Determination of element with overlap peaks in NAA by event-event coincidence technique



The spectra of Montana II Soil in normal and coincidence modes; the coincidence is gated at 264.7 keV.

Detection limit improvement of INAA

The area, the peak to background ratios and detection limits of selenium in Montana II Soil in normal and coincidence modes.

Energy (keV)	Peak area		Peak to background ratio		Detection limit (mg/kg)	
	Normal	Coincidence	Normal	Coincidence	Normal	Coincidence
121 ($^{75}Se+^{152}Eu$)	6924(104)	16(1)	0.29	0.84	0.21	**2.34**
136 ($^{75}Se+^{181}Hf$)	939(170)	40(3)	0.04	6.67	1.52	**0.53**
264 ($^{75}Se+^{182}Ta$)	912(196)	45(3)	0.05	6.43	1.41	**0.51**
279 ($^{75}Se+^{203}Hg$)	**262(28)**	**26(2)**	**0.01**	**13.00**	**4.90**	**0.23**

Design and manufacture of radiation measurement systems

- Purpose:

- Improve skills of maintenance for radiation measurement systems;

- Design and manufacture of some radiation measurement systems for research, applications and training.

- Method:

- Field Programmable Gate Array (FPGA) and Digital Signal Processing (DSP);

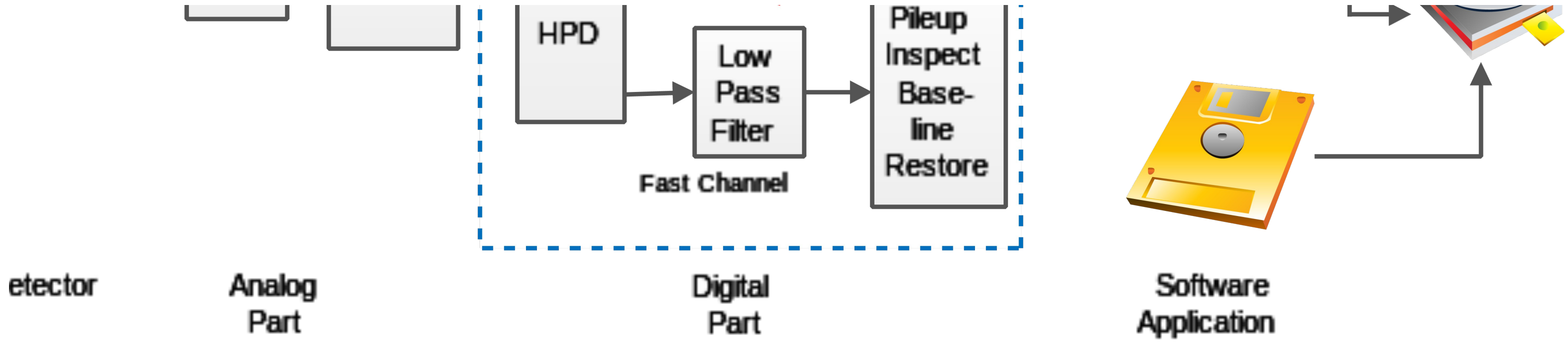
- Using simulation tools for designing of spectroscopy and neutron detectors (VHDL, Matlab software).

- Application:

- Design and manufacture of multichannel analyzer, event-event gamma coincidence spectroscopy;

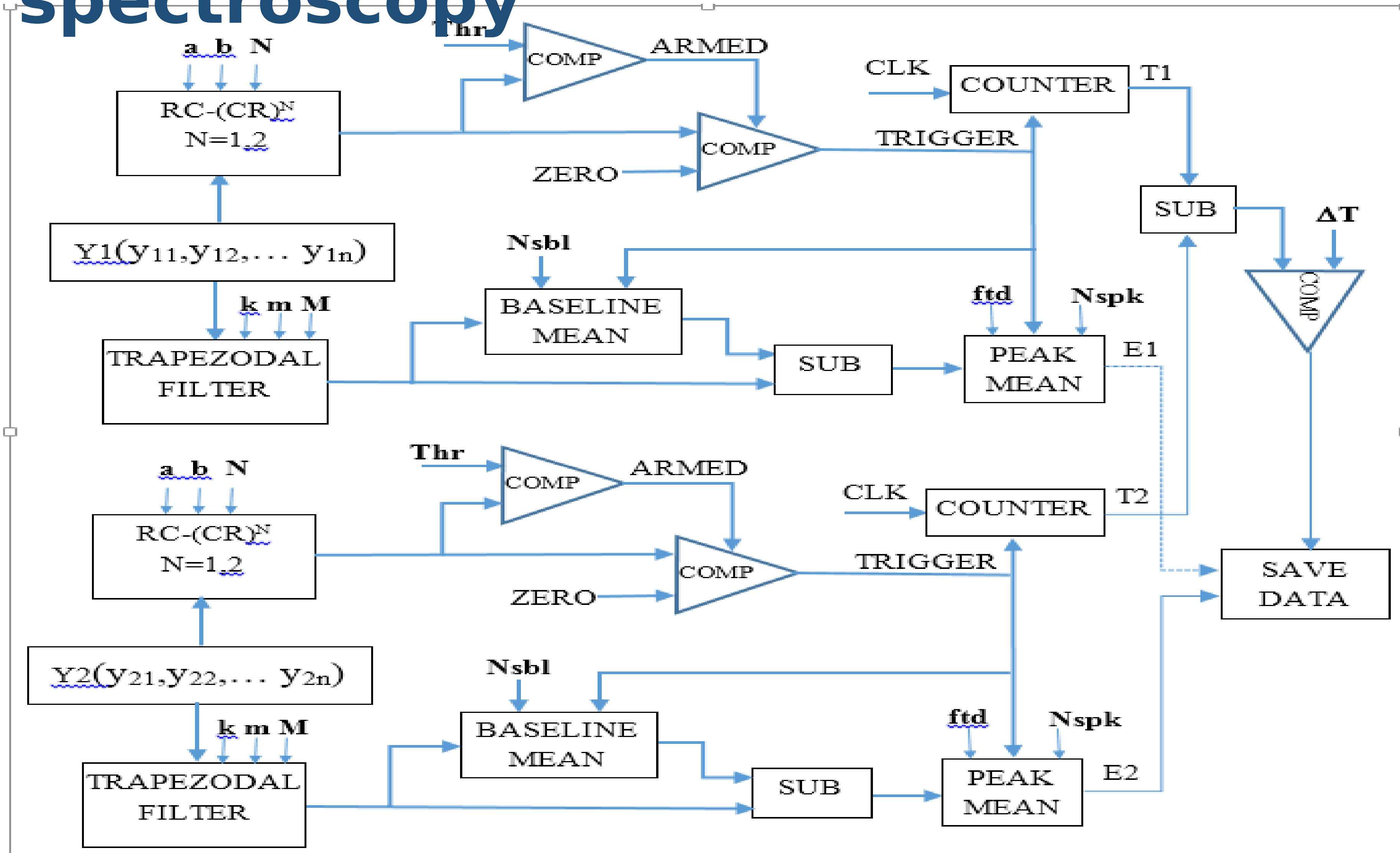
- Design and manufacture of scintillator neutron detector.

Some results of application DSP and FPGA for manufacturing of spectroscopy



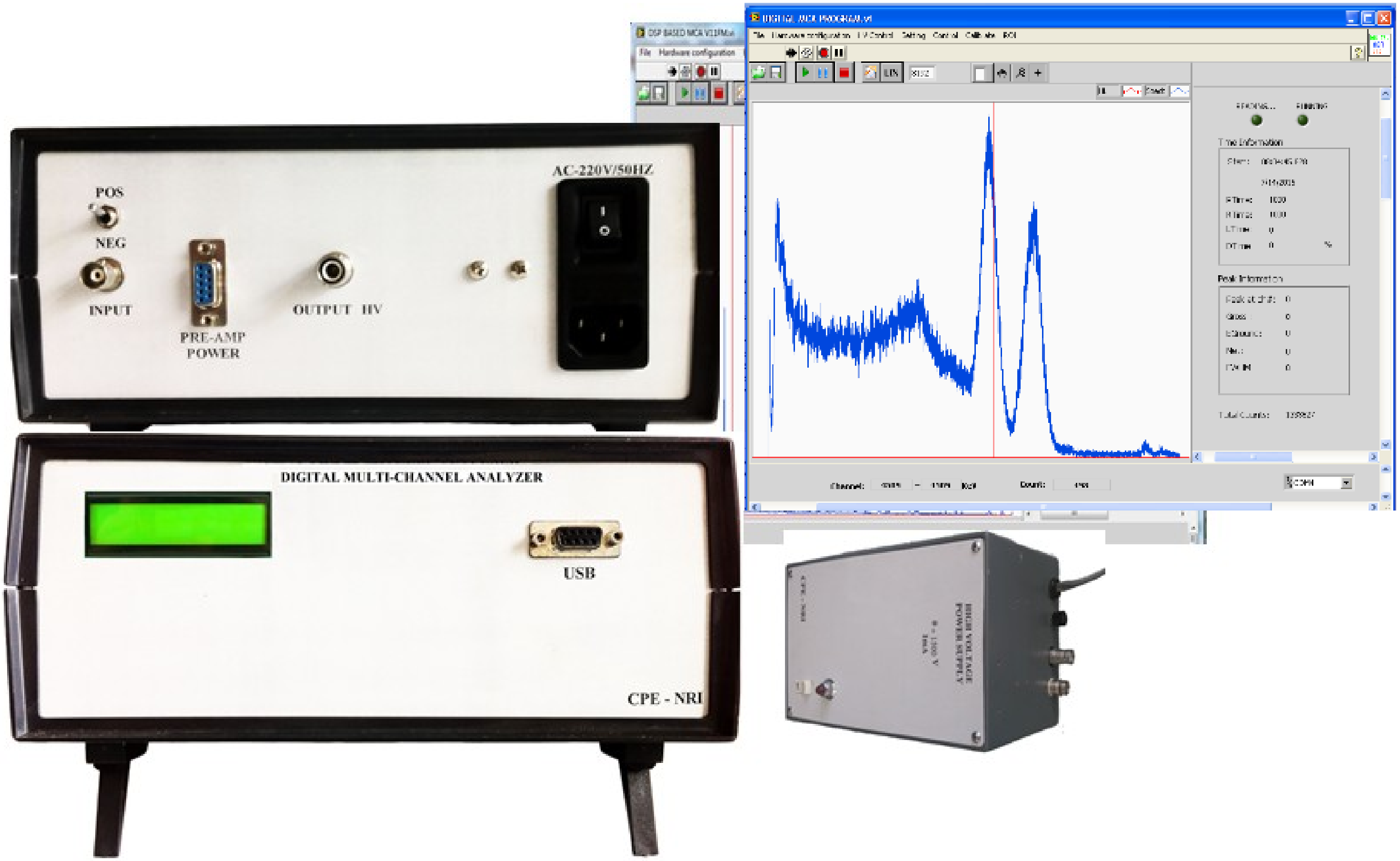
Block diagram of gamma spectroscopy using DSP technique

Some results of application DSP and FPGA for manufacturing of spectroscopy



Coincidence spectroscopy design based on DSP

Some results of application DSP and FPGA for manufacturing of spectroscopy

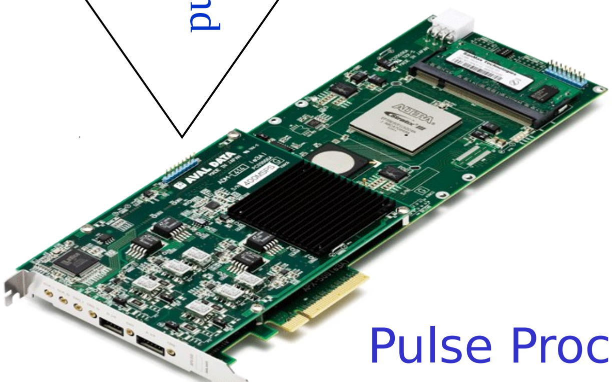


The gamma spectroscopy using DSP and FPGA

Some results of application DSP and FPGA for manufacturing of spectroscopy

DSP and FPGA

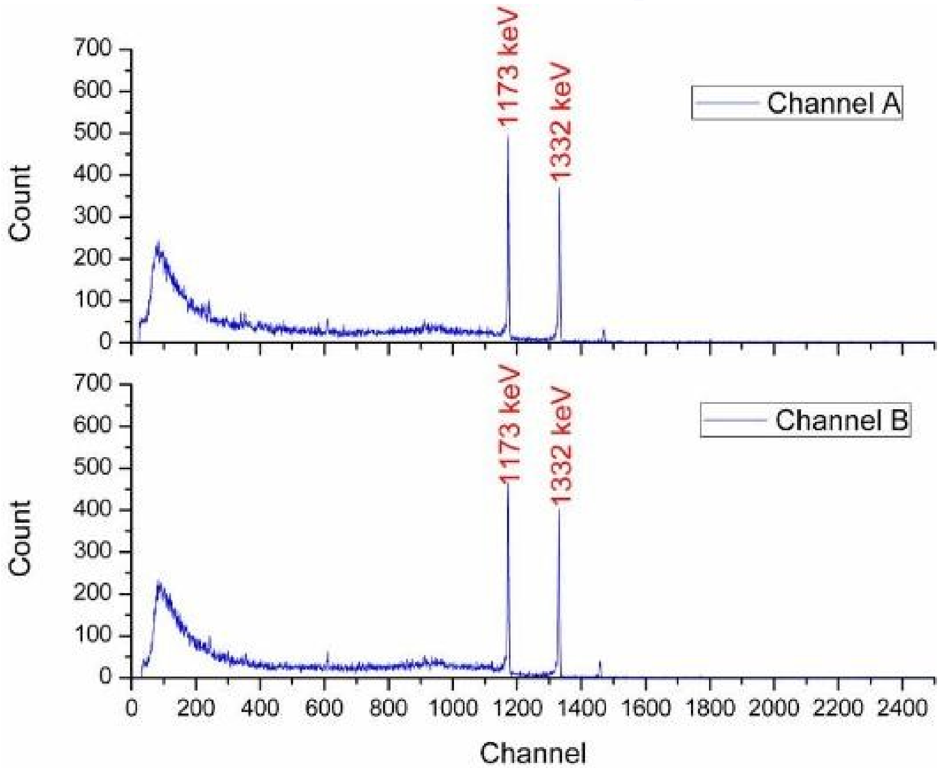
DSP and PC



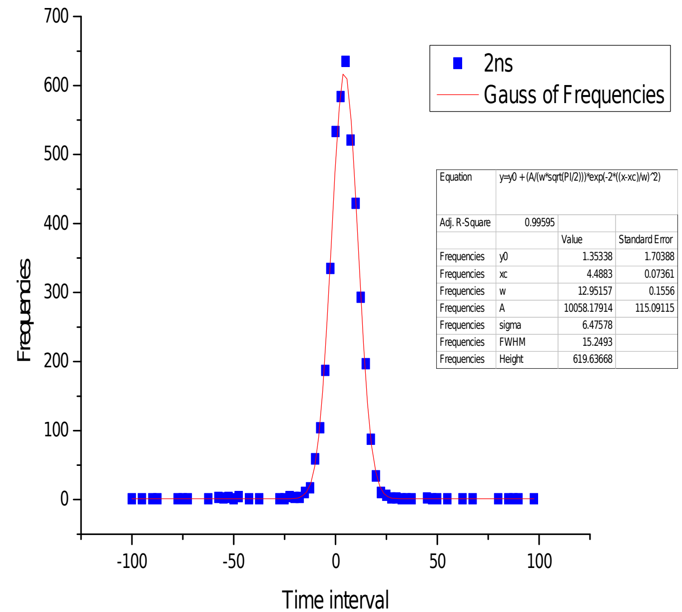
The integrated coincidence spectroscopy (2M size), using FPGA and DSP

Pulse Processing by PC (DSP by software)

The quality of DSP based gamma coincidence spectroscopy



Energy spectrum of both detectors. Energy resolution is better 12% at 1332 keV (Co-60), slightly better than our current analog one.

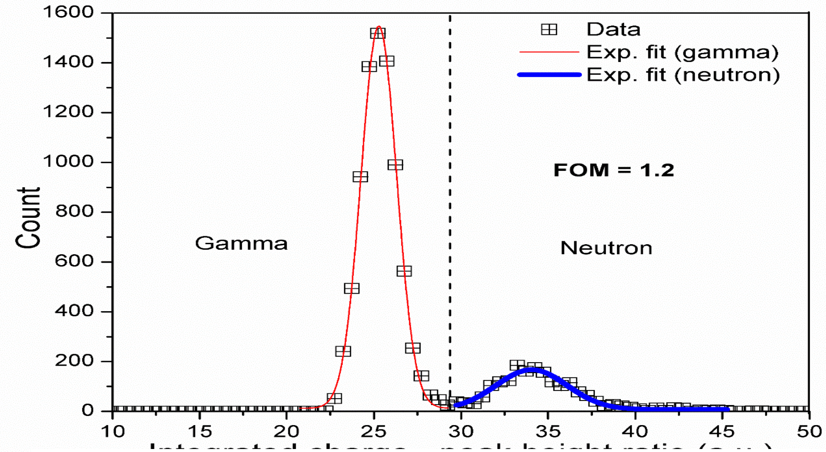


Equation	y=y0 + (A/(w*sqrt(PI/2)))*exp(-2*((x-xc)/w)^2)		
Adj. R-Square	0.99595		
		Value	Standard Error
Frequencies	y0	1.35338	1.70388
Frequencies	xc	4.4883	0.07361
Frequencies	w	12.95157	0.1556
Frequencies	A	10058.17914	115.09115
Frequencies	sigma	6.47578	
Frequencies	FWHM	15.2493	
Frequencies	Height	619.63668	

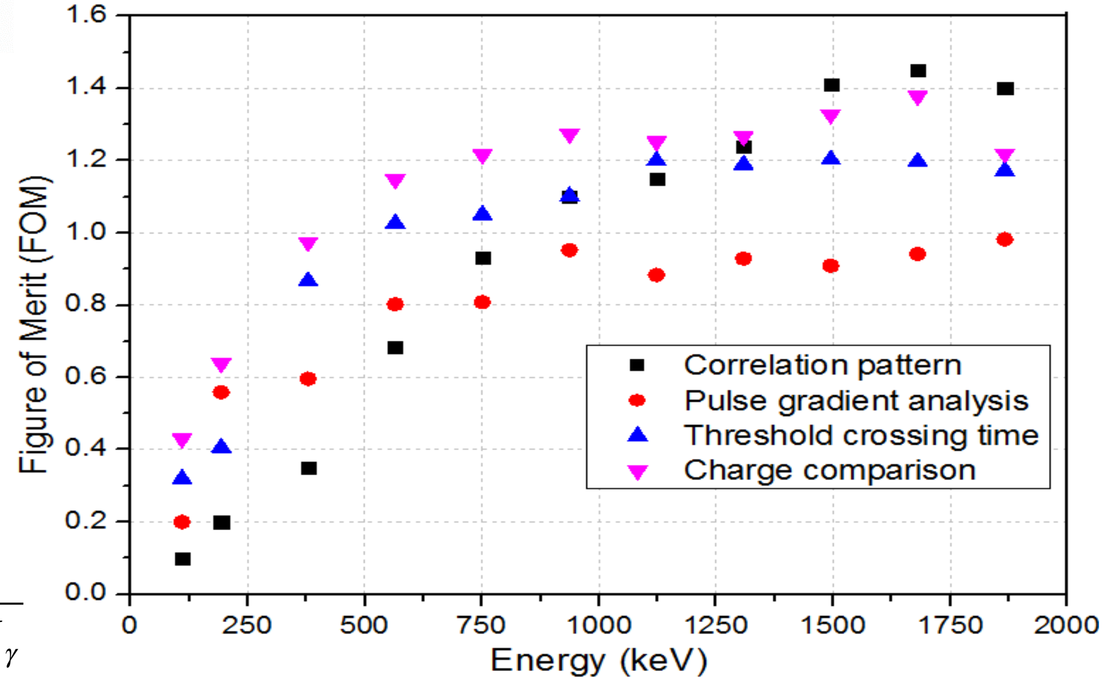
Coincidence curve. Timing resolution is ~13 ns (compared to 10 ns with the current analog one).

A prototype of scintillator detector for neutron measurement

A comparison of FOM (Figure of Merit) value as a function of energy threshold for threshold crossing time, pulse gradient analysis, charge comparison, and correlation pattern recognition in range of energy from 100keV to 1200keV



Histogram of correlation pattern recognition



$$FOM = \frac{Ch_n - Ch_\gamma}{FWHM_n + FWHM_\gamma}$$

Where: Ch_n, Ch_γ positions of neutron and gamma peaks respectively;

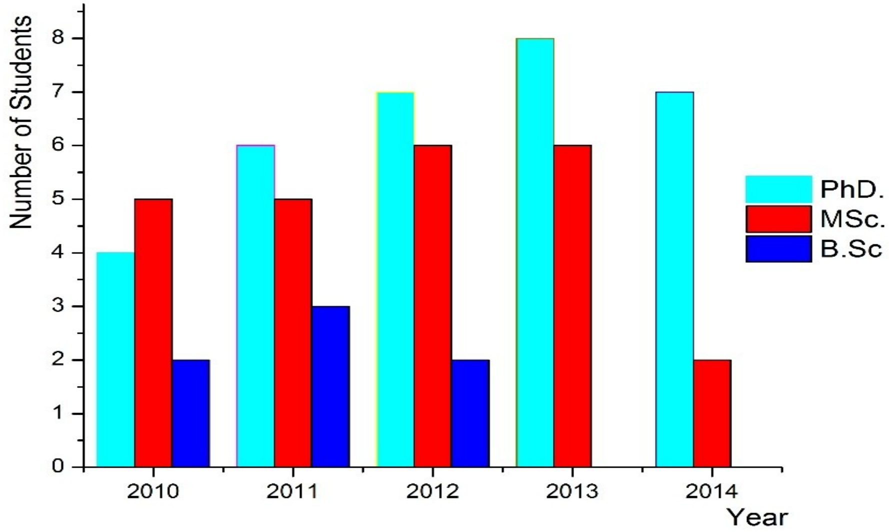
$FWHM_n$ *and* $FWHM_\gamma$: full-width-maximums of neutron and gamma peaks respectively.

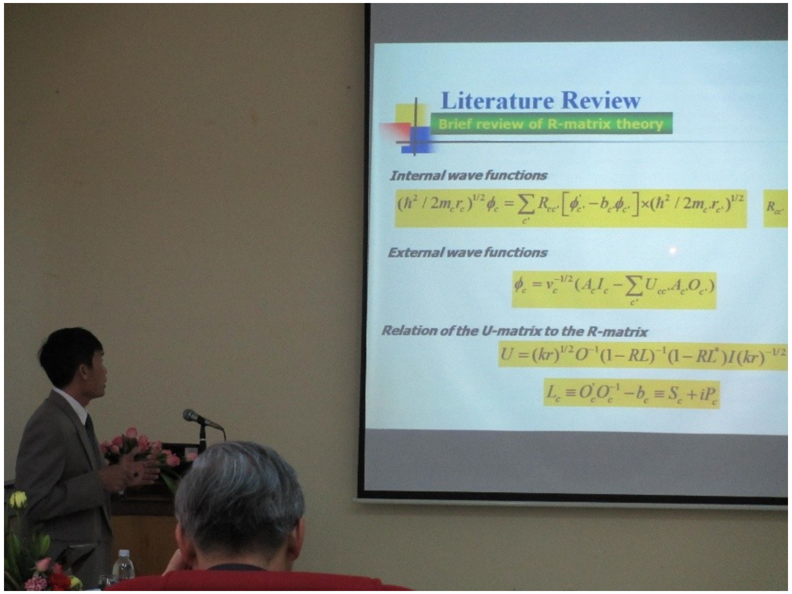
Aspect of education

Belong to the application for research activities, these filtered neutron beams with modern radiation spectrometers are also utilized as experimental facilities for PhD and Master students to carry out their research topics

Aspect of education

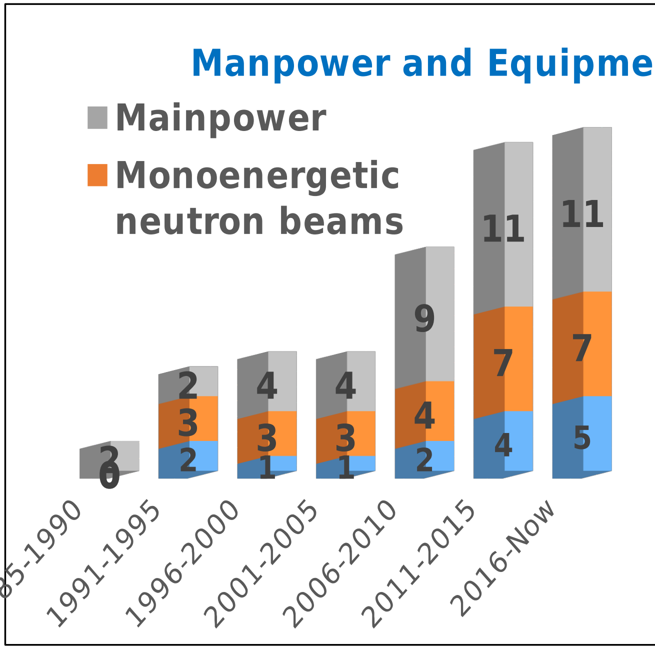
	2010	2011	2012	2013	2014
BSc.	1	2	2		
MSc.	5	5	6	6	2
PhD.	4	6	8	9	7



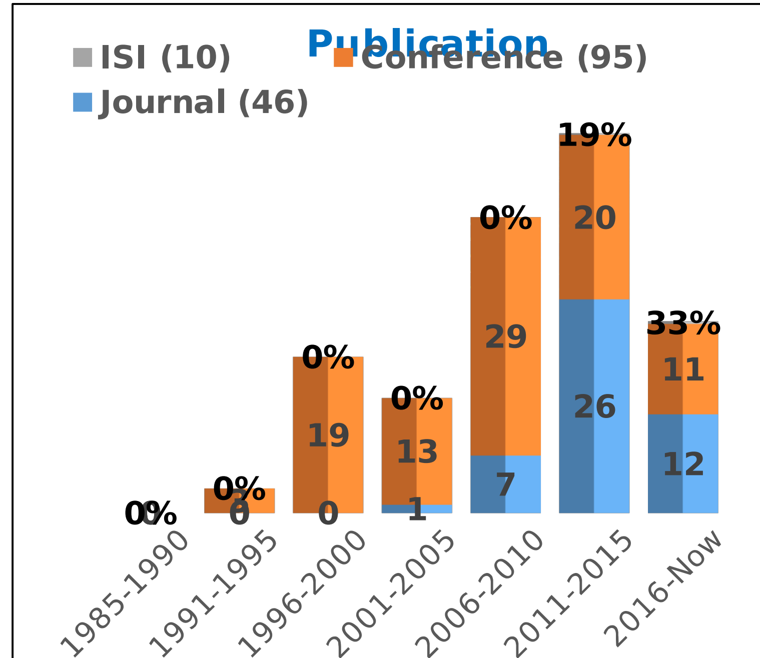


Yearly graduate students perform their research projects used neutron beams at Dalat research reactor

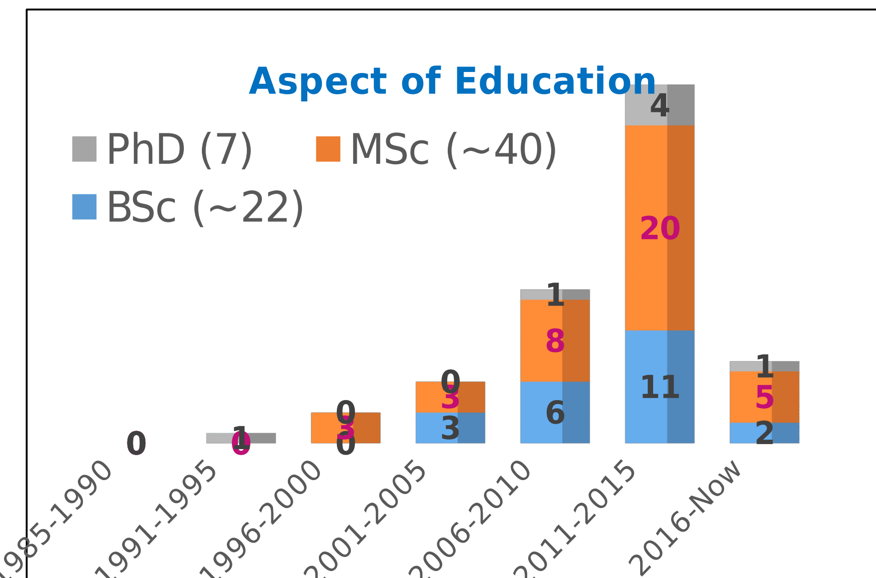
Summary: 32 years utilization of neutron beams at DNRR



e, Experienc e: Neutron beam, (n,γ); (n,2γ); CS, LD, RSF, PGNAA, CNAA, FPGA,



Application: Analysis; Maintenance; Manufacture equipment,



Nuclear human resource development; Exploit efficient DNRR; Improve fundamental research,...

Summary

- The neutron filter technique has been successfully applied for development of mono-energetic neutron beams at the Dalat research reactor.
- The neutron beams are currently applied for basis research, applications and education at the Nuclear Research Institute/VINATOM.
- The research topic carried out includes: measurements of neutron total and neutron capture reaction cross-sections; Measurement of nuclear energy level scheme and level density.
- The Monte Carlo code (Geant4 or MCNP5) have been used for simulations of selt-shielding, multi-scattering parameters and HPGe detector efficiency in order to reduce uncertainty of experimental results.

Summary

- The neutron filtered beams of 2, 24, 54, 59, 133 and 148keV are available and useful for measurement of nuclear data.
- The neutron capture cross sections of ^{139}La, ^{152,154}Sm, ^{191,193}Ir, ^{146,148,150}Nd, ^{69,71}Ga, ^{185,187}Re, ^{181}Ta, ^{160}Gd and ^{180}Hf within the uncertainties of about 5-8% have been measured at keV energies by the activation method.
- The total neutron cross sections of ^{12}C, ^{93}Nb, ^{238}U, ^{181}Ta within the uncertainties of about 1-3% have been measured at keV energies by the neutron transmission technique.
- Level schema, level density and gamma strength function of nucleus (^{153}Sm, ^{172}Yb, ^{239}U, ^{56}Fe, ^{59}Ni, ^{49}Ti,...) have been determined by gamma-gamma coincident method from (n,2g) reactions.

Future plan

- Continue neutron cross-section measurement (Determination of neutron resonance parameters; Publication of the experimental data to EXFOR; EXFOR compilation,…);
- Continue gamma cascade measurement (level, density, strength and nuclear structure), extracting LD and RSF from other method such as Oslo method;
- Improvement of accuracy and precision of self-manufactured equipment for nuclear physics research and applications;

THANK YOU FOR YOUR ATTENTION