Activities for Nuclear Data Measurements in Korea

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Kyungpook National University
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Activities on Nuclear Data Measurements

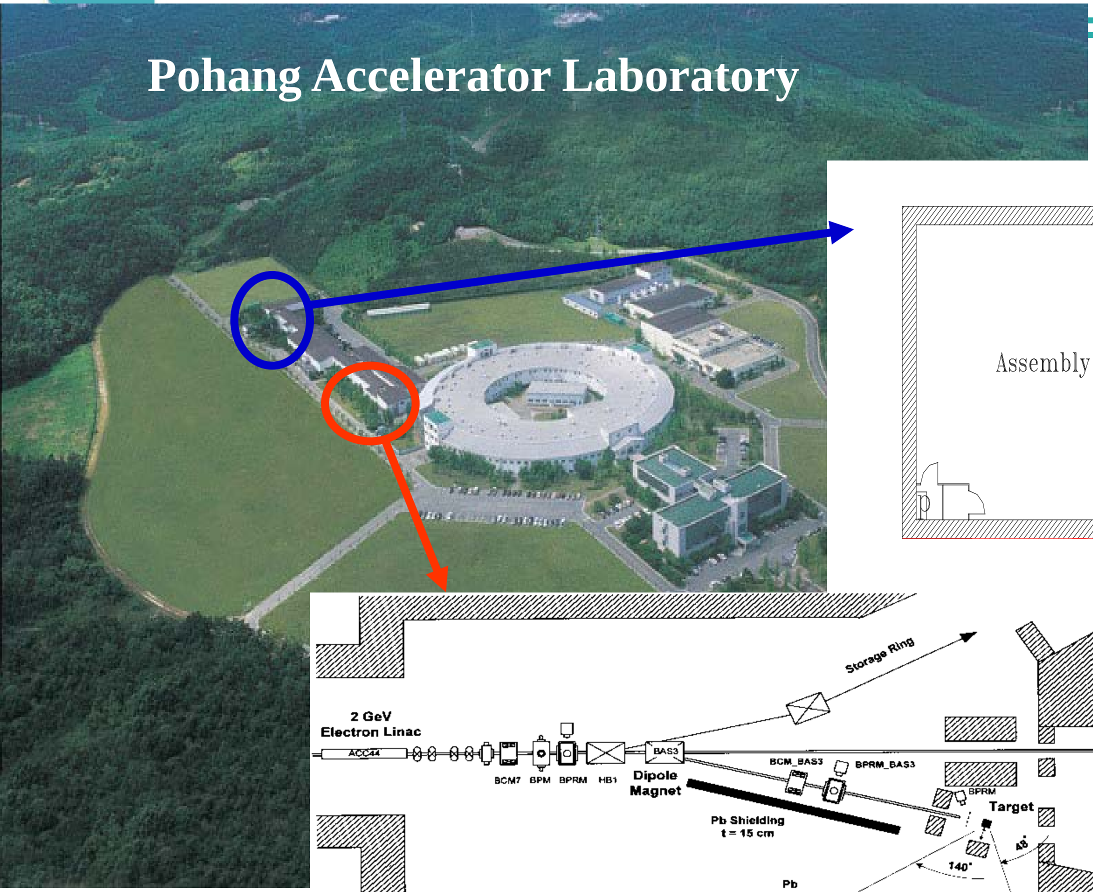
Nuclear Data Measurements using Pohang Neutron Facility

- **Neutron Total Cross-section measurements with TOF method**
- **Measurement of Thermal Neutron Cross-sections and Resonance Integrals by Neutron Activation Method**
- **Photo-nuclear reactions with Bremsstrahlung Activation Method**

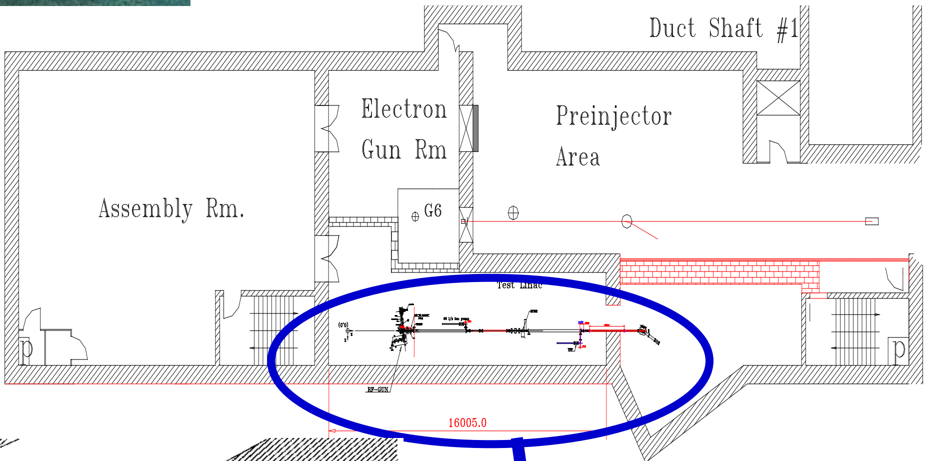
Charged Particle Induced Reaction Cross-section Measurements using the Stacked-foil Activation Method

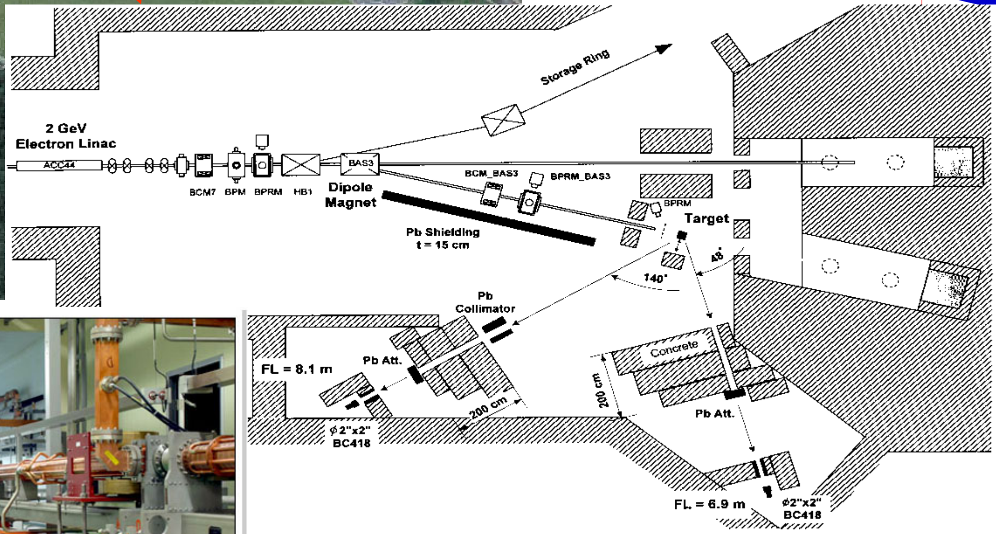
Nuclear Data Measurements using Pohang Neutron Facility

Pohang Accelerator Laboratory



Pohang Neutron Facility based on 100-MeV e-linac





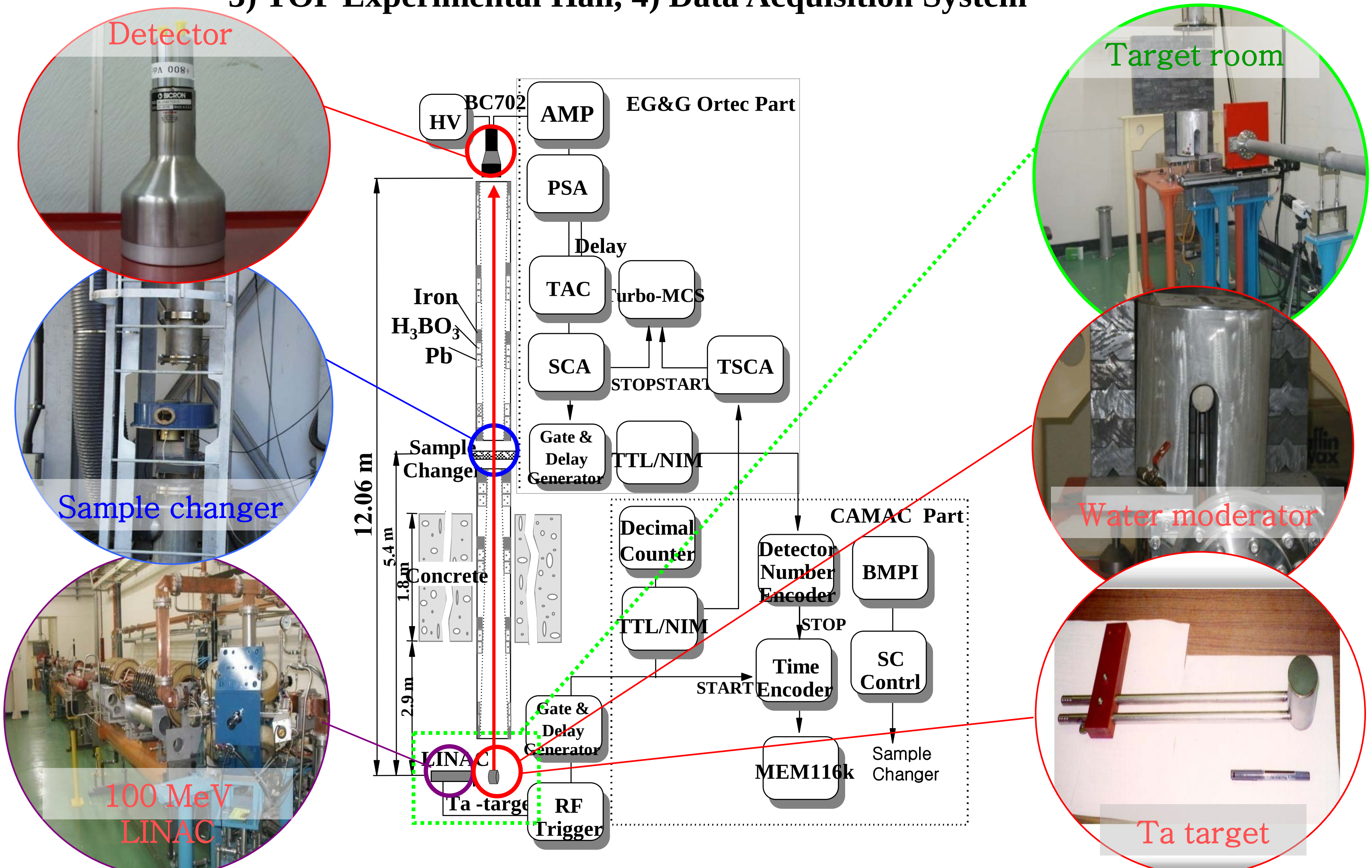
Pohang High Energy Radiation Facility with 2.5 GeV e-linac

1. Neutron Total Cross-section measurements by neutron TOF method

Pohang Pulsed Neutron Facility (PNF)

1) Electron Linear Accelerator, 2) Target System

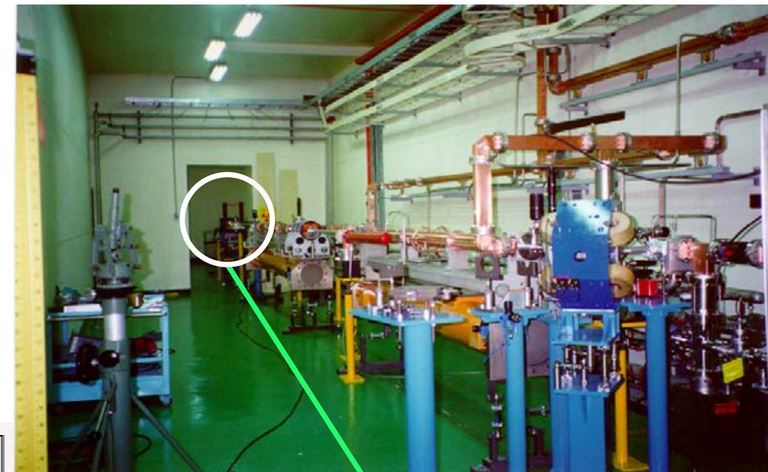
3) TOF Experimental Hall, 4) Data Acquisition System

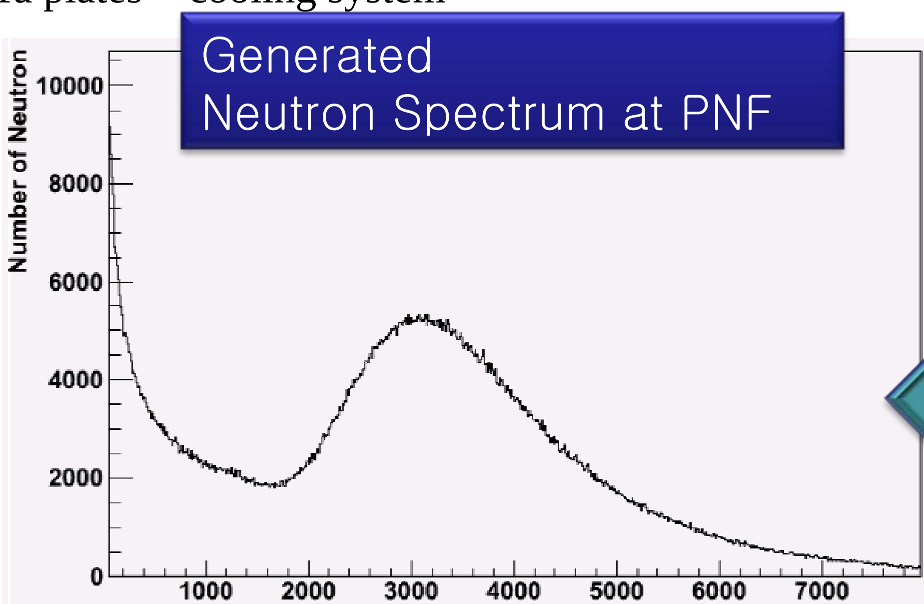


Pohang Pulsed Neutron Facility (PNF)

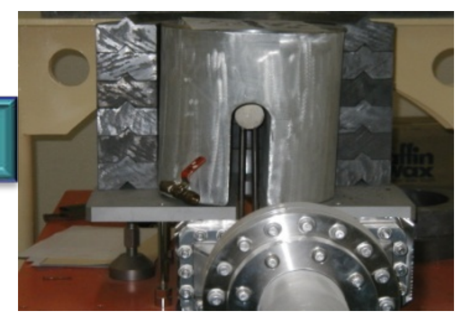
(1) Electron Linear Accelerator

- Electron accelerator based Time of Flight system
  - ✓ electron energy = 50 ~ 70 MeV
  - ✓ repetition rate =   Below 30Hz
  - ✓ pulse width = 1 ~ 2 μs
  - ✓ peak beam current = 30 ~ 60 mA
  - ✓ TOF flight length = 11.5~12m
  - ✓
- Target + water moderator : to produce neutron pulse
  - ✓ Ta plates + cooling system

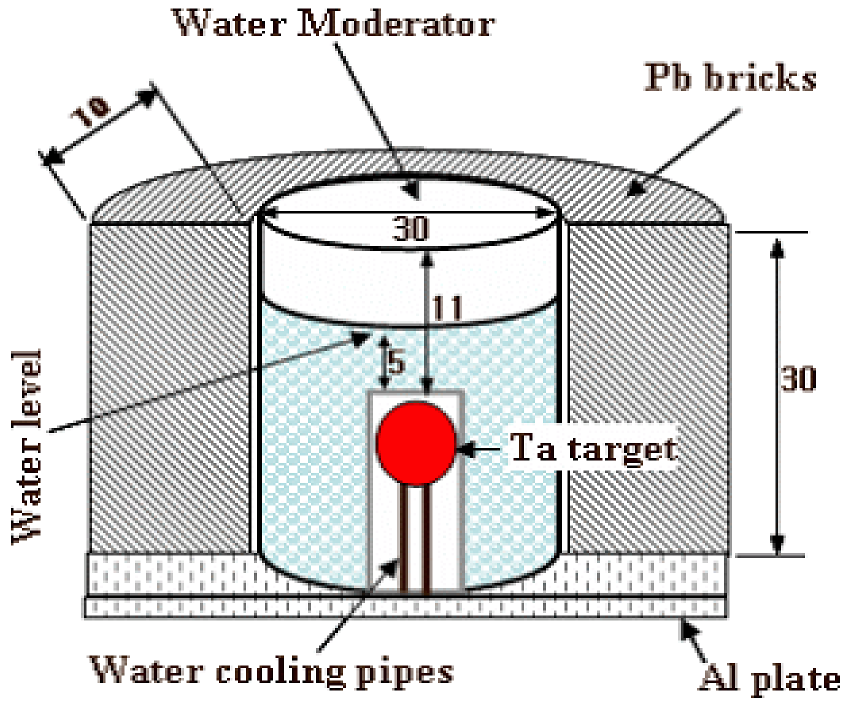


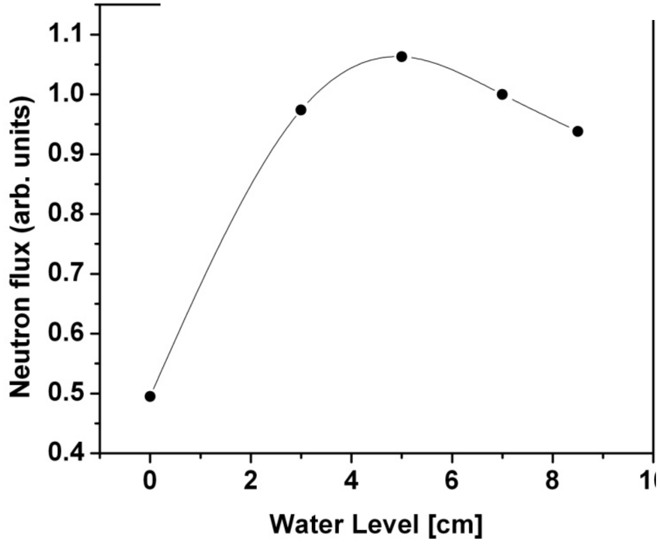


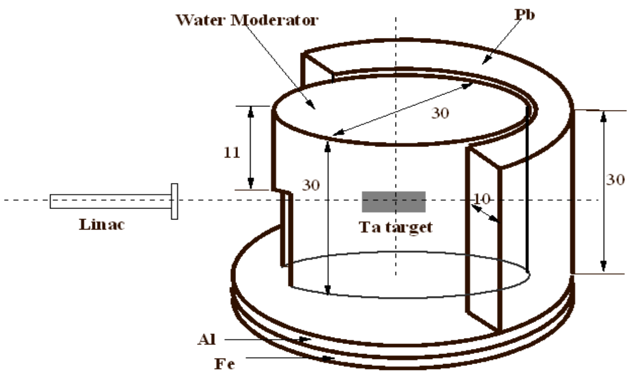
Neutron Arrival Time (μs)



(2) Water Moderator for the Water-Cooled Ta-Target



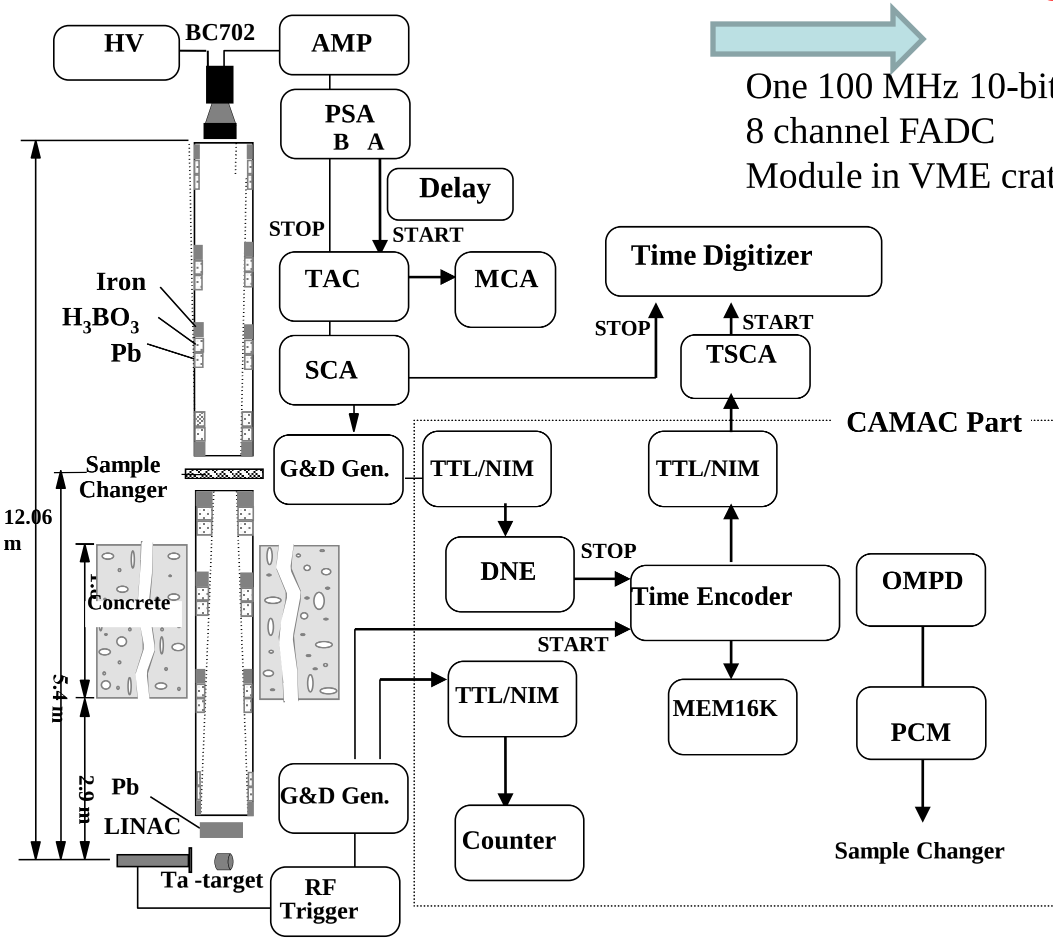




Water level was fixed to 5 cm above the target surface

3) Data Acquisition System

Current DAQ

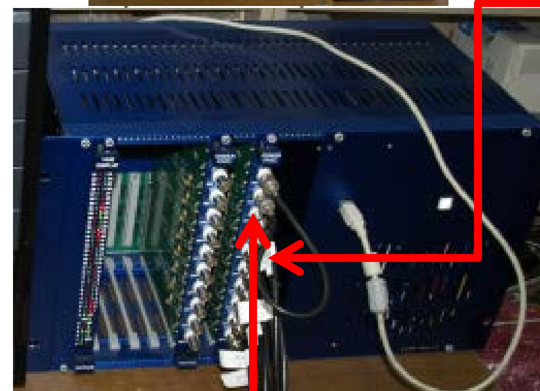


FADC DAQ

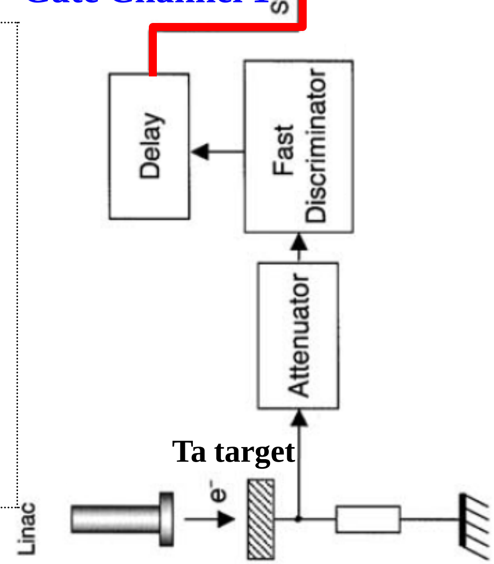
One 100 MHz 10-bit 8 channel FADC Module in VME crate

DAQ Computer

Neutron Signal Channel 2



Gate Channel 1



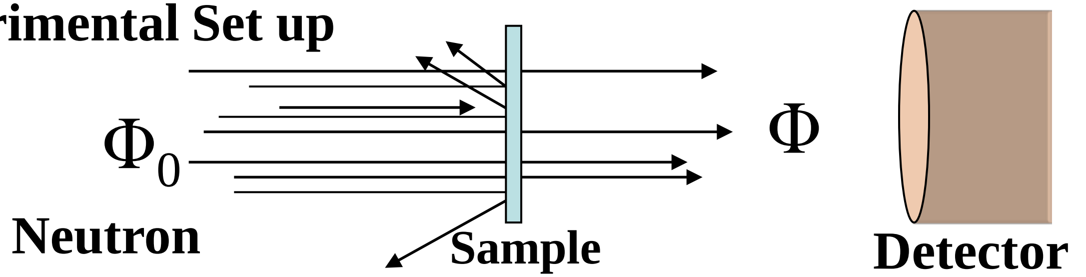
Measurement of Neutron Total Cross Section

1. Neutron Energy E in eV corresponding to channel I in TOF

$$E[eV] = \left(\frac{72.3 \times L[m]}{(I - I_0) \times W[\mu s]} \right)^2$$

L: flight path length
W: channel width

2. Experimental Set up



3. Neutron Transmission rate

$$T(E_i) = \frac{[In(E_i) - In^B(E_i)] / M_{In}}{[Out(E_i) - Out^B(E_i)] / M_{Out}}$$

4. Total Cross Section

$$\sigma(E_i) = -\frac{1}{N} \ln T(E_i)$$

N: atomic density

5. Total Cross Section after Purity Correction

$$\sigma_T = \frac{\sigma - M_T \cdot \sum_j P_j \sigma_j M_j^{-1} \times 10^{-6}}{1 - \sum_j P_j \times 10^{-6}}$$

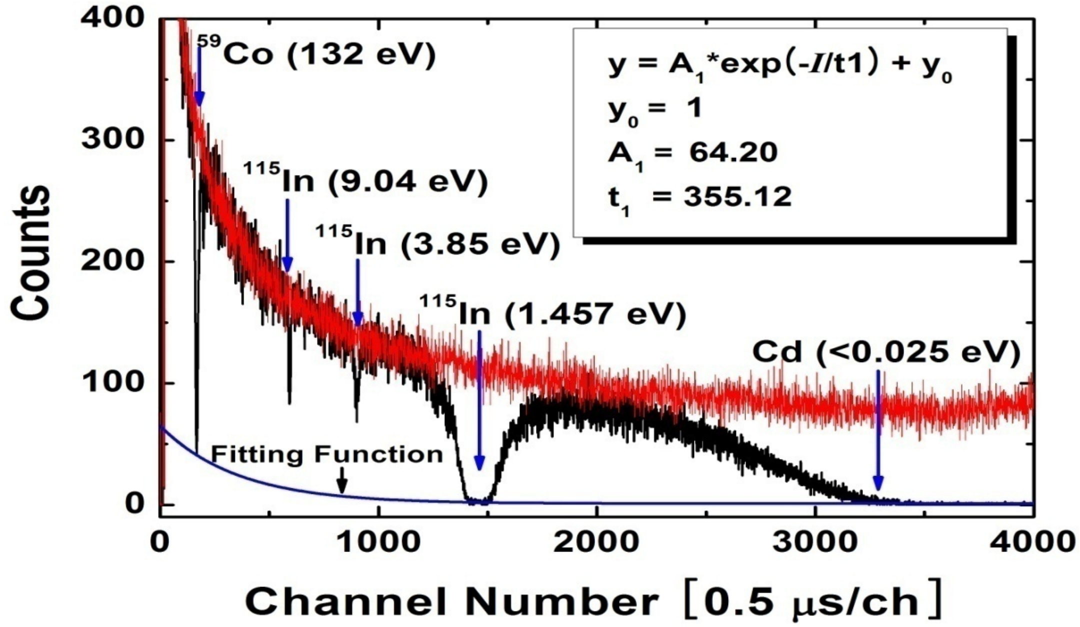
σ: measured total cross section

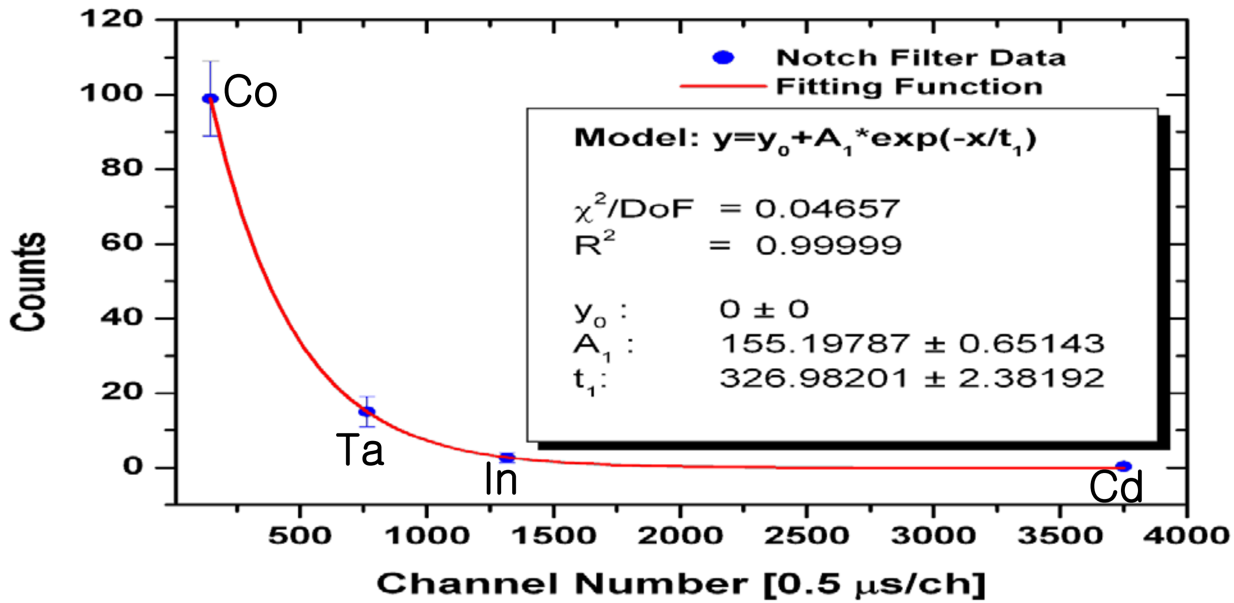
M_T: total weight of sample

M_j: weight of impurity sample

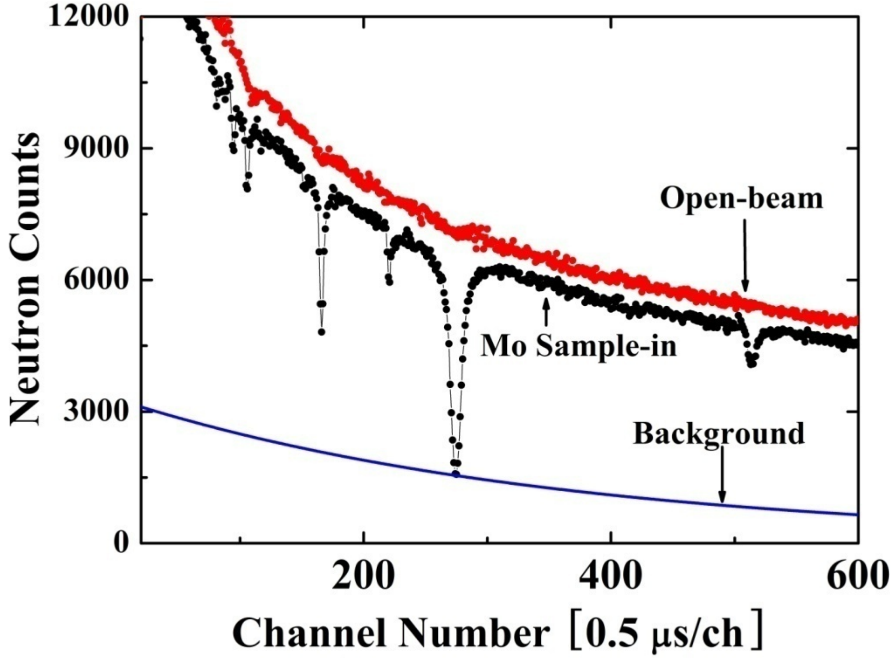
P_j : impurity in ppm

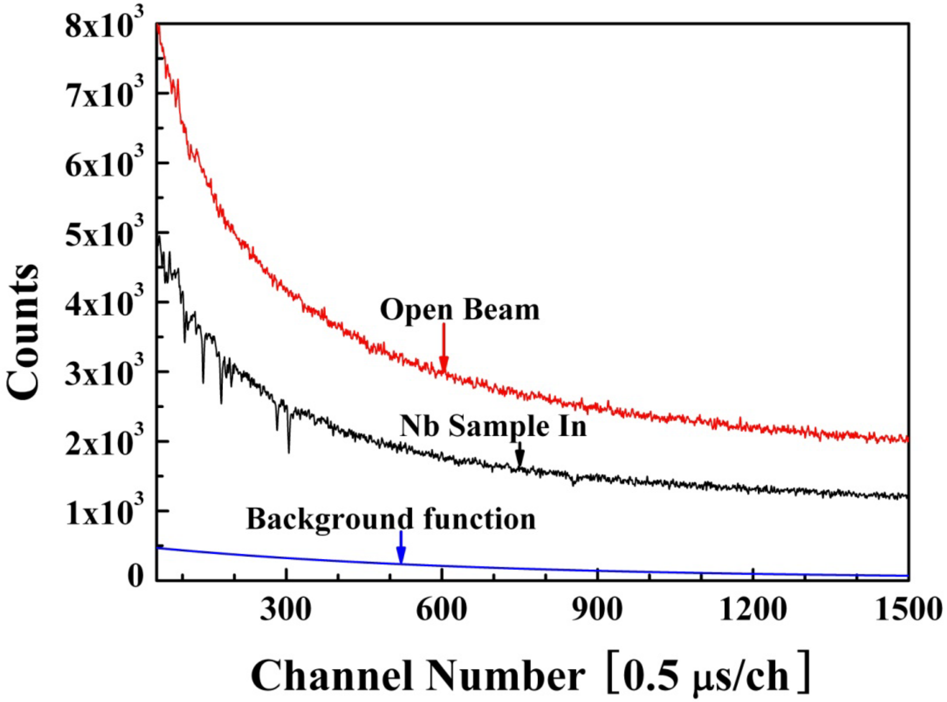
Background Estimation





Neutron TOF Spectra

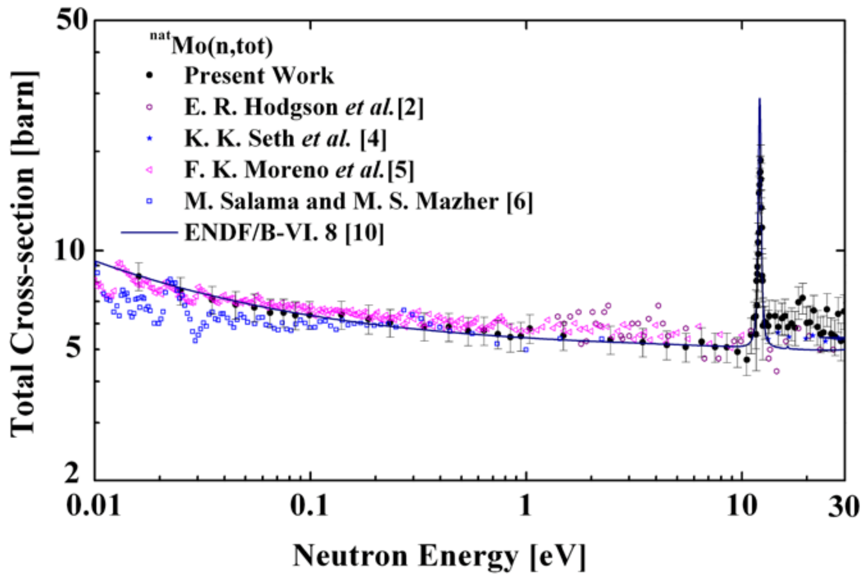


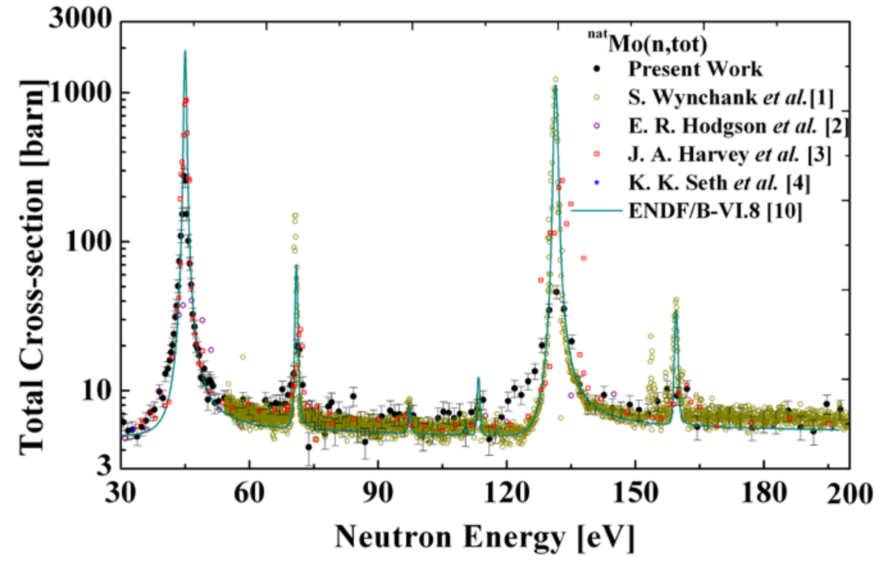


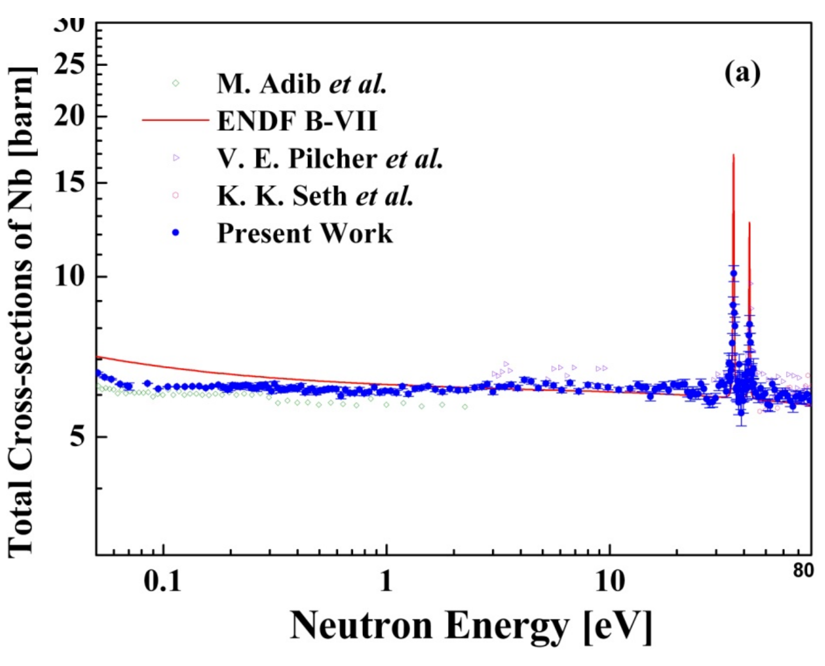
$$\sigma(E_j) = -\frac{1}{\sum_i N_i} T(E_j) \qquad T(E_j) = \frac{[I(E_j) - IB(E_j)]/M_I}{[O(E_j) - OB(E_j)]/M_O}$$

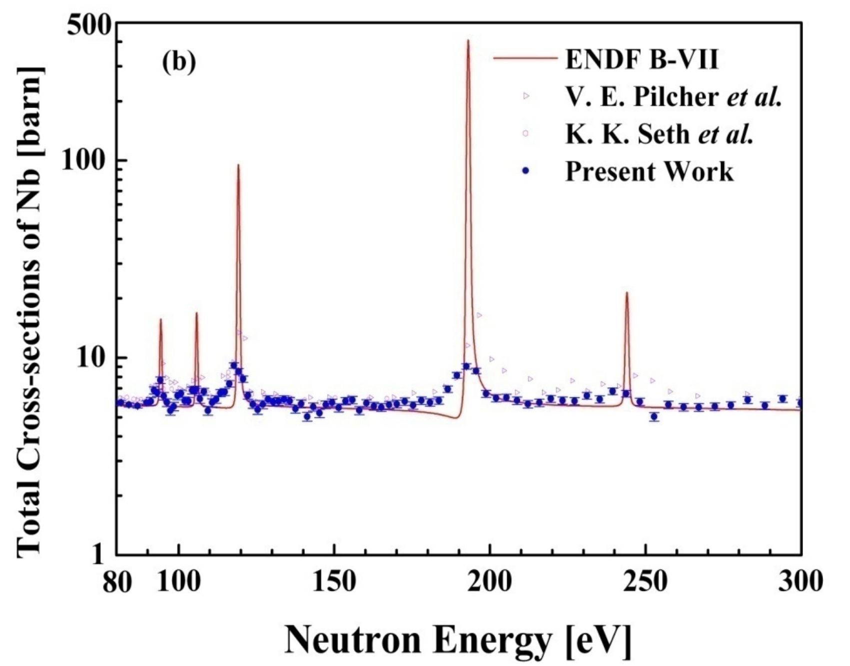
$$\left(\Delta\sigma_{stat.}\right)_j = \frac{1}{N_i}\sqrt{\frac{I(E_i) + IB(E_i)}{[I(E_i) - IB(E_i)]^2} + \frac{O(E_i) + OB(E_i)}{[O(E_i) - OB(E_i)]^2}}$$

Measured Total Cross Sections of Mo and Nb









Recent Measurement of Neutron Total Cross Section

Nuclear Instruments and Methods in Physics Research B 268 (2010) 106–113

Contents lists available at ScienceDirect

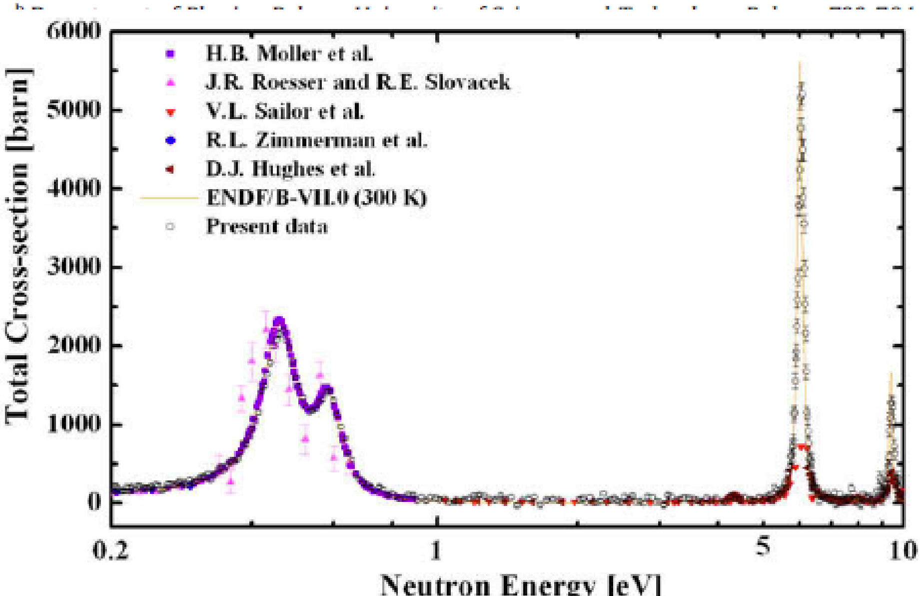
Nuclear Instruments and Methods in Physics Research B

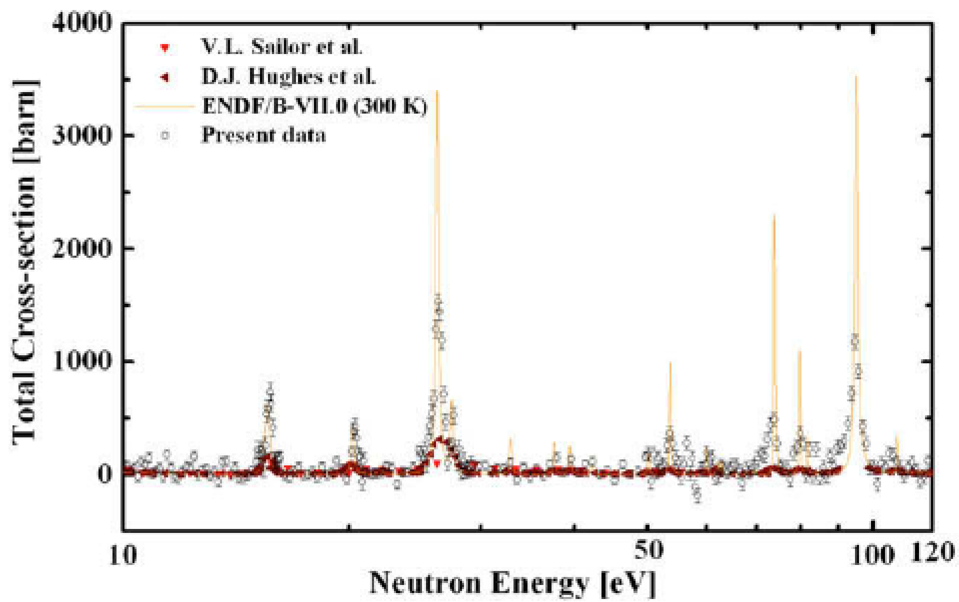
journal homepage: www.elsevier.com/locate/nimb

Measurements of neutron total cross-sections and resonance parameters of erbium at the Pohang Neutron Facility

Taofeng Wang [a], Manwoo Lee [a], Kyung-Sook Kim [a], Guinyun Kim [a,*], Young Do Oh [b], Moo-Hyun Cho [b], In Soo Ko [b], Won Namkung [b], Tae-Ik Ro [c]

[a] Department of Physics, Kyungpook National University, Daegu 702-701, Republic of Korea

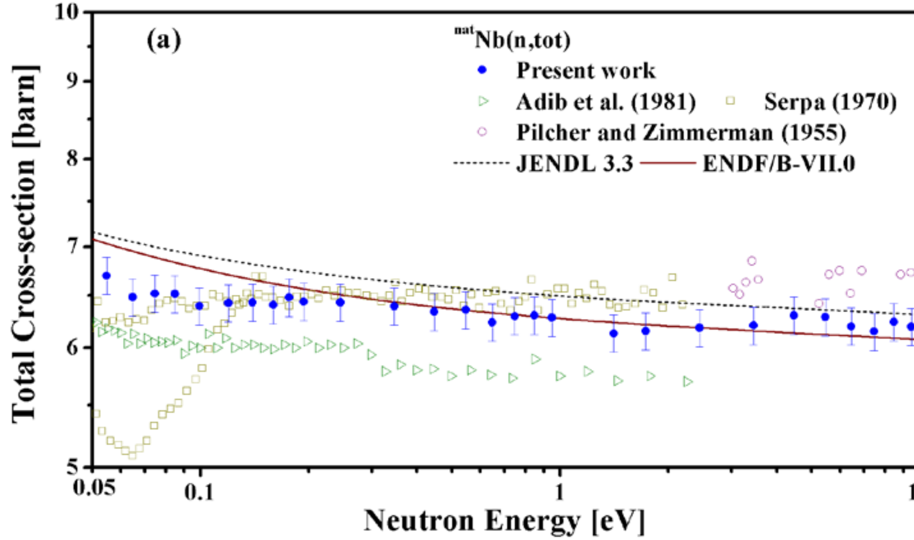


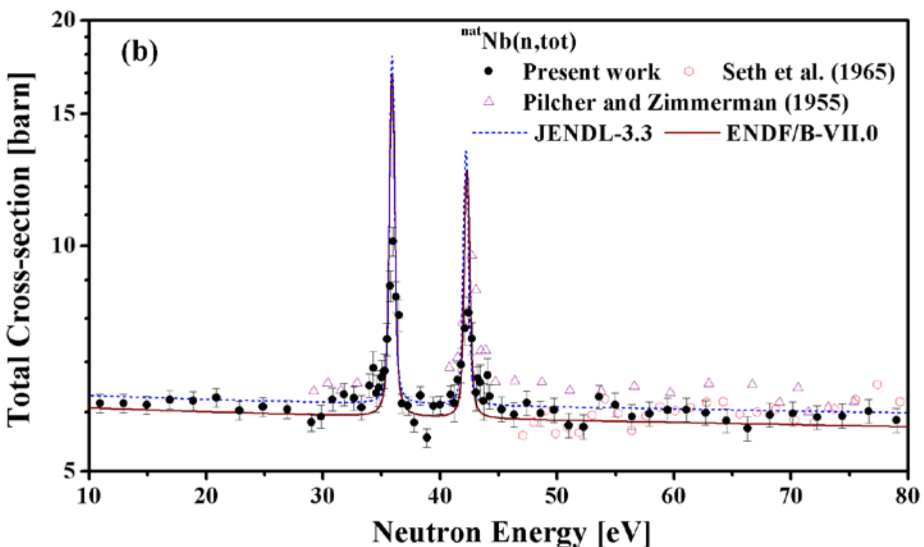


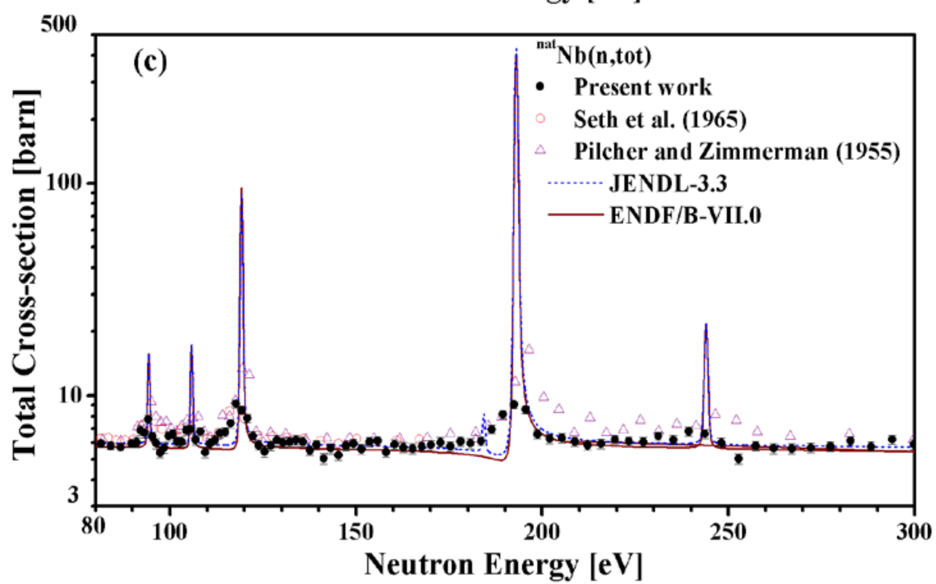
J Radioanal Nucl Chem (2011) 289:945–952
DOI 10.1007/s10967-011-1216-6

Measurements of neutron total cross-sections and resonance parameters of niobium using pulsed neutrons generated by an electron linac

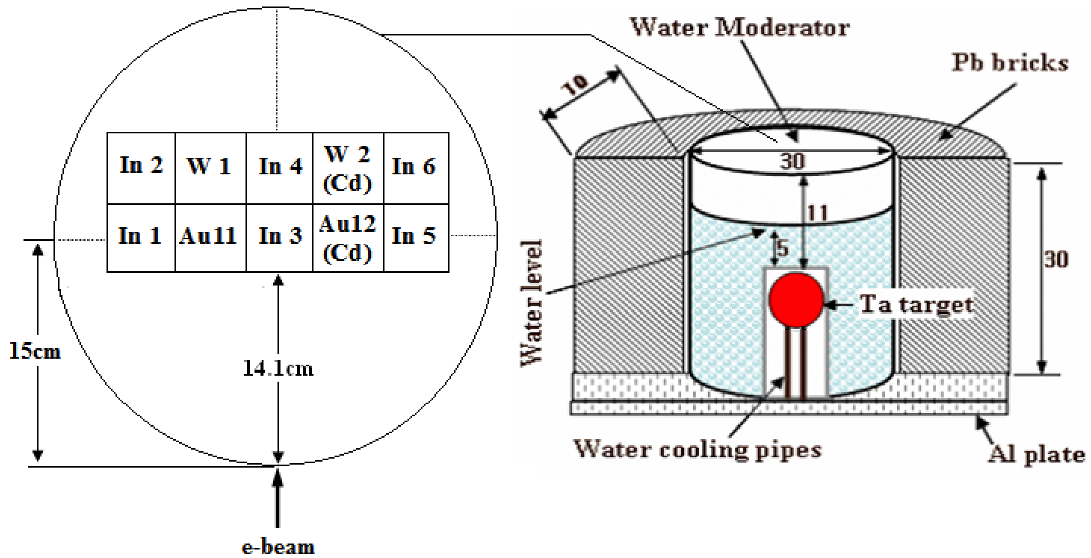
Taofeng Wang · Guinyun Kim · Man-Woo Lee ·
Kyung-Sook Kim · Moo-Hyun Cho ·
Heung-Sik Kang · Won Namkung







2. Measurement of Thermal Neutron Cross-sections and Resonance Integrals by Neutron Activation Method



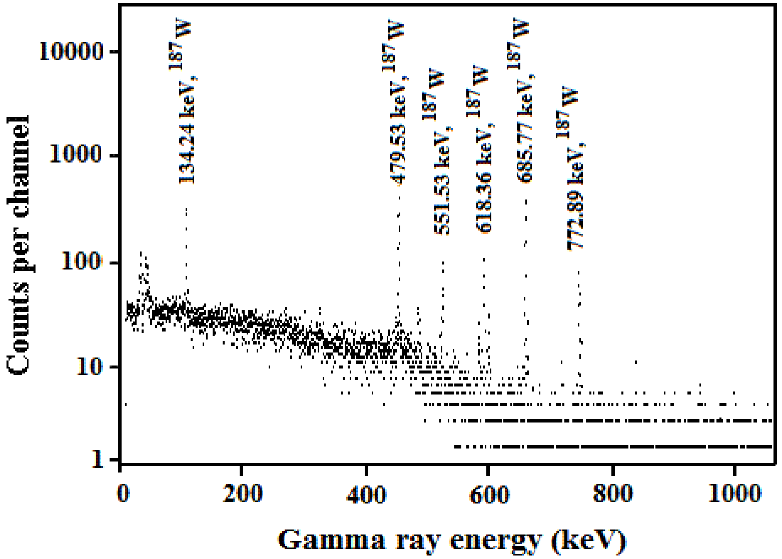
Foil	Size (mm)	Weight (g)	Thickness (mm)	Purity (%)
Au 11	18×18	0.1863±0.0005	0.03	99.95
Au 12	18×18	0.1885±0.0005	0.03	99.95
W 1	18×18	1.2636±0.0008	0.2	99.95
W 2	18×18	1.2891±0.0008	0.2	99.95
In 1	18×18	0.1276±0.0004	0.05	99.99
In 2	18×18	0.1217±0.0004	0.05	99.99
In 3	18×18	0.1214±0.0004	0.05	99.99
In 4	18×18	0.1220±0.0004	0.05	99.99
In 5	18×18	0.1271±0.0004	0.05	99.99
In 6	18×18	0.1245±0.0004	0.05	99.99

Data Analysis

$$\sigma_{0,W} = \sigma_{0,Au} \times \frac{R_W - F_{W,Cd} R_{W,Cd}}{R_{Au} - F_{Au,Cd} R_{Au,Cd}} \times \frac{G_{th,Au}}{G_{th,W}} \times \frac{g_{Au}}{g_W}$$

$$R_{W(Au)} \quad or \quad R_{W(Au),Cd} = \frac{N_{obs}\lambda(1-e^{-\lambda T})}{n_o \varepsilon I_\gamma (1-e^{-\lambda\tau})(1-e^{-\lambda t_i}) e^{-\lambda t_w} (1-e^{-\lambda t_c})}$$

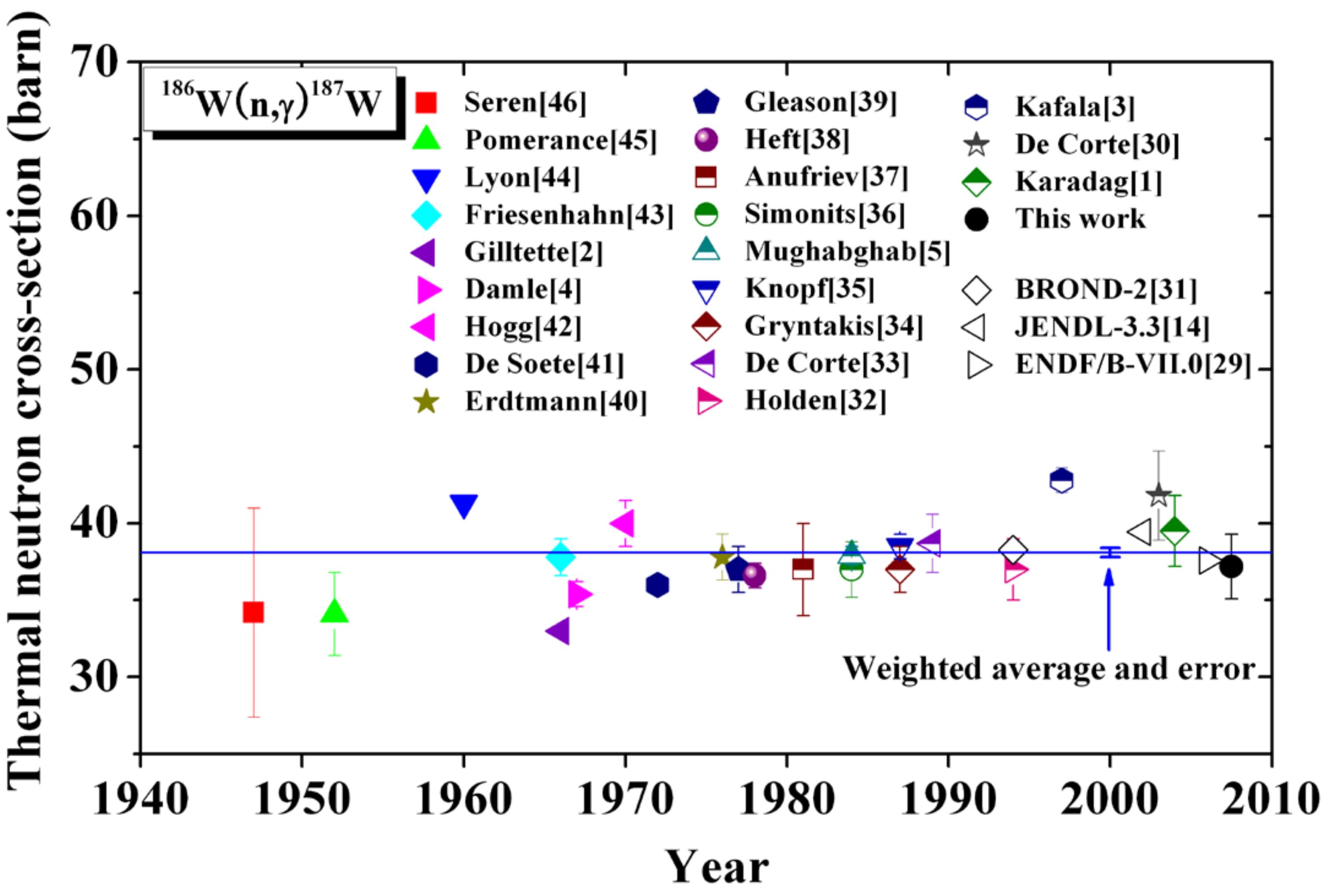
$$I_{0,W}(\alpha) = I_{0,Au}(\alpha) \times \frac{g_W \sigma_{0,W}}{g_{Au}\sigma_{0,Au}} \times \frac{CR_{Au} - F_{Au,Cd}}{CR_W - F_{W,Cd}} \times \frac{G_{epi,Au}}{G_{th,Au}} \times \frac{G_{th,W}}{G_{epi,W}}$$



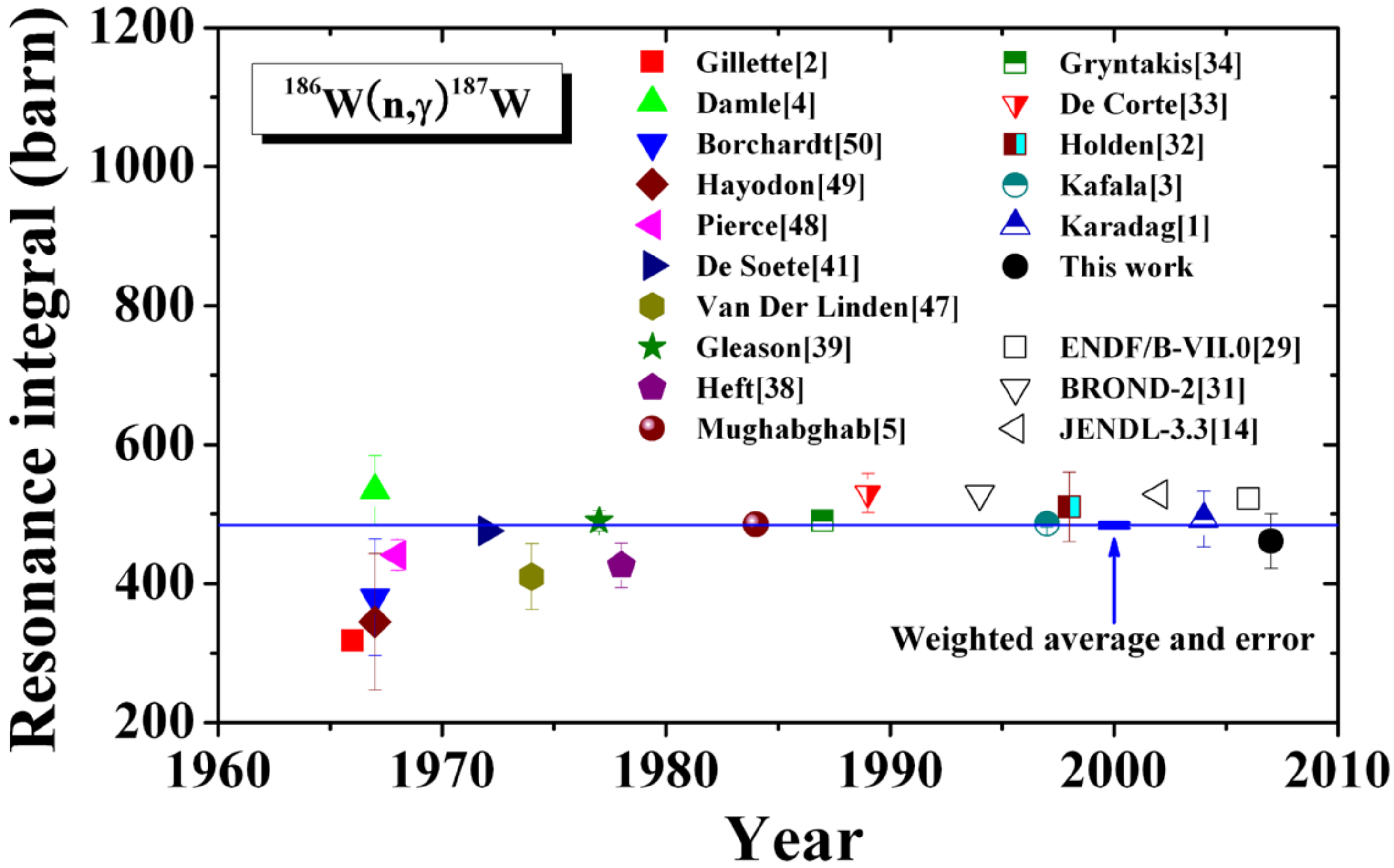
Reaction	Main resonance energy [eV]	Half-life	Main γ- rays		Isotopic abundance [%]
			Energy [keV]	Intensity [%]	
$^{186}W(n,\gamma)^{187}W$	18.8	23.72 h (6)	479.550 (22)*	21.8 (7)	28.6 (2)
			551.52 (4)	5.08 (17)	
			618.26(4)	6.28 (21)	
			685.73 (4)*	27.3 (9)	
$^{197}Au(n,\gamma)^{198}Au$	4.9	2.69517 d (21)	411.80205 (17)*	95.58	100
			675.8836 (7)	0.084 (3)	

* Gamma rays used in calculations

Thermal Neutron Cross-sections of the $^{186}W(n,\gamma)^{187}W$ reaction



Resonance Integrals of the $^{186}W(n,\gamma)^{187}W$ reaction



Recent Measurement of Thermal Neutron Cross-sections and Resonance Integrals

Nuclear Instruments and Methods in Physics Research B 269 (2011) 159–166

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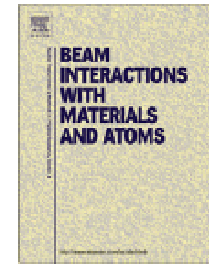
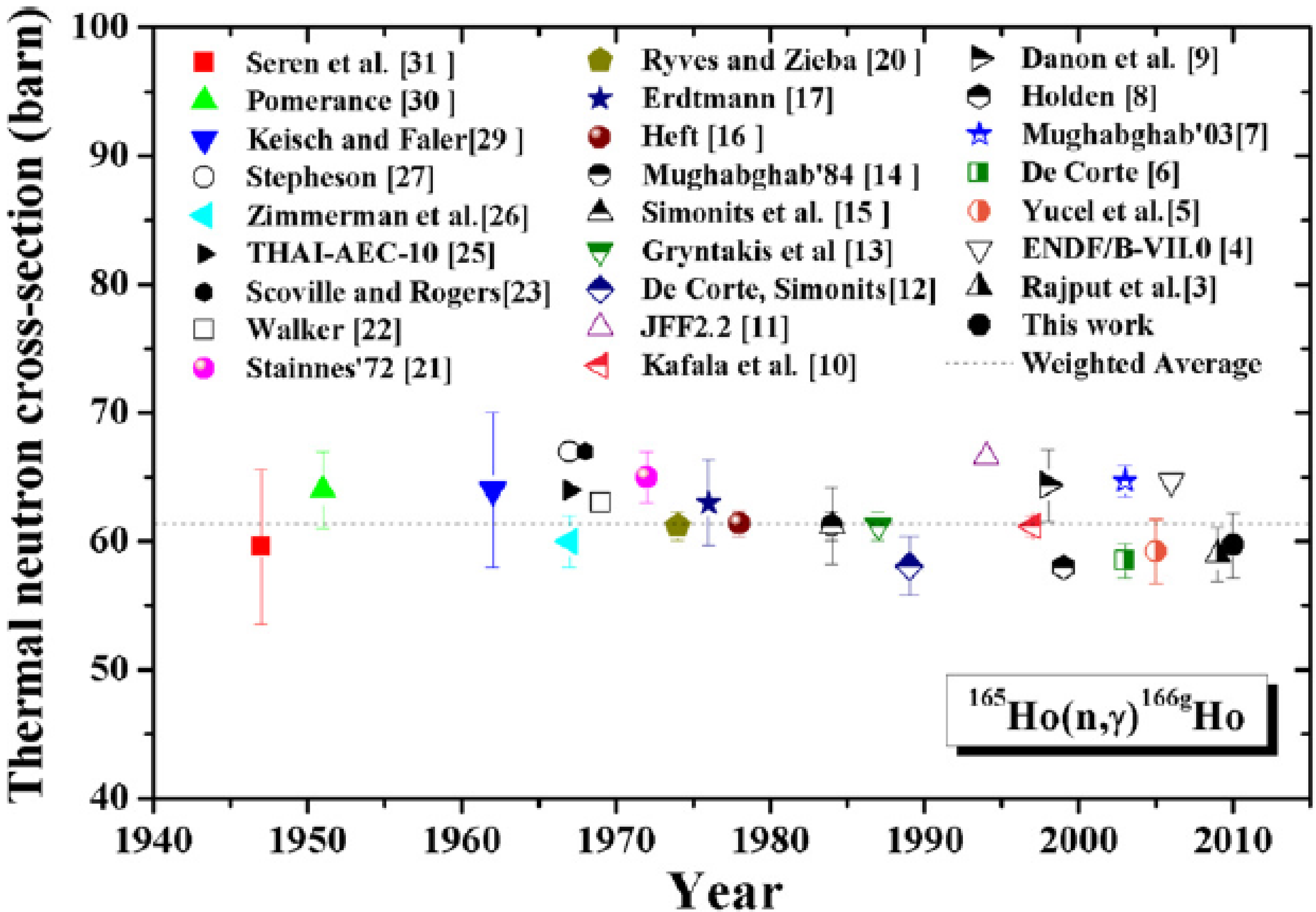


Measurement of thermal neutron cross-section and resonance integral for the ^{165}Ho(n,γ)^{166g}Ho reaction using electron linac-based neutron source

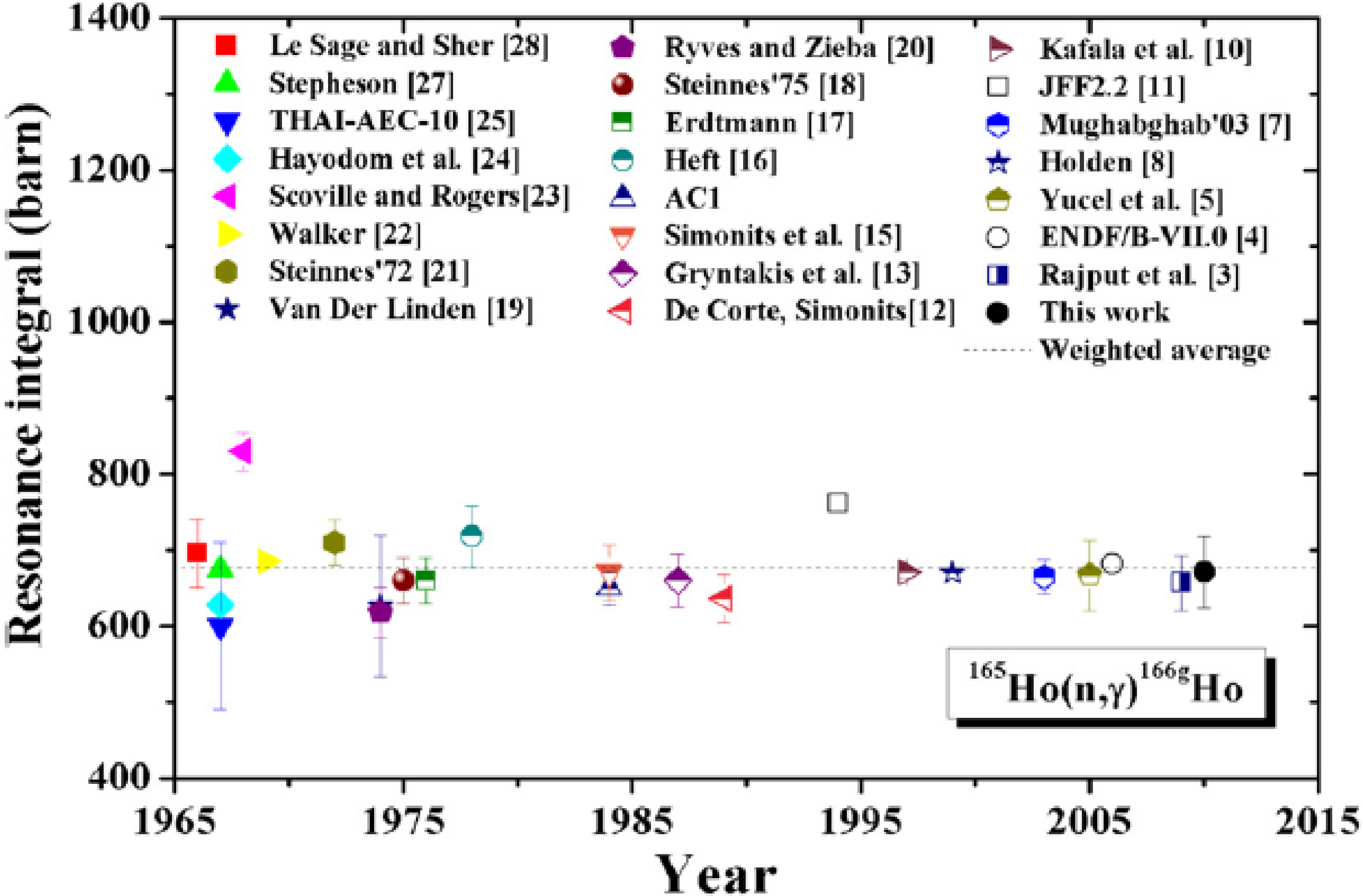
Van Do Nguyen [a], Duc Khue Pham [a], Tien Thanh Kim [a], Guinyun Kim [b,*], Manwoo Lee [b], Kyung Sook Kim [b], Heung-Sik Kang [c], Moo-Hyun Cho [c], In Soo Ko [c], Won Namkung [c]

[a] Institute of Physics, Vietnam Academy of Science and Technology, 10 Dao Tan, Hanoi, Viet Nam
[b] Department of Physics, Kyungpook National University, Daegu 702-701, Republic of Korea
[c] Pohang Accelerator Laboratory, Pohang University of Science and Technology, Pohang 790-784, Republic of Korea

Thermal Neutron Cross-sections of the $^{165}Ho(n,\gamma)^{166g}Ho$ reaction



Resonance Integrals of the $^{165}Ho(n,\gamma)^{166g}Ho$ reaction



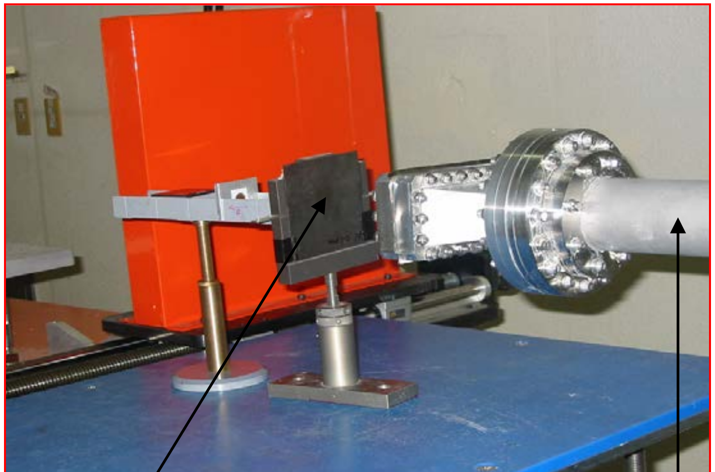
Experiments with Bremsstrahlung beam at PAL

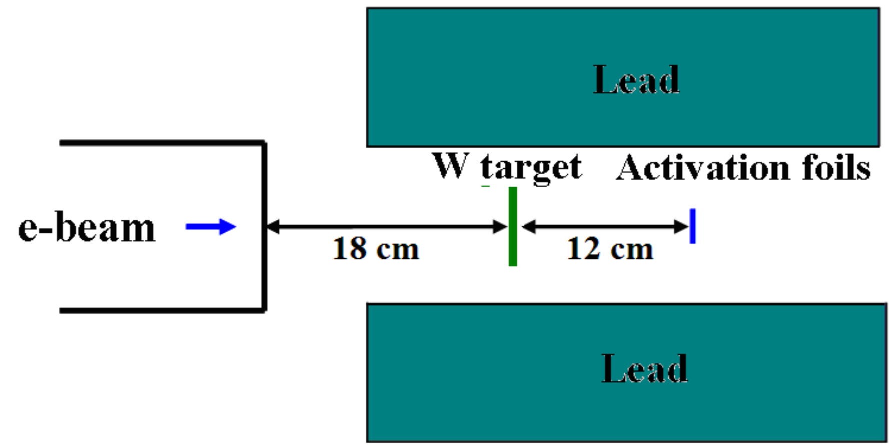
1. **Photo-nuclear Reaction**
   - **Isomeric Yield Ratio Measurement**
2. **Photo-fission Reaction**
   - **Mass yield distribution**
   - **(γ,xn) reaction cross section**

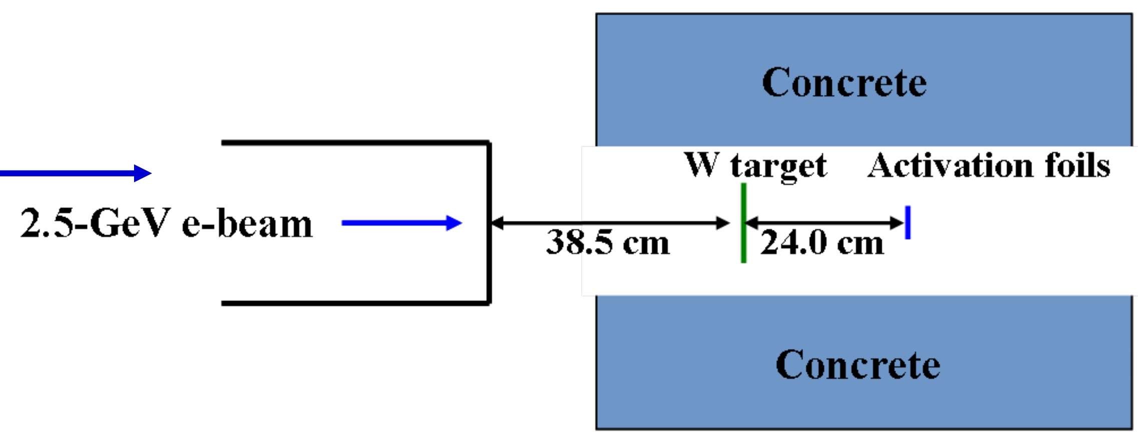
1. Isomeric Yield Ratio Measurement

Experimental Arrangement

- Electron energy : 50, 60, 70 MeV, 2.5 GeV
- Target : thin W (50 mm × 50 mm × 0.2 mm)

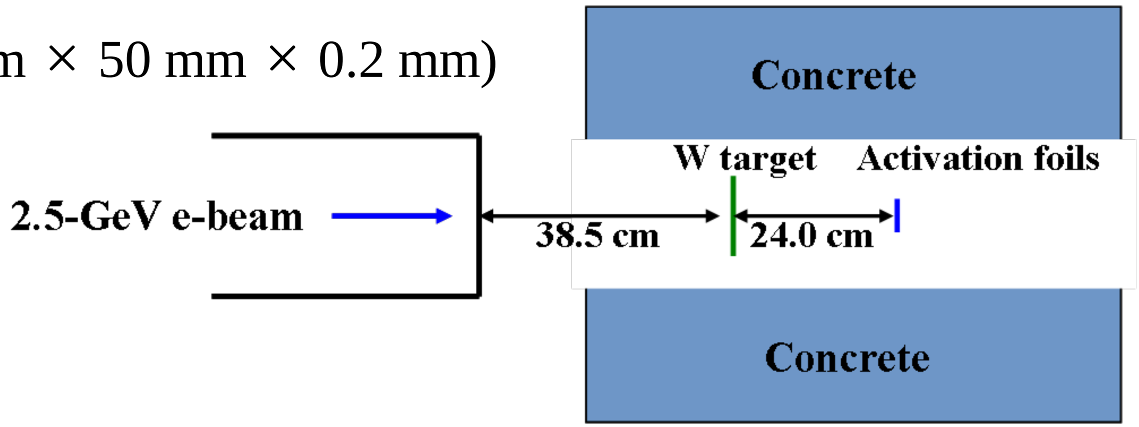






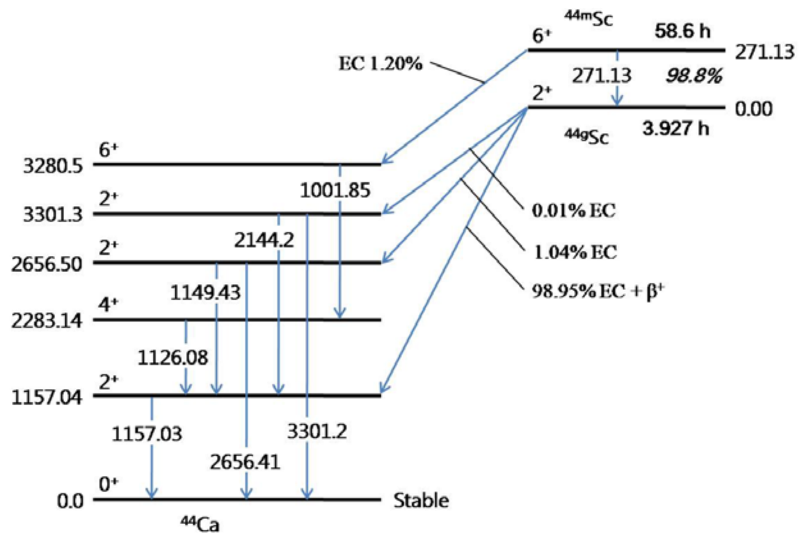
Experiment for $^{44m,g}Sc$ isomeric pairs

- Electron energy : 2.5 GeV
- Beam current : 2.19×10^{14} electron
- Repetition rate : 10 Hz
- Pulse width : 1.0 nsec
- Target : thin W (50 mm × 50 mm × 0.2 mm)



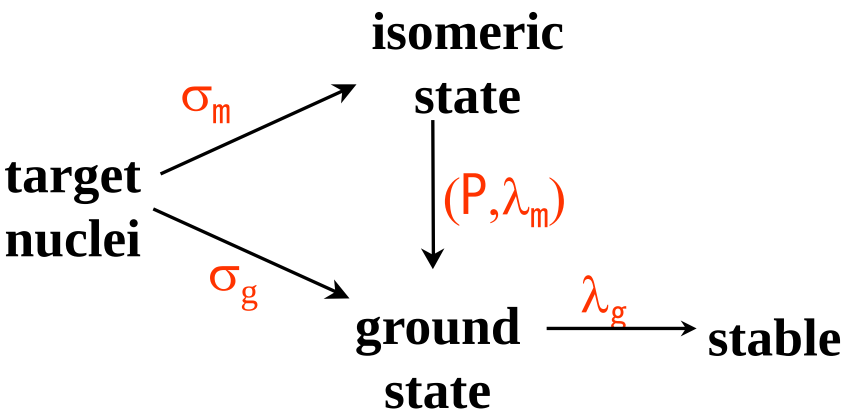
Sample	Purity (%)	Diameter (inch)	Thickness (inch)
Sc	99.81	0.5	0.005
Ti	99.63	0.5	0.004
Fe	99.559	0.5	0.005
Cu	99.96	0.5	0.004

Decay scheme and Nuclear reactions leading to ^{44m,g}Sc isomeric pairs



Nuclear reaction	Threshold energy (MeV)	Half-life, $T_{1/2}$	Main γ-ray energy, E_γ (keV)	γ-ray intensity, Iγ (%)
$^{45}Sc(\gamma,n)^{44g}Sc$ $^{45}Sc(\gamma,n)^{44m}Sc$	11.32 11.60	3.927 h 58.6 h	1157.03 271.13	99.9 86.7
$^{nat}Ti(\gamma,xn1p)^{44g}Sc$ $^{nat}Ti(\gamma,xn1p)^{44m}Sc$	41.18 41.45	3.927 h 58.6 h	1157.03 271.13	99.9 86.7
$^{nat}Fe(\gamma,xn5p)^{44g}Sc$ $^{nat}Fe(\gamma,xn5p)^{44m}Sc$	114.89 115.16	3.927 h 58.6 h	1157.03 271.13	99.9 86.7
$^{nat}Cu(\gamma,xn8p)^{44g}Sc$ $^{nat}Cu(\gamma,xn8p)^{44m}Sc$	180.63 180.90	3.927 h 58.6 h	1157.03 271.13	99.9 86.7

Methodology



$$\frac{dN_m}{dt} = Y_m - \lambda_m N_m$$

$$\frac{dN_g}{dt} = Y_g - \lambda_g N_g + P\lambda_m N_m$$

where: N_m, N_g are the numbers of nuclei for m, g state, λ_m and λ_g are the decay constants of these states, and P is the branching ratio for the decay of metastable to ground state. Y_m and Y_g are the reaction yields .

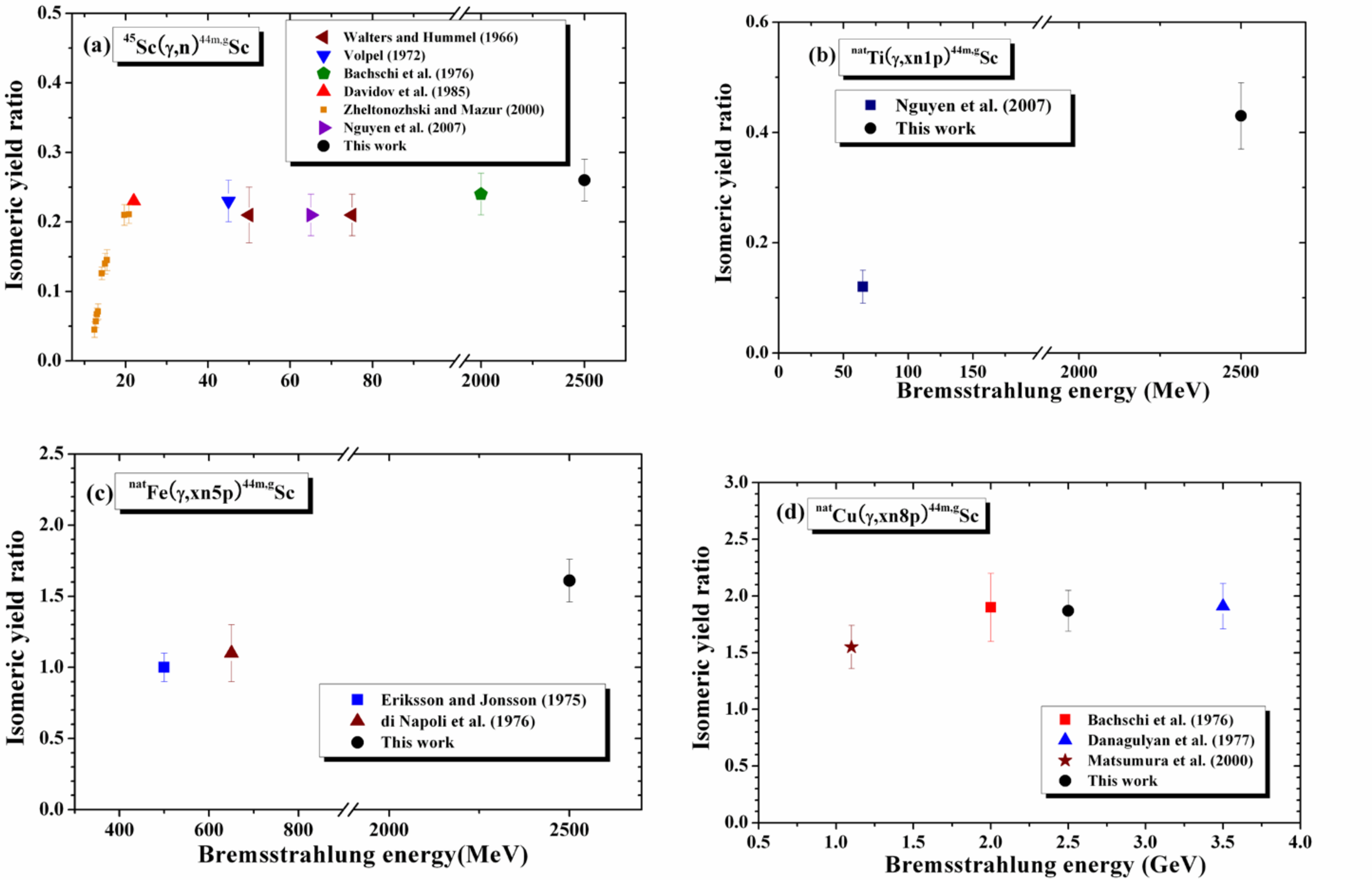
- Reaction Yield: $$Y = N_0 \phi \sigma = \frac{C\lambda(1-e^{-\lambda T})}{\varepsilon I_\gamma F(1-e^{-\lambda\tau})(1-e^{-\lambda t_i})e^{-\lambda t_d}(1-e^{-\lambda t_m})}$$

where: C is the net counts under the full-energy peak, N_o is the number of target nuclei, ε is the detector efficiency, I_γ is the intensity of the gamma-ray, λ is the decay constant, F is corection factor, t_i is the irradiation time, t_d is the waiting time, t_m is the measuring time, τ is the pulse width, and T is the cycle period.

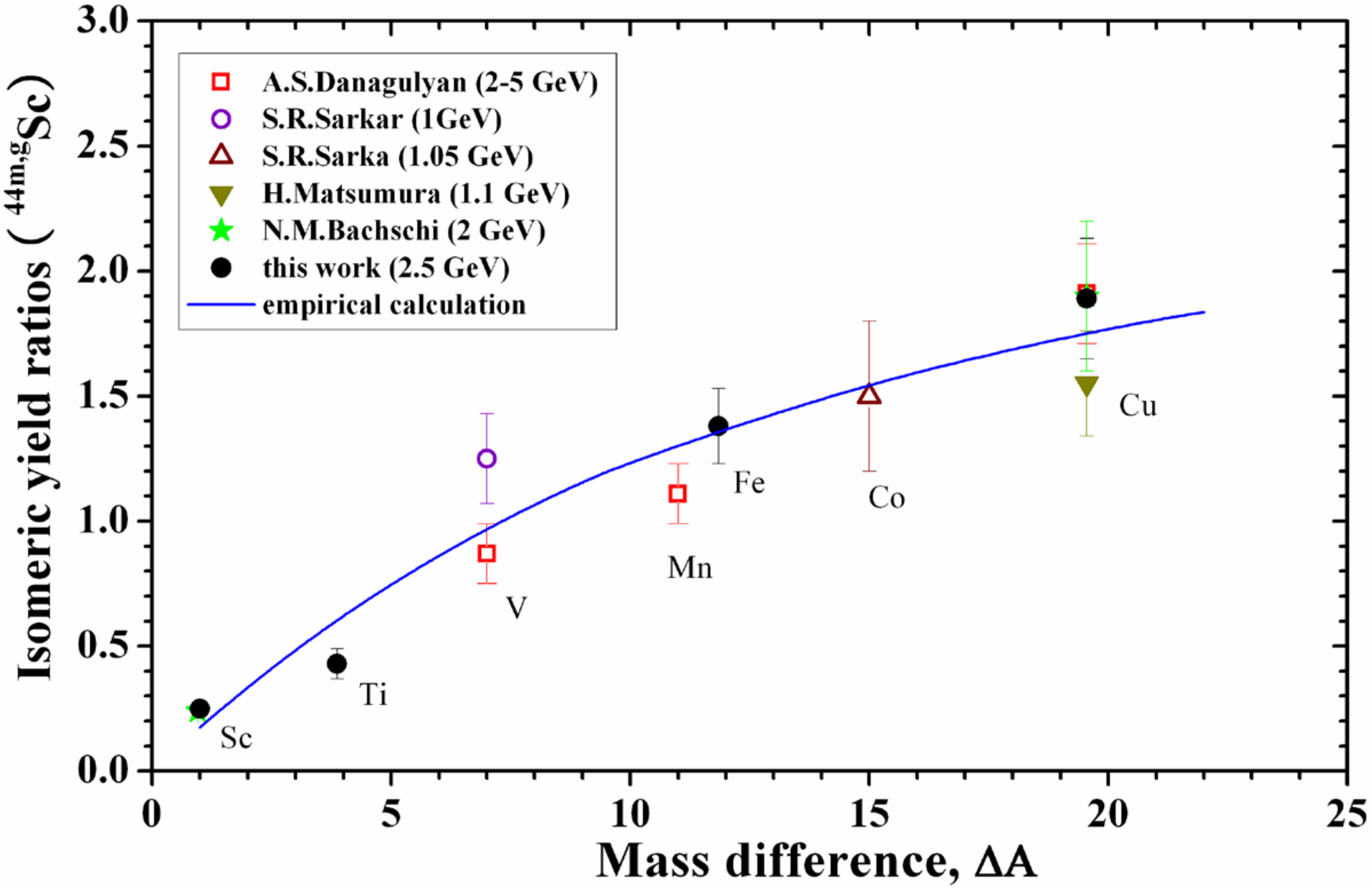
- Isomeric Ratio: $$IR = \frac{\sigma_m}{\sigma_g} = \left[\left(\frac{C_g}{C_m} \times \frac{\varepsilon_m I_{\gamma m}}{\varepsilon_g I_{\gamma g}} - \frac{P\lambda_g}{\lambda_g - \lambda_m}\right) \times \frac{A_m B_m C_m D_m}{A_g B_g C_g D_g} + \frac{P\lambda_m}{\lambda_g - \lambda_m}\right]^{-1}$$

where: $A_{m(g)} = \frac{1-e^{-\lambda_{m(g)}\tau}}{1-e^{-\lambda_{m(g)}T}} e^{-\lambda_{m(g)}(T-\tau)}$ $B_{m(g)} = \frac{1-e^{-\lambda_{m(g)}t_i}}{\lambda_{m(g)}}$ $C_{m(g)} = e^{-\lambda_{m(g)}t_w}$ $D_{m(g)} = 1-e^{-\lambda_{m(g)}t_c}$

The experimental isomeric yield ratios of $^{44m,g}Sc$ pairs



Isomeric yield ratios of $^{44m,g}Sc$ formed in different targets: Sc, Ti, V, Mn, Fe, Co and Cu with bremsstrahlung in the energy range 1-5 GeV as a function of mass difference, ΔA.



Results of Isomeric Yield Ratio Measurement

- **Isomeric yield ratios in the photoproduction of ^{52m,g}Mn from natural iron using 50-, 60-, 70-MeV, and 2.5-GeV bremsstrahlung**

  J Radioanal Nucl Chem (2010) 283:683–690

  Van Do Nguyen · Duc Khue Pham · Tien Thanh Kim · Md. Shakilur Rahman · Kyung-Sook Kim · Guinyun Kim · Hee-Seock Lee · Moo-Hyun Cho · In Soo Ko · Won Namkung · Tae-Ik Ro

- **Measurement of isomeric-yield ratios for the ^{197}Au(γ,n)^{196m,g}Au reactions induced by bremsstrahlung**

  J Radioanal Nucl Chem (2010) 283:519–525

  Md. Shakilur Rahman · Kyung-Sook Kim · Manwoo Lee · Guinyun Kim · Youngdo Oh · Hee-Seock Lee · Moo-Hyun Cho · In Soo Ko · Won Namkung · Van Do Nguyen · Duc Khue Pham · Tien Thanh Kim · Tae-Ik Ro

- **Measurement of isomeric yield ratios for ^{93}Nb(γ,4n)^{89m,g}Nb and ^{nat}Mo(γ,xn1p)^{95m,g}Nb reactions with 50-, 60-, and 70-MeV bremsstrahlung**

  J Radioanal Nucl Chem (2011) 287:869–877

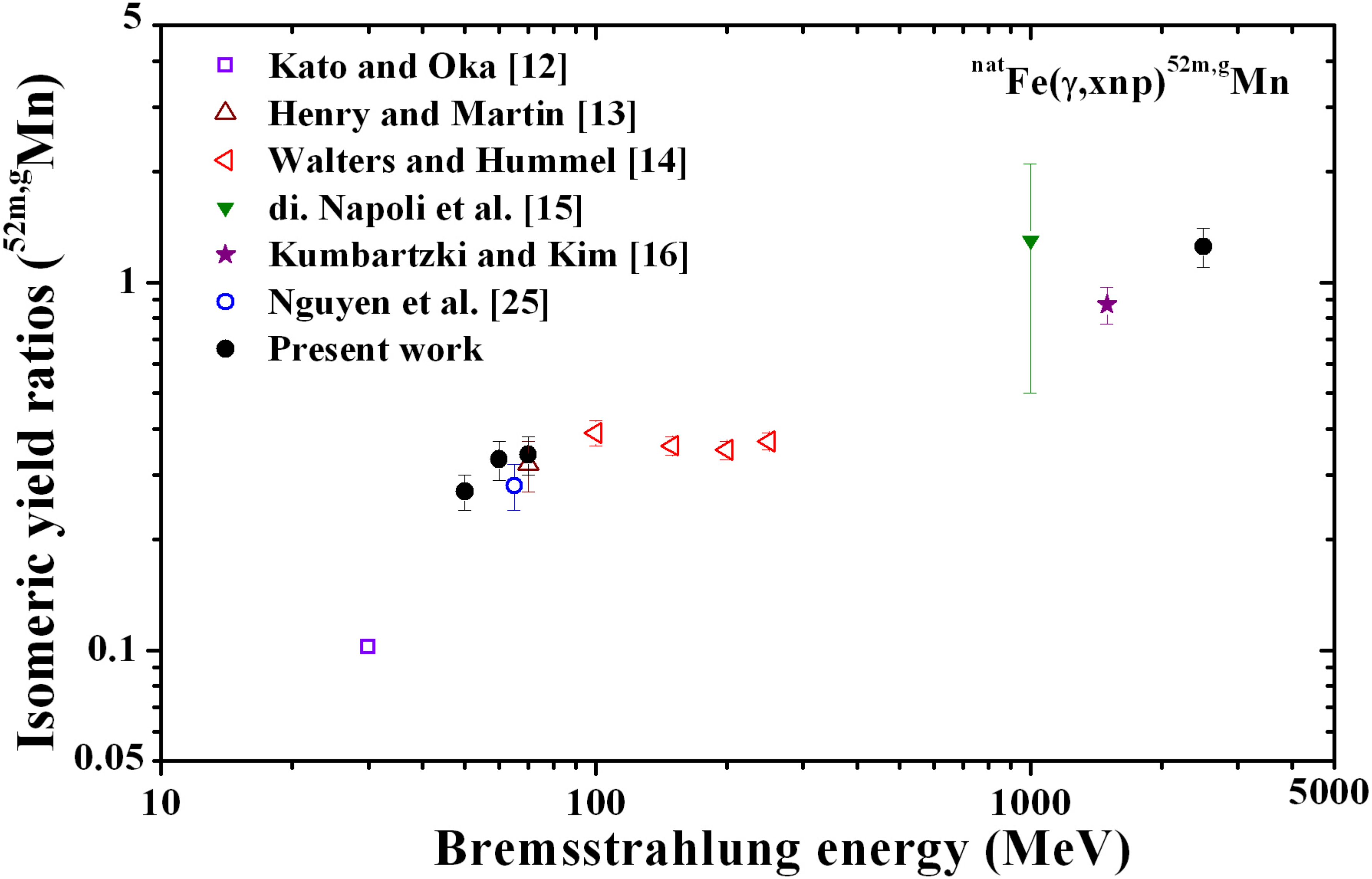
  Kyung Sook Kim · MD. Shakilur Rahman · Manwoo Lee · Guinyun Kim · Pham Duc Khue · Nguyen Van Do · Moo-Hyun Cho · In Soo Ko · Won Namkung · H. Naik · Tae-Ik Ro

- Measurement of isomeric yield ratios in ^{nat}In and ^{nat}Sn with 50, 60, and 70 MeV bremsstrahlung photons

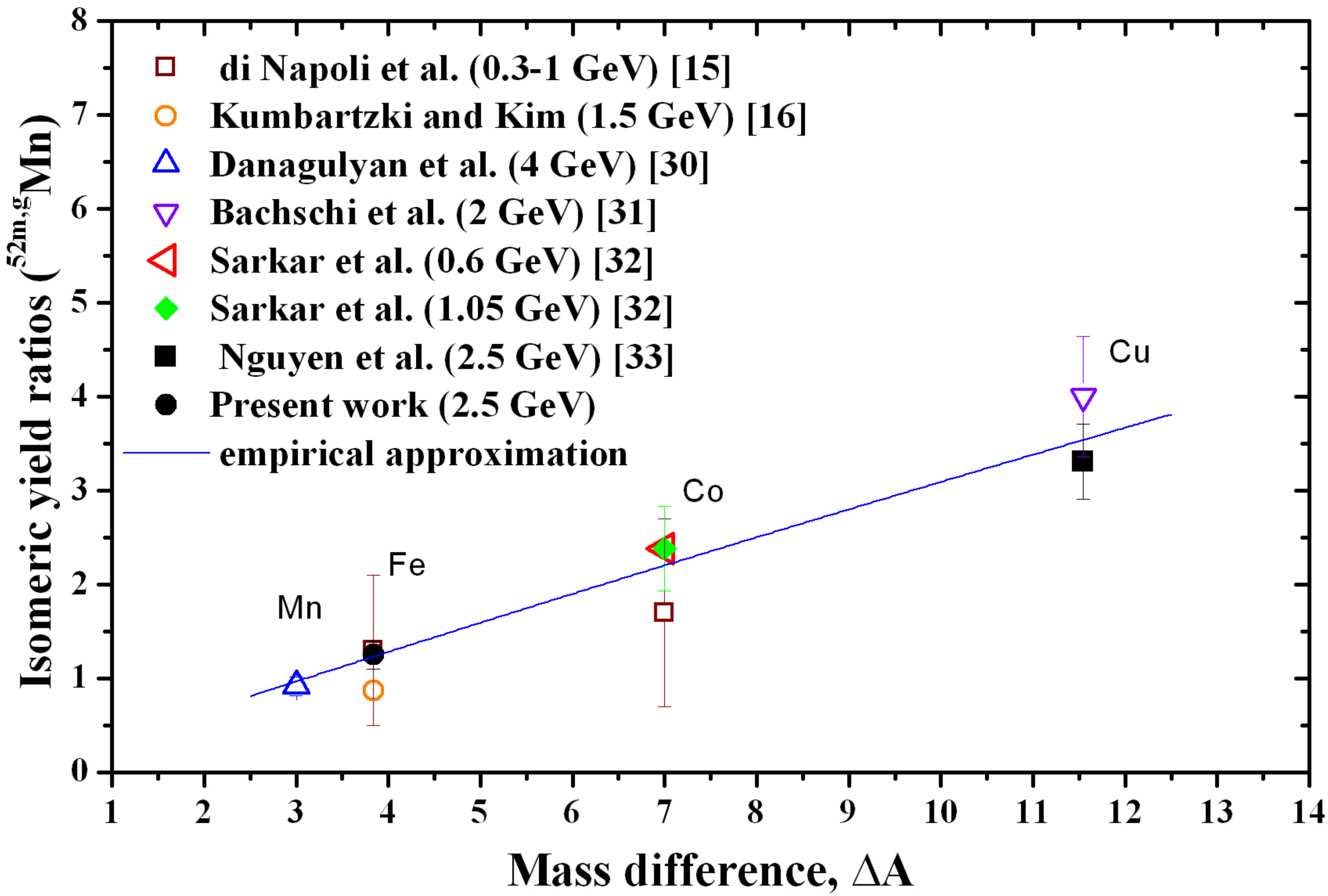
  Nuclear Instruments and Methods in Physics Research B 268 (2010) 13–19

  Md. Shakilur Rahman [a], Kyung-Sook Kim [a], Manwoo Lee [a], Guinyun Kim [a,*], Youngdo Oh [b], Hee-Seock Lee [b], Moo-Hyun Cho [b], In Soo Ko [b], Won Namkung [b], Nguyen Van Do [c], Pham Duc Khue [c], Kim Tien Thanh [c], Tae-Ik Ro [d]

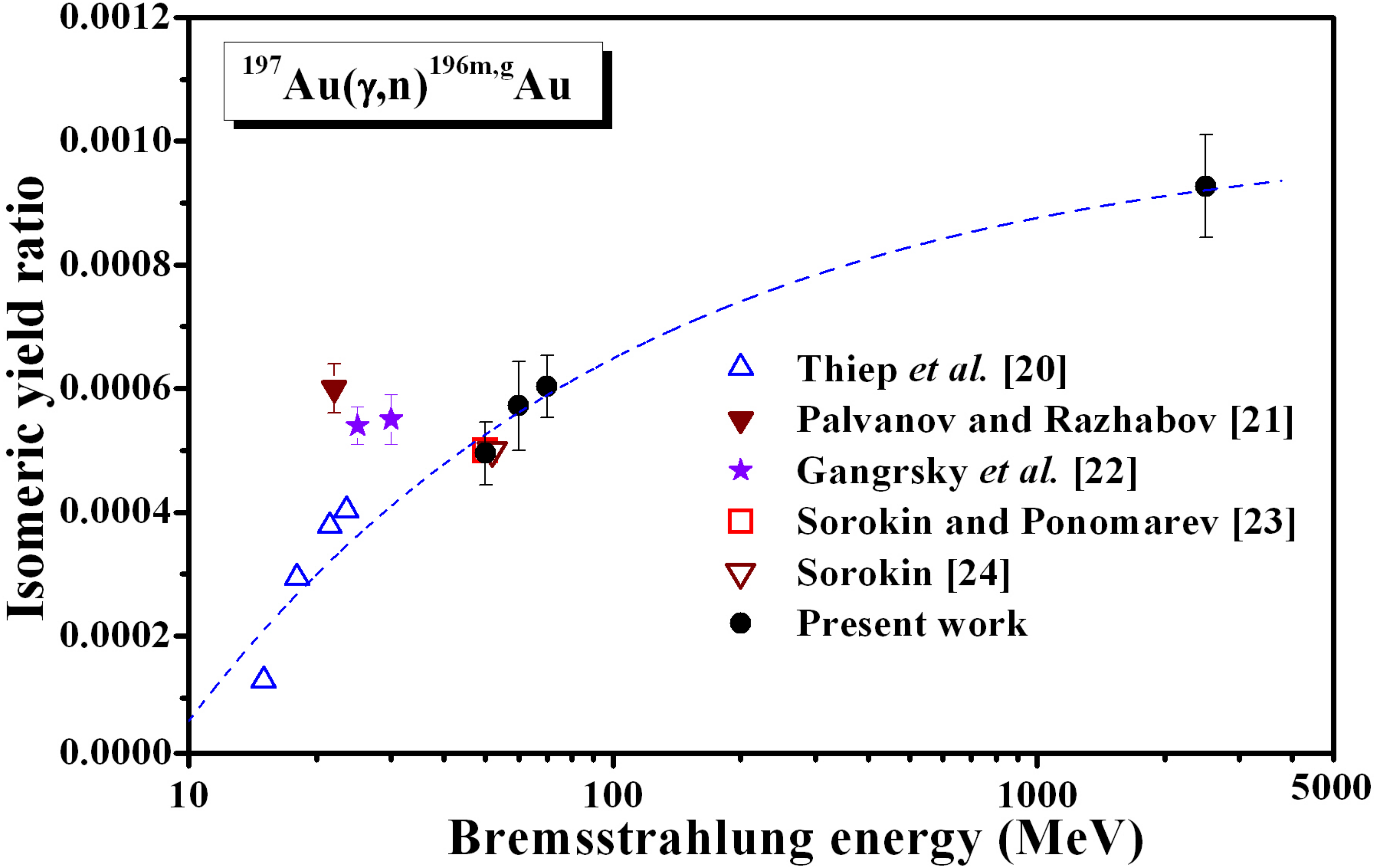
Isomeric yield ratios in the photoproduction of ^{52m,g}Mn from natural iron using 50-, 60-, 70-MeV, and 2.5-GeV bremsstrahlung



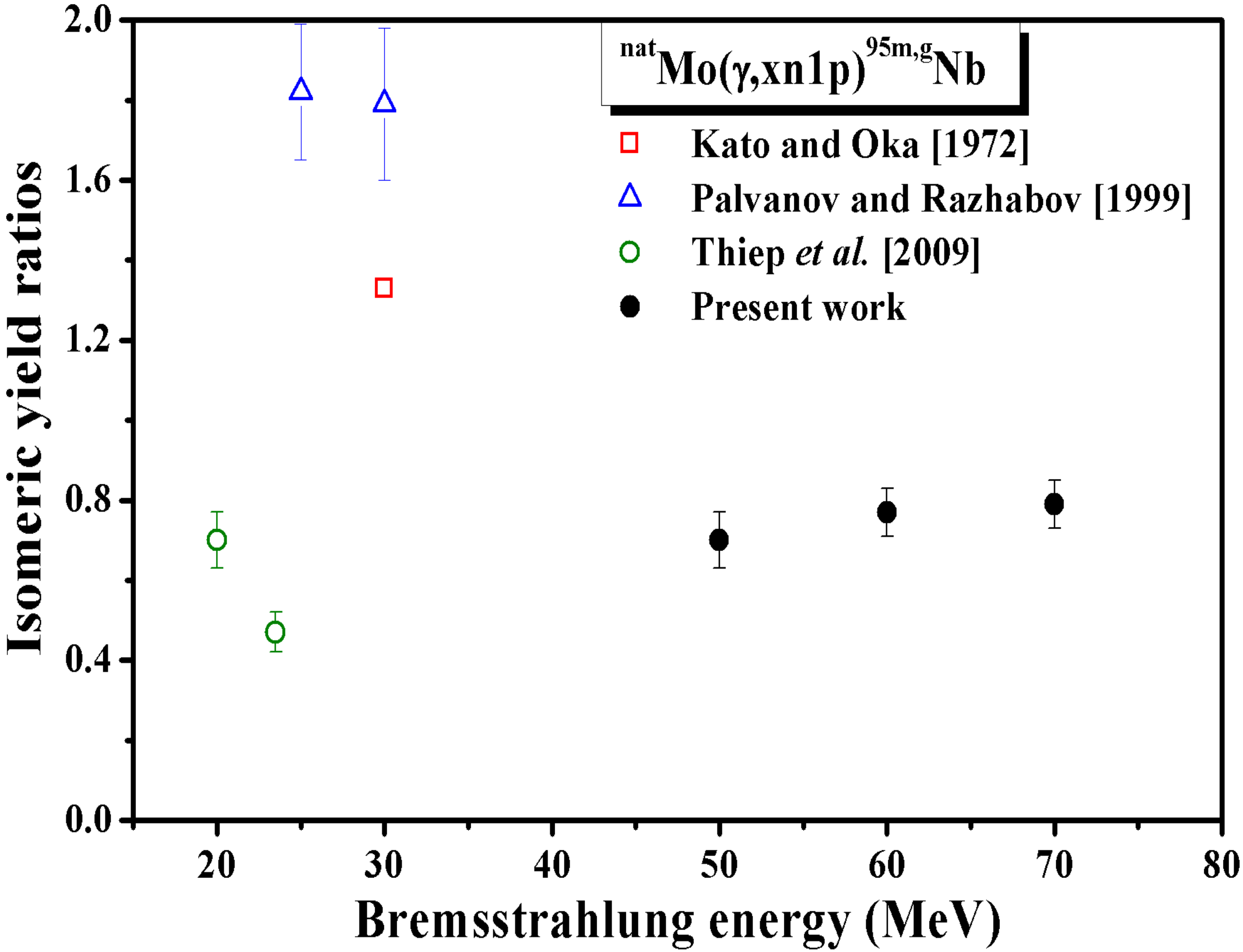
Isomeric yield ratios of ^{52m,g}Mn formed in different targets: Mn, Fe, Co and Cu with bremsstrahlung in the energy range 1-5 GeV as a function of mass difference, ΔA.



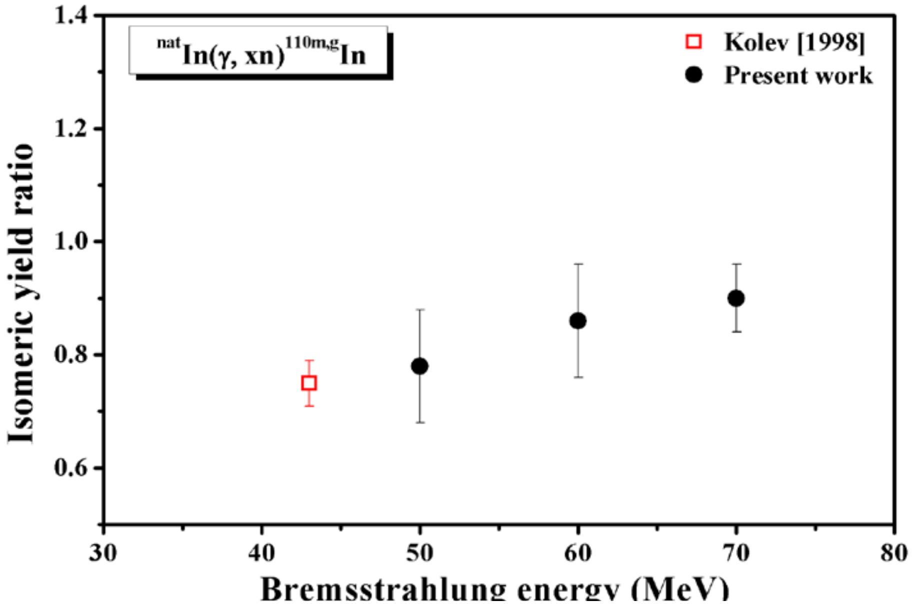
Measurement of isomeric-yield ratios for the $^{197}Au(\gamma,n)^{196m,g}Au$ reactions induced by bremsstrahlung

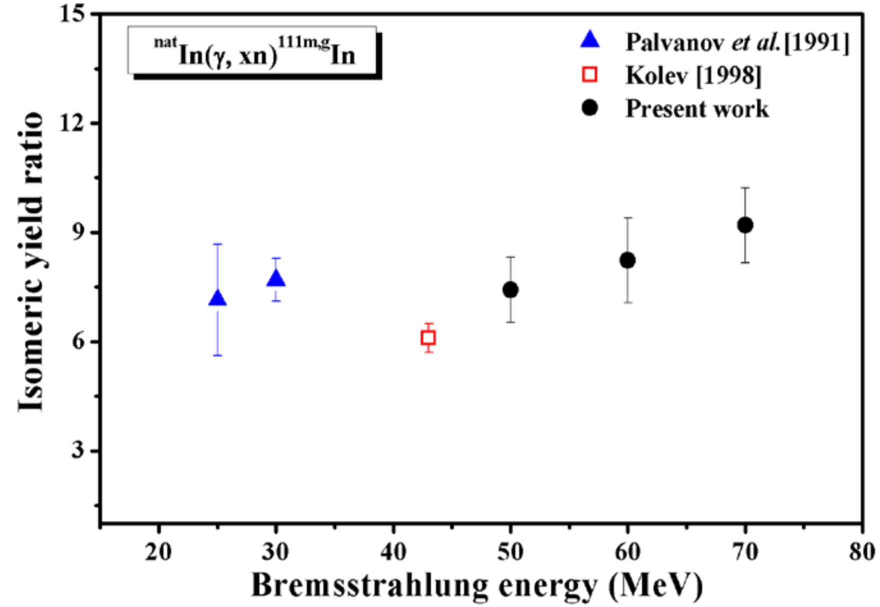


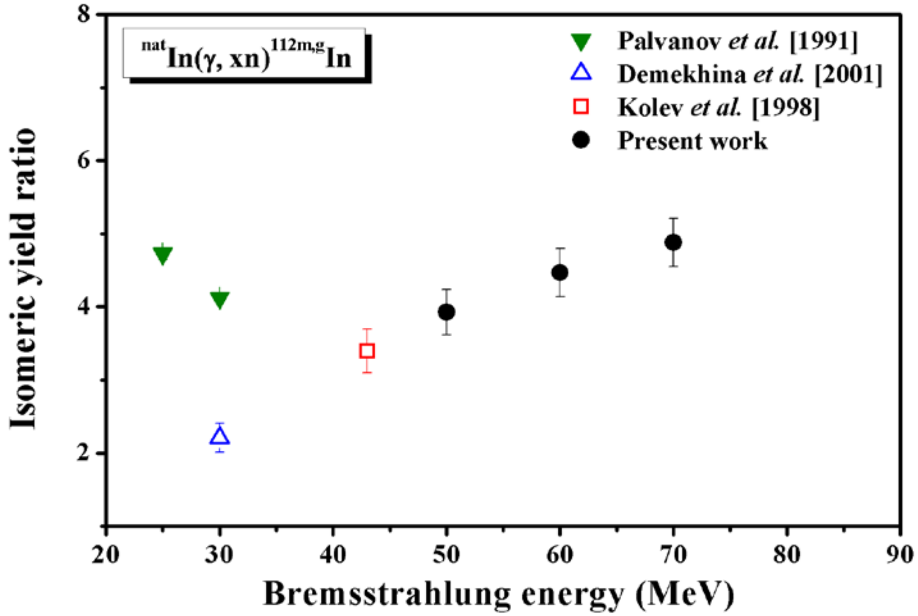
Measurement of isomeric yield ratios for ^{93}Nb(γ,4n)^{89m,g}Nb and ^{nat}Mo(γ,xn1p)^{95m,g}Nb reactions with 50-, 60-, and 70-MeV bremsstrahlung

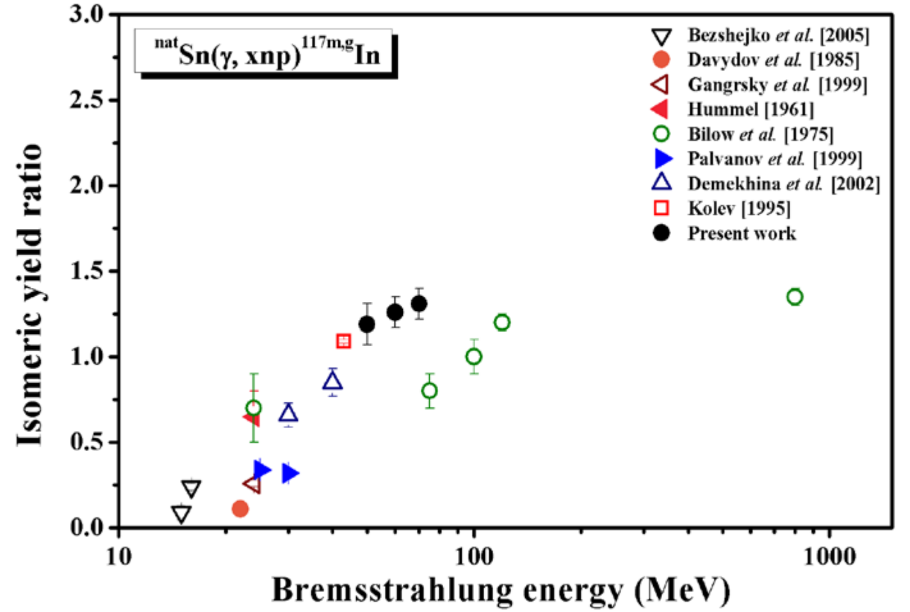


Measurements of isomeric yield ratios in ^{nat}In and ^{nat}Sn with 50-, 60-, and 70-MeV bremsstrahlung photons









2. Photo-fission Reaction

Mass–yield distributions of fission products from photo-fission of ^{nat}Pb induced by 50–70 MeV bremsstrahlung

J Radioanal Nucl Chem (2010) 283:439–445

Haladhara Naik · Guinyun Kim · Ashok Goswami · Sarbjit Singh · Vijay Kumar Manchanda · Devesh Raj · Srinivasan Ganesan · Young Do Oh · Hee-Seock Lee · Kyung Sook Kim · Man-Woo Lee · Moo-Hyun Cho · In Soo Ko · Won Namkung

Mass-yield distribution of fission products from photo-fission of ^{nat}Pb induced by 2.5 GeV bremsstrahlung

Eur. Phys. J. A 47 (2011) 37

Haladhara Naik[1], Sarbjit Singh[1], Ashok Goswami[1], Vijay Kumar Manchanda[1], S.V. Suryanarayana[2], Devesh Raj[3], Srinivasan Ganesan[3], Md. Shakilur Rahman[4], Kyung Sook Kim[4], Man Woo Lee[4], Guinyun Kim[4,a], Moo-Hyun Cho[5], In Soo Ko[5], and Won Namkung[5]

Product yields for the photo-fission of ^{209}Bi with 2.5 GeV bremsstrahlung

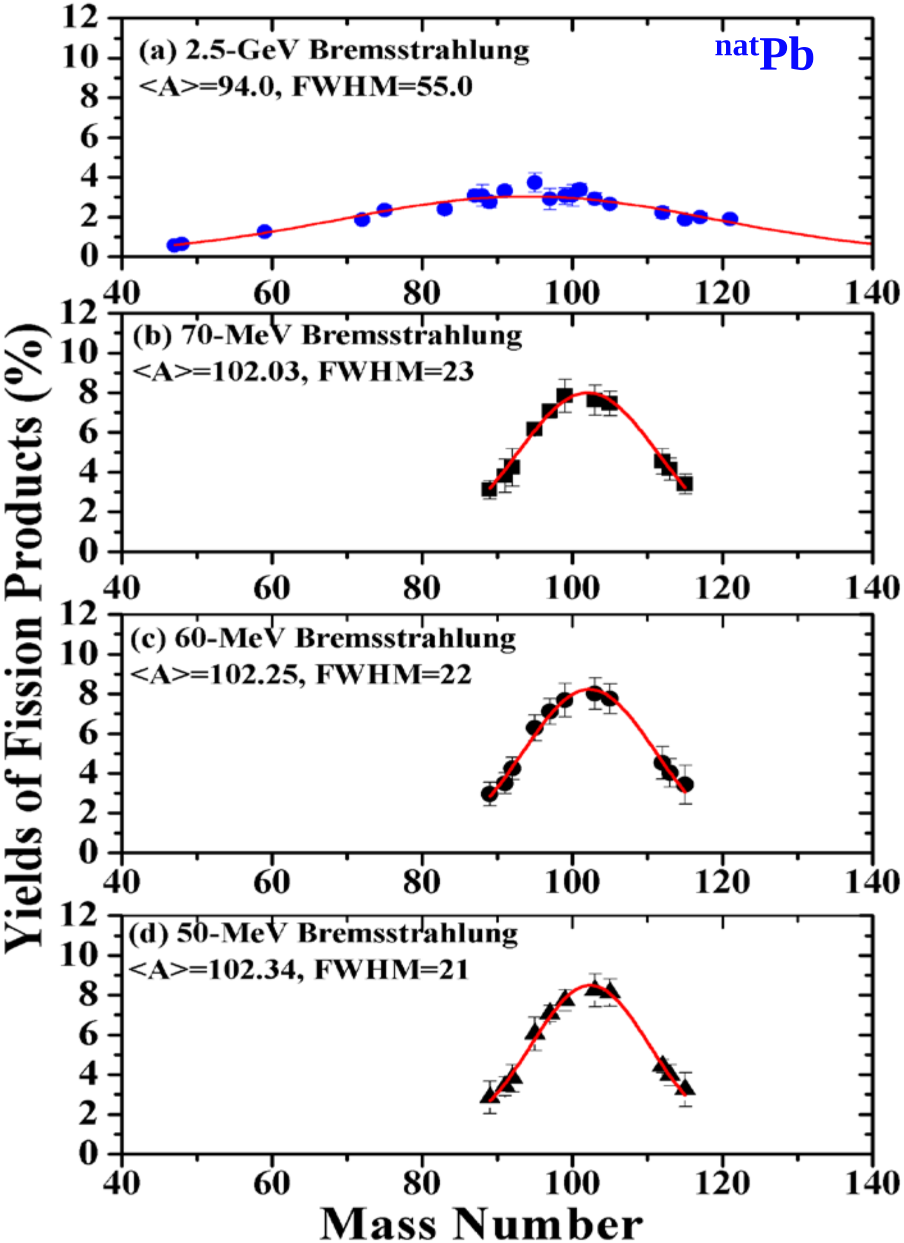
Nucl. Instr. Meth. B 267 (2009) 1891-1898

Haladhara Naik[a], Sarbjit Singh[a], Annareddy Venkat Raman Reddy[a], Vijay Kumar Manchanda[a], Guinyun Kim[b,*], Kyung Sook Kim[b], Man-Woo Lee[b], Srinivasan Ganesan[c], Devesh Raj[c], Hee-Seock Lee[d], Young Do Oh[d], Moo-Hyun Cho[d], In Soo Ko[d], Won Namkung[d]

Measurement of photo-neutron cross-sections in ^{208}Pb and ^{209}Bi with 50-70 MeV bremsstrahlung

Nucl. Instr. Meth. B 269 (2011) 1417-1424

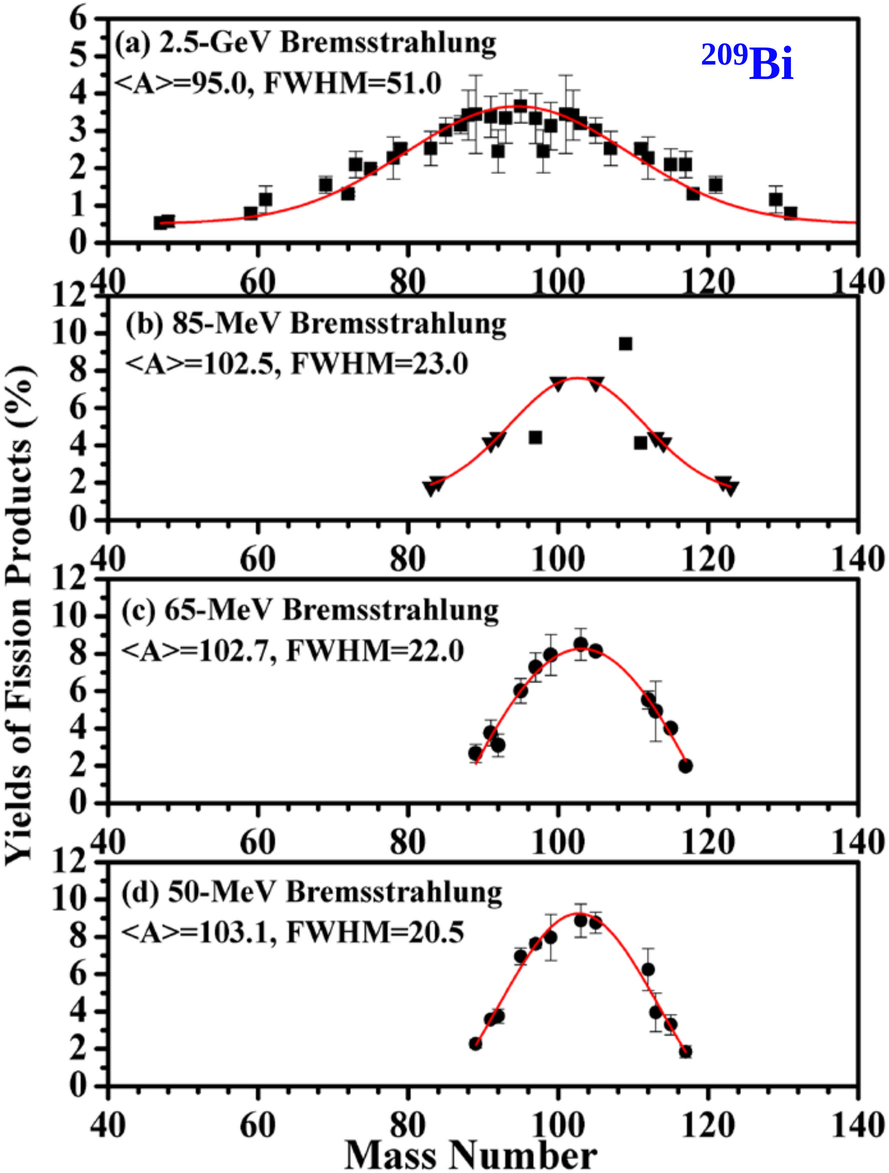
Mass-yield distributions of fission products from photo-fission of ^{nat}Pb by 50-70 MeV and 2.5-GeV bremsstrahlung

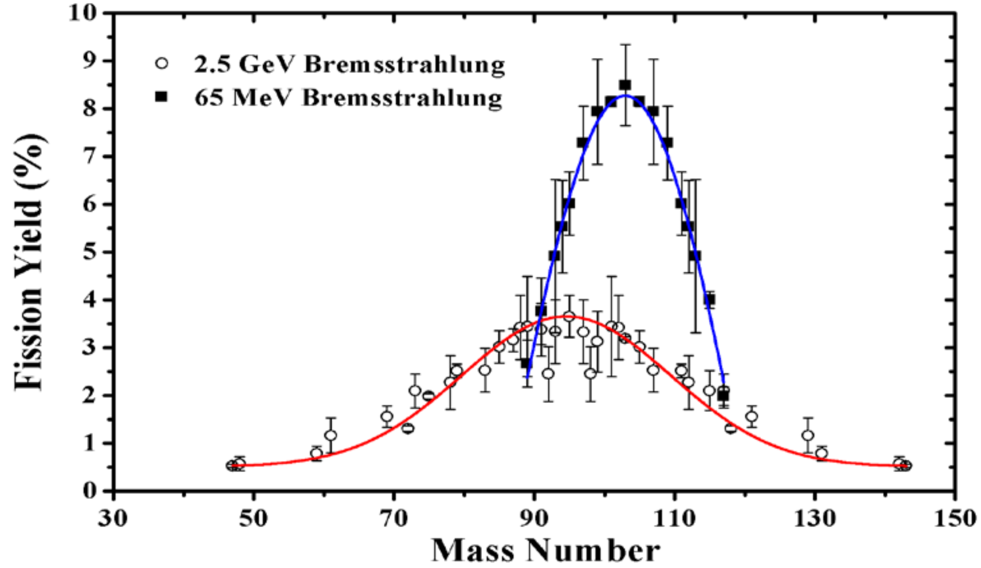


Measured yields of fission products (%) from (a) 2.5-GeV (b)70-MeV, (c) 60-MeV, and (d) 50-MeV bremsstrahlung induced fission of ^{nat}Pb as a function of mass number. The line indicated the fitting for measured data points.

Nuclei	Energy (MeV)	Mean mass (mass units)	FWHM (mass units)
^{nat}Pb	50	102.34	21
	60	102.25	22
	70	102.03	23
	2500	94.0±0.5	55.0±2.0

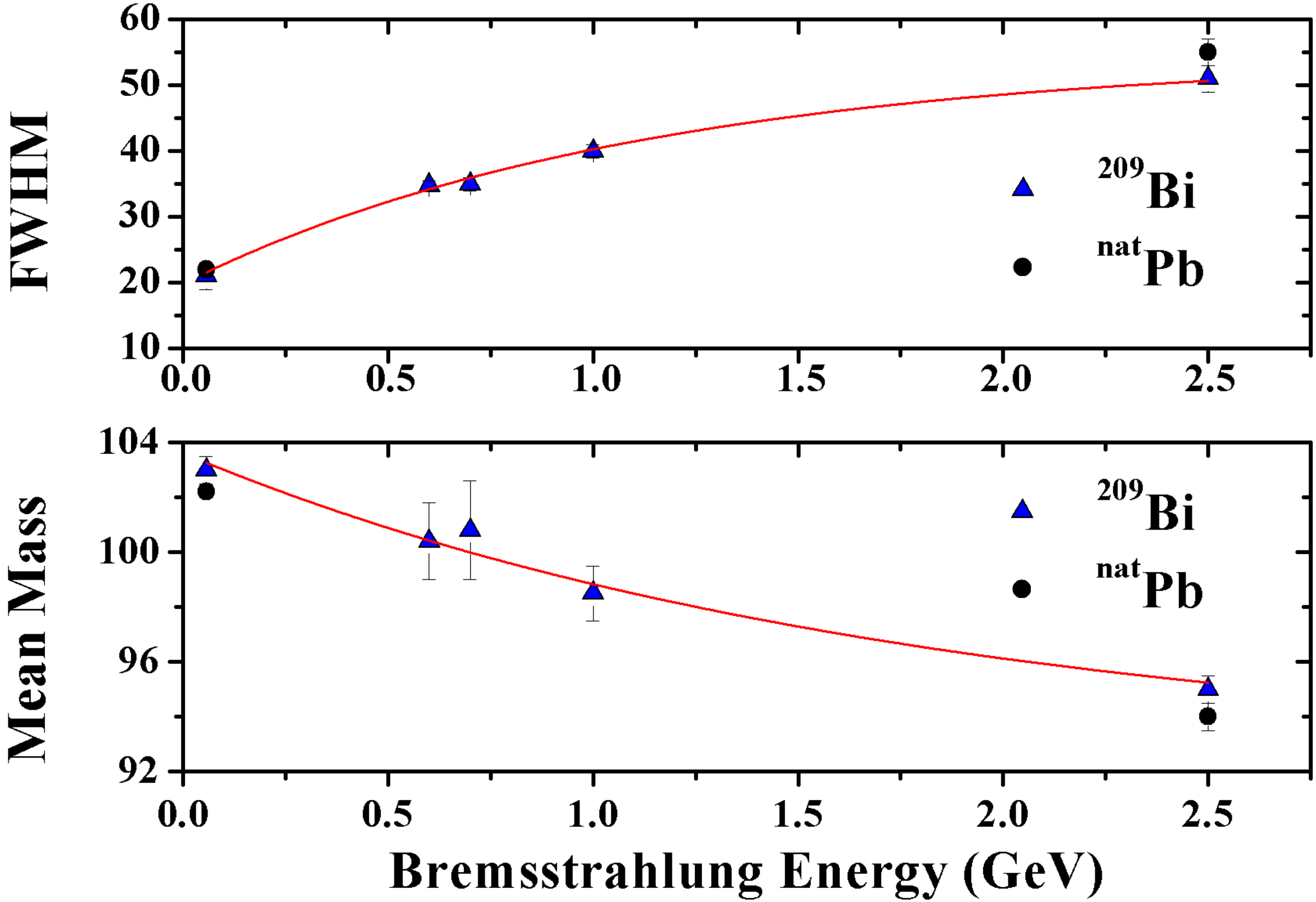
Mass-yield distributions of fission products from photo-fission of ^{209}Bi induced by 50-70 MeV and 2.5-GeV bremsstrahlung





Fissioning nuclei	Energy (MeV)	Mean mass (mass units)	FWHM (mass units)
^{209}Bi	28-40	103.5	19.0
	50	103.1	20.5
	65	102.7	22.0
	85	102.5	23.0
	600	100.4 ± 1.4	34.8 ± 0.7
	700	100.8 ± 1.8	35.0 ± 1.0
	1000	98.5 ± 1.0	40.0 ± 1.0
	2500	95.0 ± 0.5	51.0 ± 2.0

The FWHM and the mean mass of the mass-yield distributions for the photo-fission of ^{nat}Pb and ^{209}Bi



Nuclear Instruments and Methods in Physics Research B 267 (2009) 1891–1898

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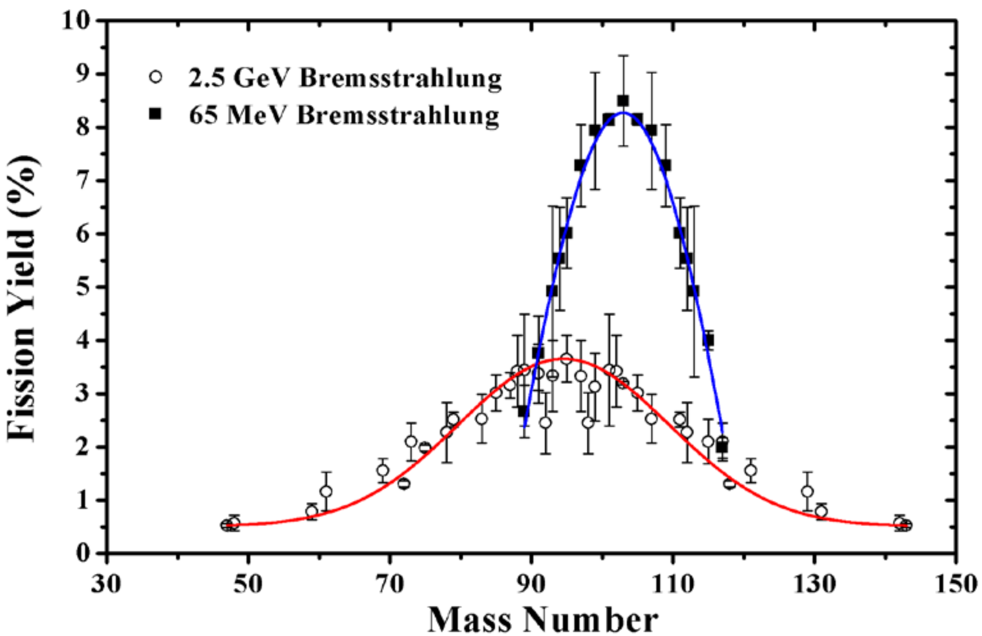
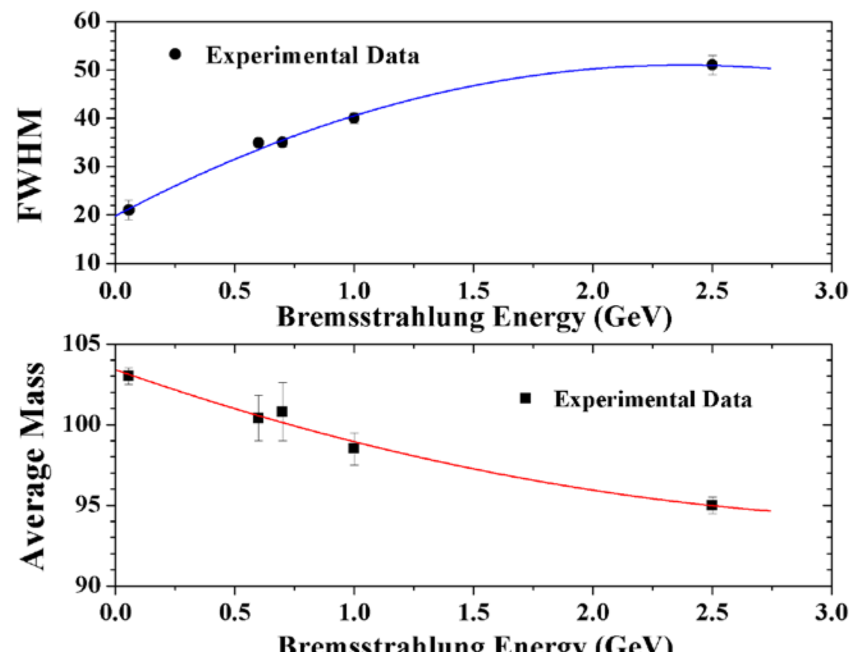
journal homepage: www.elsevier.com/locate/nimb

Product yields for the photo-fission of ^{209}Bi with 2.5 GeV bremsstrahlung

Haladhara Naik[a], Sarbjit Singh[a], Annareddy Venkat Raman Reddy[a], Vijay Kumar Manchanda[a], Guinyun Kim[b,*], Kyung Sook Kim[b], Man-Woo Lee[b], Srinivasan Ganesan[c], Devesh Raj[c], Hee-Seock Lee[d], Young Do Oh[d], Moo-Hyun Cho[d], In Soo Ko[d], Won Namkung[d]

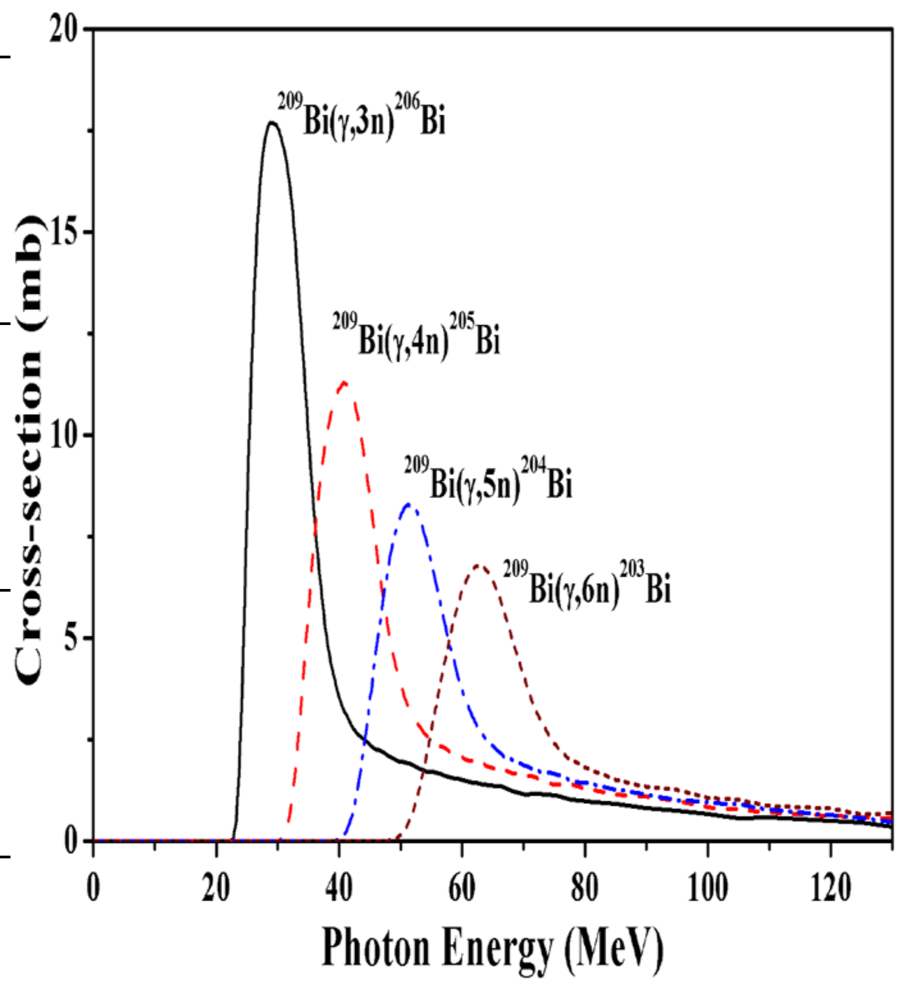
[a] Radiochemistry Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India
[b] Department of Physics, Kyungpook National University, Deagu 702-701, Republic of Korea
[c] Reactor Physics Design Division, BARC, Trombay, Mumbai 400085, India
[d] Pohang Accelerator Laboratory, Pohang University of Science and Technology, Pohang 790-784, Republic of Korea





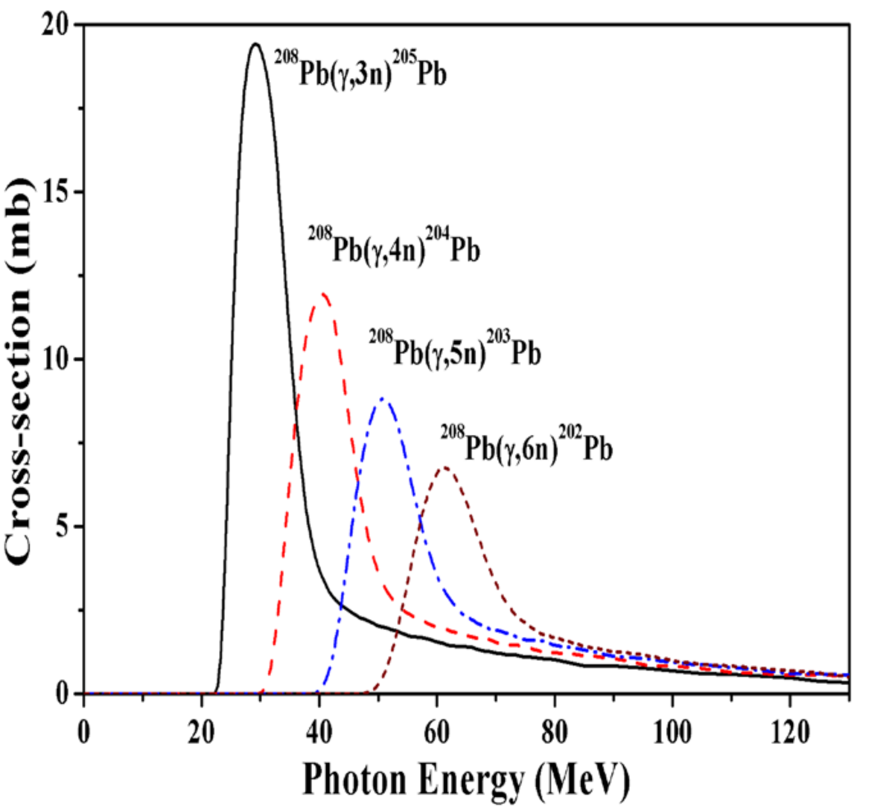
The flux-weighted average photo-neutron cross-sections for the (γ,xn) reactions of ^{209}Bi with the end point bremsstrahlung energies of 50-70 MeV.

Photo-neutron reaction [E_{th} (MeV)]	Bremsstrahlung energy (MeV)	Photo-neutron cross-section (mb)	
		Experimental	Theoretical
$^{209}Bi(\gamma,6n)^{203}Bi$ [45.15]	50	-	0.00007
	55	-	0.00515
	60	0.023±0.004	0.02728
	65	0.057±0.008	0.06717
	70	0.105±0.022	0.10168
$^{209}Bi(\gamma,5n)^{204}Bi$ [37.95]	50	0.058±0.006	0.04178
	55	0.101±0.022	0.10685
	60	0.149±0.015	0.15030
	65	0.163±0.023	0.17704
	70	0.171±0.019	0.19544
$^{209}Bi(\gamma,4n)^{205}Bi$ [29.48]	50	0.315±0.054	0.26137
	55	0.374±0.035	0.31195
	60	0.389±0.051	0.33912
	65	0.403±0.056	0.36246
	70	0.420±0.055	0.37013
$^{209}Bi(\gamma,3n)^{206}Bi$ [22.45]	50	0.652±0.04	0.65195
	55	0.673±0.065	0.66765
	60	0.701±0.048	0.69432
	65	0.783±0.077	0.71608
	70	0.819±0.088	0.73721



The flux-weighted average photo-neutron cross-sections for the (γ,xn) reactions of ^{208}Pb with the end point bremsstrahlung energies of 50-70 MeV.

Photo-neutron reaction [E_{th} (MeV)]	Bremsstrahlung energy (MeV)	Photo-neutron cross-section (mb)	
		Experimental	Theoretical
^{208}Pb(γ,6n)^{202}Pb	50	-	0.00016
	55	-	0.00720
	60	-	0.03321
	65	-	0.07439
	70	0.106±0.023	0.10565
^{208}Pb(γ,5n)^{203}Pb	50	0.055±0.010	0.05062
	55	-	0.12092
	60	0.145±0.025	0.16461
	65	-	0.19070
	70	0.187±0.024	0.20909
^{208}Pb(γ,4n)^{204}Pb	50	0.285±0.045	0.27754
	55	-	0.32694
	60	0.344±0.025	0.35398
	65	-	0.37747
	70	0.373±0.016	0.38433
^{208}Pb(γ,3n)^{205}Pb	50	-	0.71497
	55	-	0.73127
	60	-	0.75038
	65	-	0.78272
	70	-	0.80521



Charged Particle Induced Reaction Cross-section Measurements using the Stacked-foil Activation Method

Instruments and/or available facilities

- Machine: MC-50 cyclotron

  -- Proton and alpha: 45 MeV

  -- Deuteron: 25 MeV

- Detector: n-type coaxial ORTEC (PopTop, Gmx20)

  HPGe detector

  Crystal size: 55.1 mm by 52.2 mm.

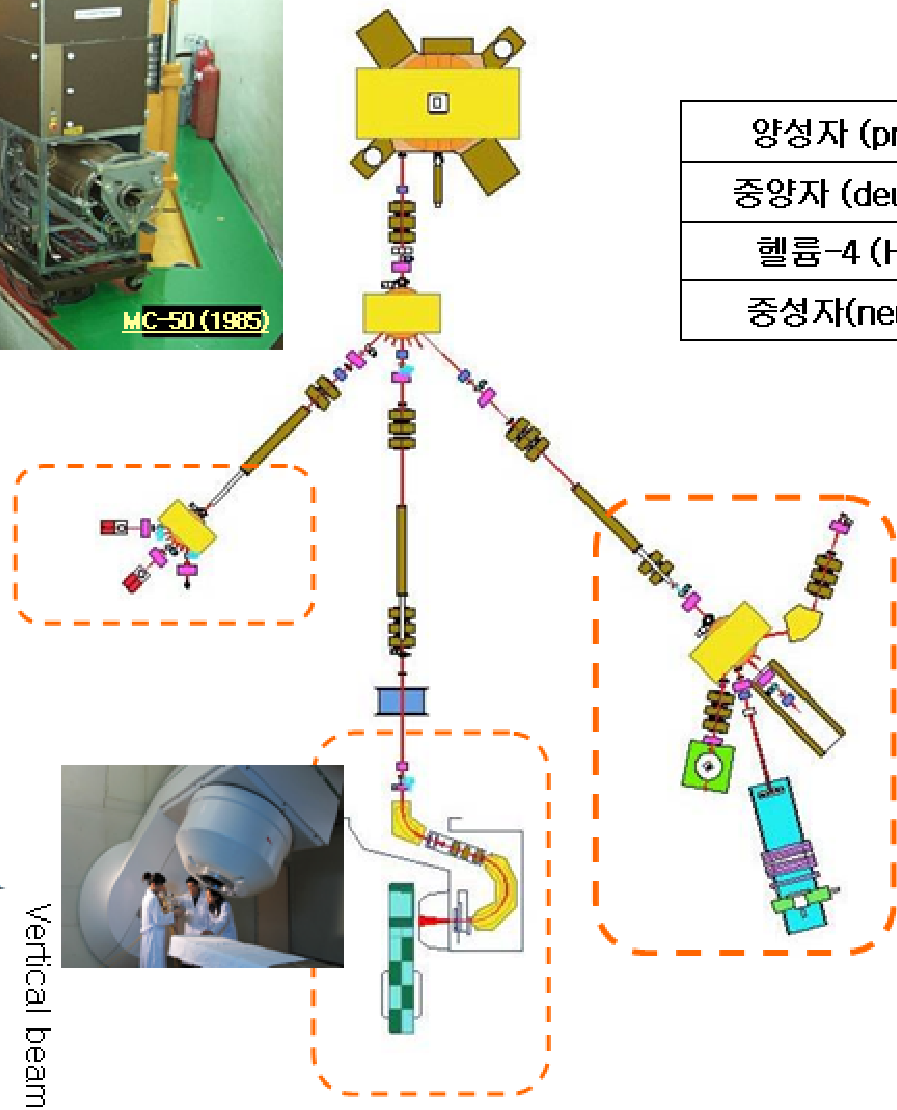
  Resolution: 1.90 keV at the 1332.50 keV peak of ^{60}Co.

- Data acquisition program:

  Gamma Vision 5.0 (EG&G Ortec)

MC-50 Cyclotron at KIRAMS

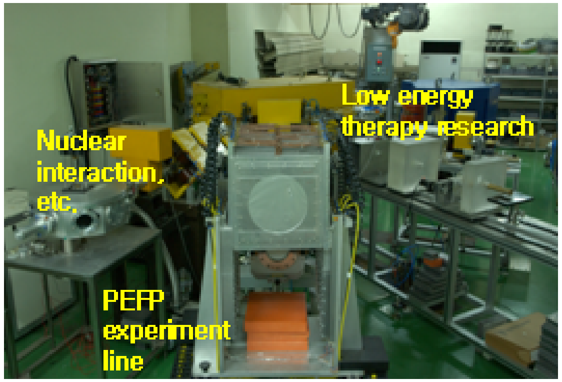
MC-50 cyclotron

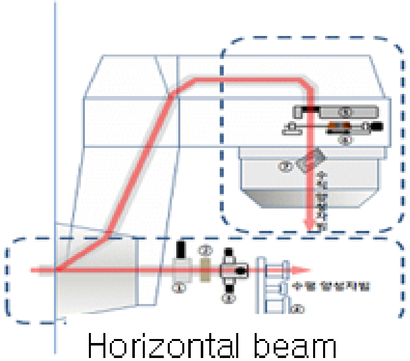


양성자 (proton)	20~51 MeV / 40 uA
중양자 (deuteron)	10~25 MeV / 30 uA
헬륨-4 (He-4)	20~50 MeV / 1 uA
중성자(neutron)	$E_{n,max} < E_{proton} - 2MeV$

RI target irradiation

Low intensity irradiation



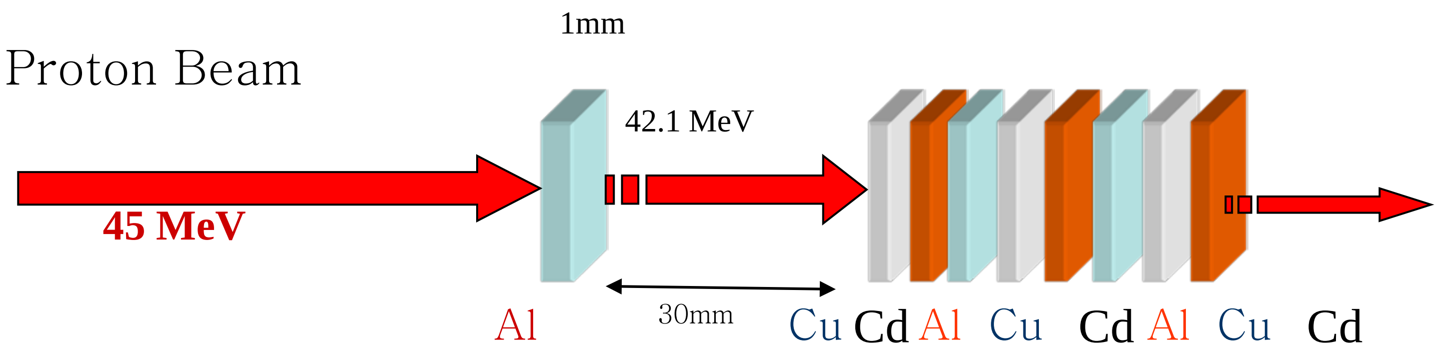


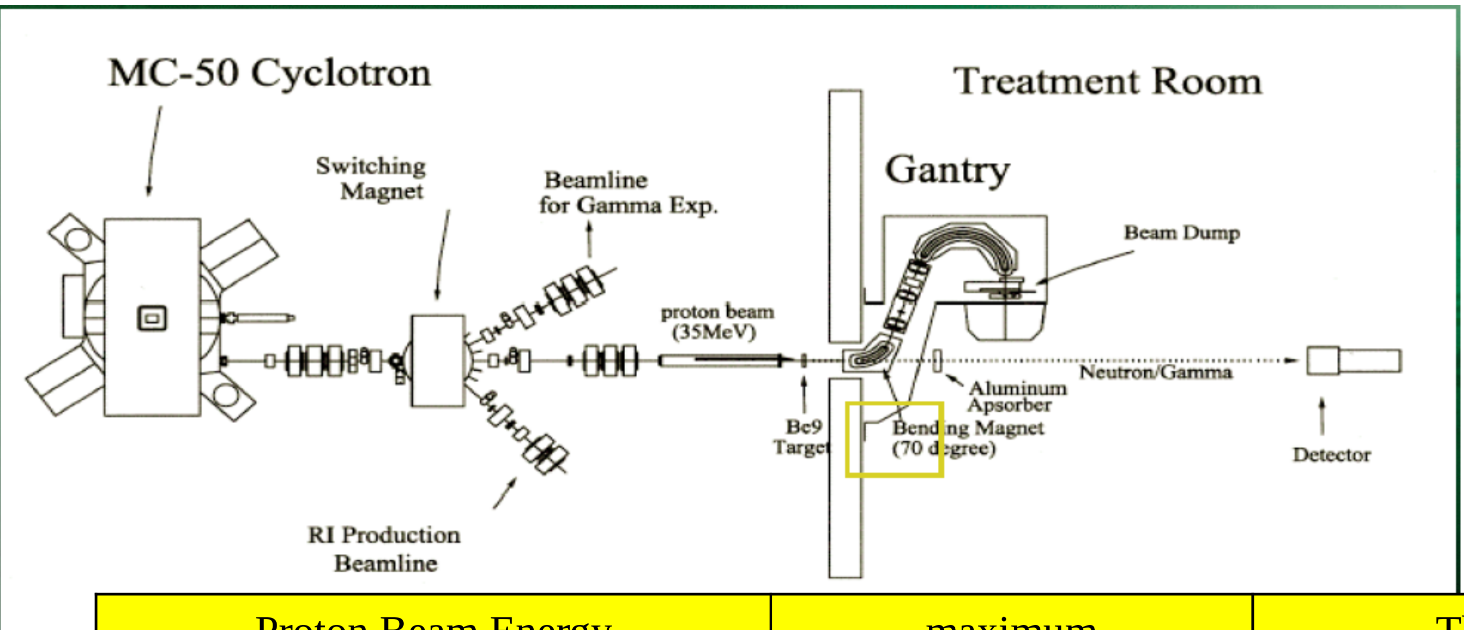
Vertical beam

Horizontal beam

Neutron and High Intensity Irradiation

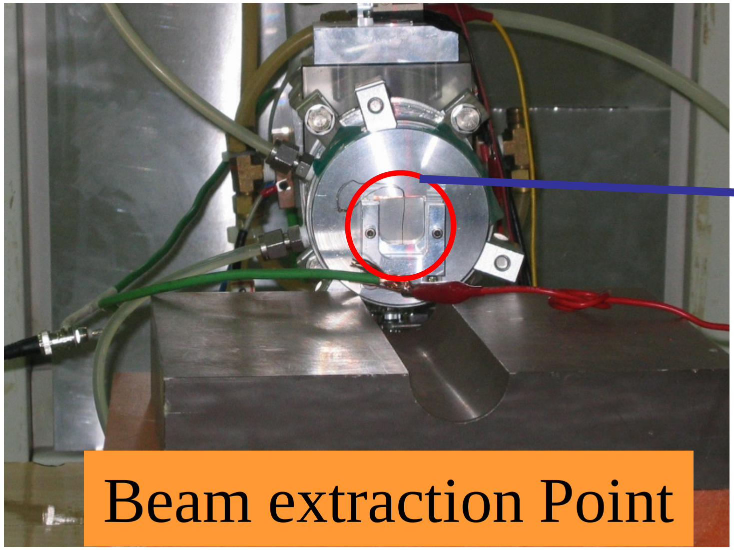
Experimental Set up at MC-50 facility



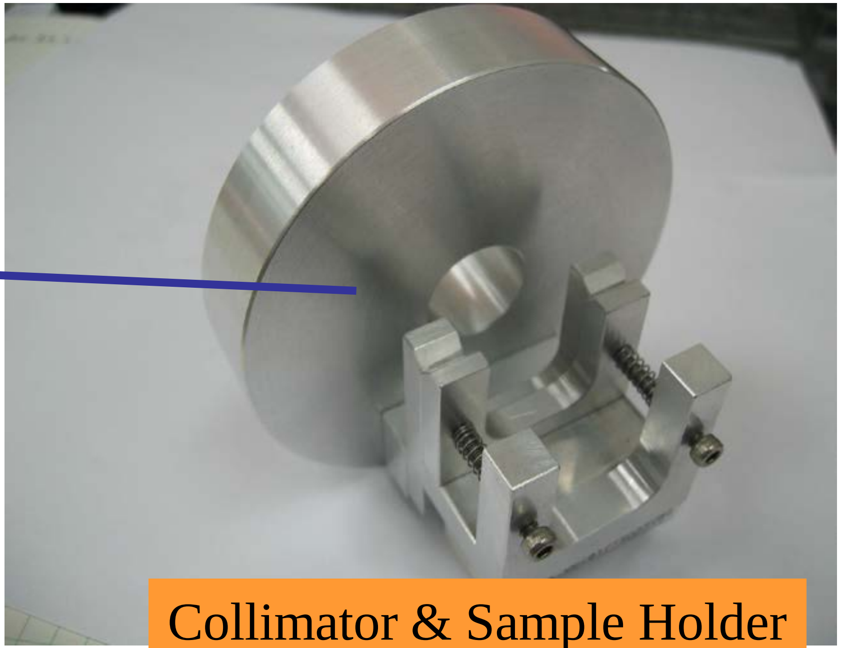


Proton Beam Energy	maximum	This work
	50 MeV	45 MeV
Current	60μA	100 nA

Sample Holder and Samples

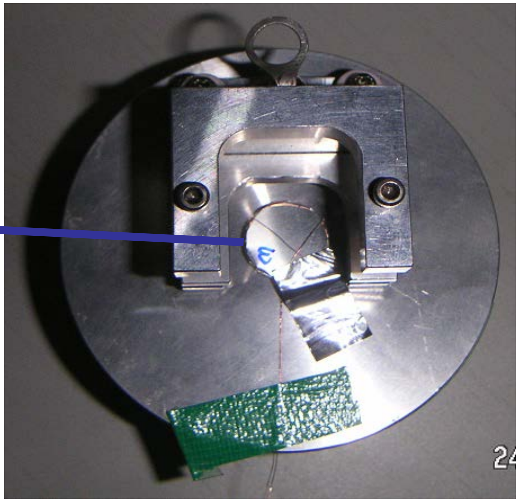


Beam extraction Point

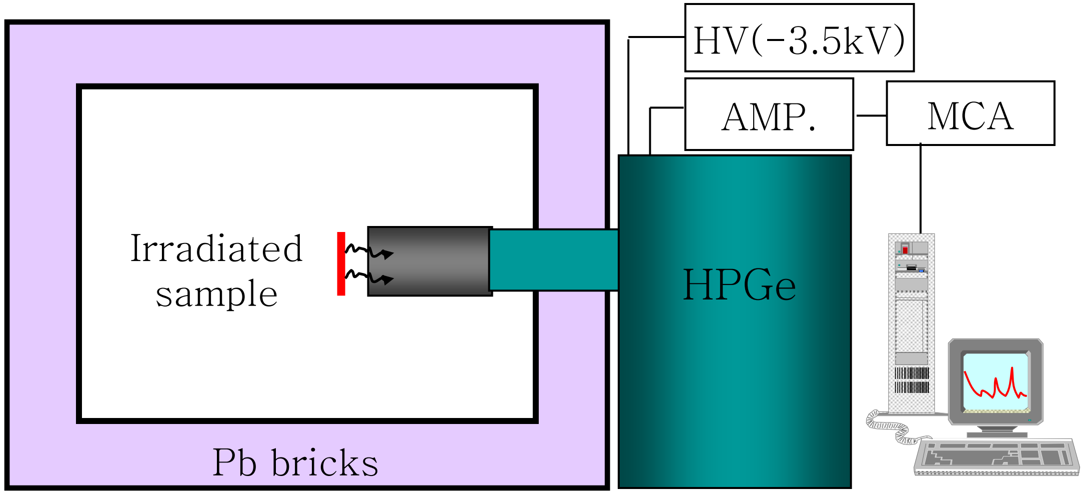


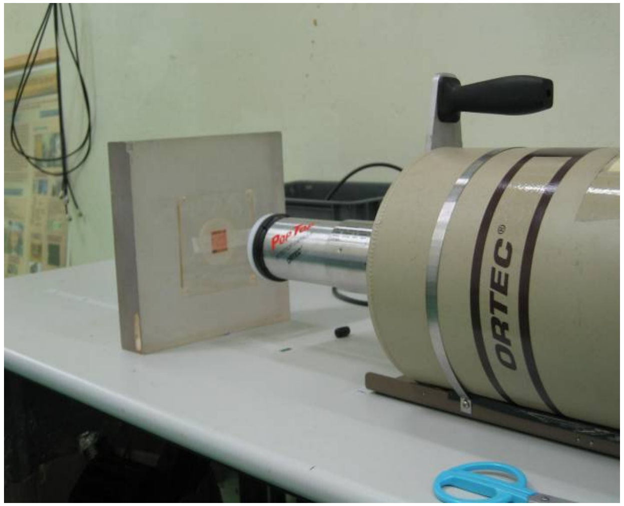
Collimator & Sample Holder

Targets & Monitor samples



The gamma-ray spectrometry



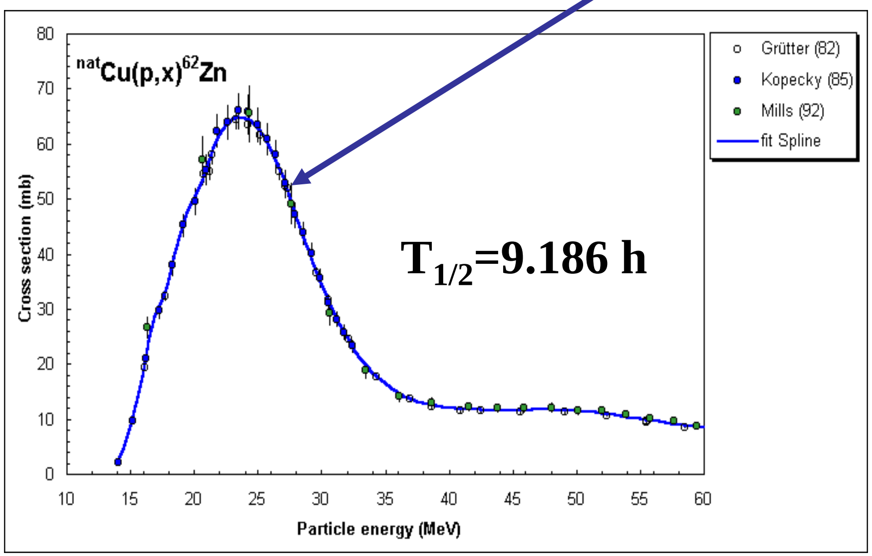


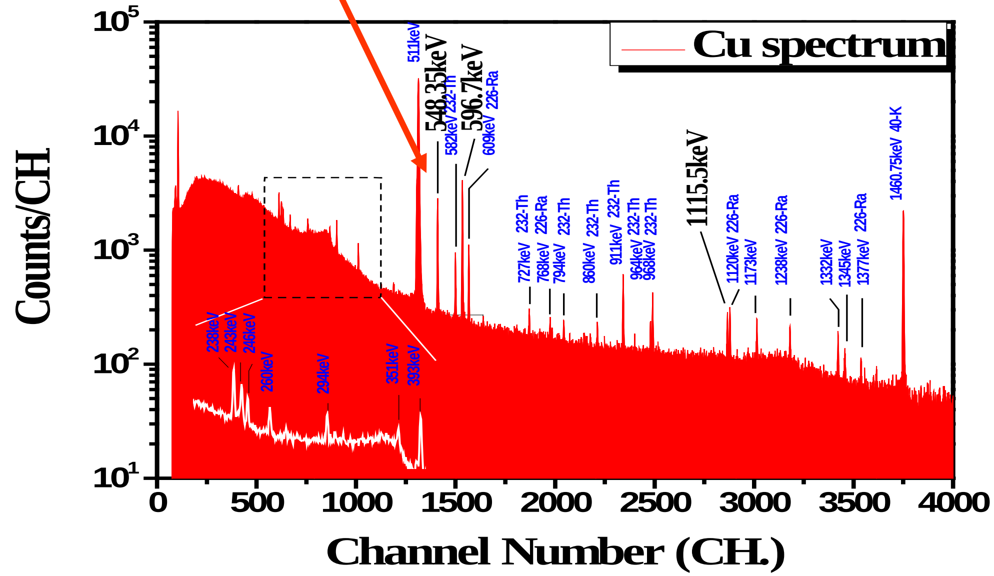
Publications for Measured Data

Projectile (MeV)	Target	Investigated radionuclides	Publication
Proton (35 MeV)	^{nat}Mo	^{99m}Tc, $^{96m,g}Tc$, ^{95m}Tc,^{95g}Tc	***J. Korean Phys. Soc.***, 48 (2006) 821
Proton (35 MeV)	^{nat}Mo	^{94m}Tc, ^{94g}Tc, ^{93m}Tc,^{93g}Tc	***J. Korean Phys. Soc.***, 50 (2007) 1518
Proton (45 MeV)	^{nat}Zn	$^{66,67}Ga$, $^{62,65,69m}Zn$, ^{61}Cu	***NIM B*** 258 (2007) 313
Proton (45 MeV)	^{nat}Mo	$^{99m,96g,96m,95m,95g,94m,94g,93m,93g}Tc$, $^{99,93m}Mo$, $^{96,95g,90}Nb$, ^{89g}Zr	***NIM B*** 262 (2007) 171
Proton (45 MeV)	^{nat}Zr	$^{90,92m,95g,96}Nb$,$^{88,89}Zr$, $^{86,87m,87mg,88}Y$	***NIM B*** 266 (2008) 13
Proton (45 MeV)	^{nat}W	$^{181,182m,182g,183,184g,186}Re$	***NIM B*** 266 (2008) 1021
Proton (45 MeV)	^{nat}Cd	$^{107,111m,115g}Cd$, $^{108m,108g,109g,110m,110,111g,113m,114m,115m,116m}In$, $^{104g,105g,106m,110m,111g,113g}Ag$	***NIM B*** 266 (2008) 4877
Proton (45 MeV)	^{nat}Ag	$^{104g,105,106m}Ag$, $^{104,107}Cd$	***NIM B*** 266 (2008) 5101
Proton (45 MeV)	^{nat}Sn	$^{124,122,120m,118m,117}Sb$, $^{117m,113}Sn$, $^{114m,111,110}In$	***NIM B*** 267 (2009) 23
Proton (45 MeV)	^{nat}Zr	$^{86g,87m,87g}Y$, $^{88,89g}Zr$, $^{90,92m}Nb$	***ARI*** 67 (2009) 1341
Proton (45 MeV)	^{nat}Ti	^{48}V, $^{43,44m,44g,46,47,48}Sc$	***ARI*** 67 (2009) 1348
Proton (45 MeV)	^{nat}Pd	$^{105g+m,106m}Ag$, $^{100,101}Pd$, $^{100g+m,101m,105g+m}Rh$	***NIM B*** 268 (2010) 2303
Proton (45 MeV)	^{nat}Ni	$^{55,56,57,58m+g}Co$, $^{56,57}Ni$	***NIM B*** 269 (2011) 1140

Determination of beam flux

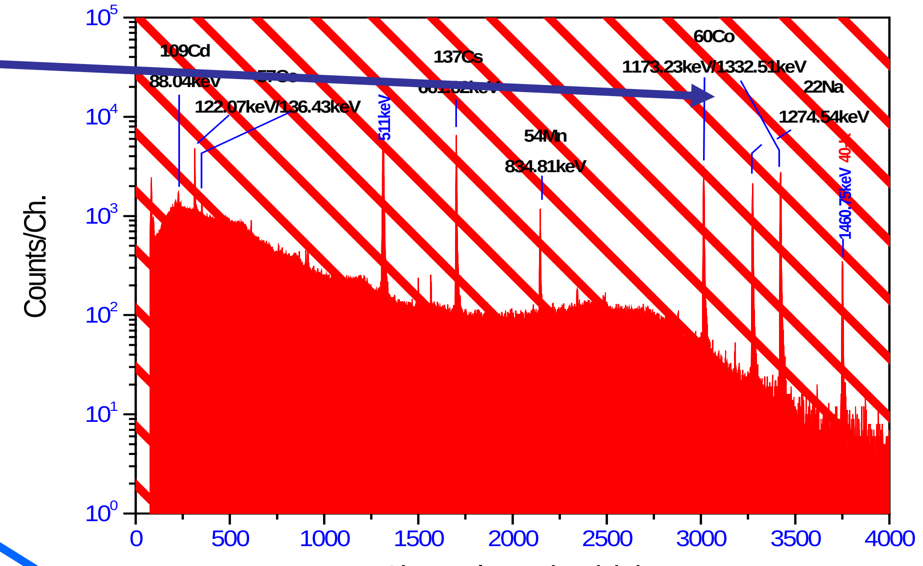
$$\phi = \frac{\lambda C}{\varepsilon \times I_\gamma \times N_d \times t \times \sigma (1-e^{-\lambda t_m}) e^{-\lambda t_c} (1-e^{-\lambda t_i})}$$

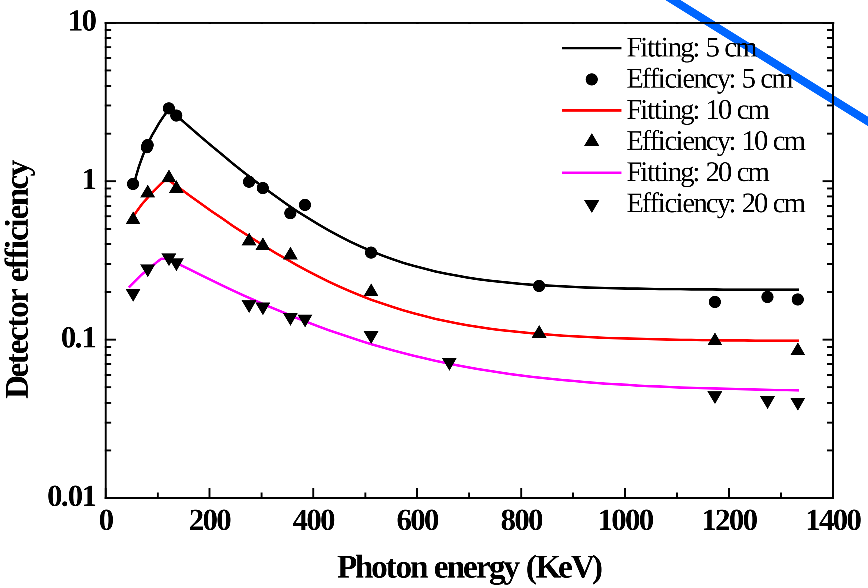




Determination of Detector Efficiency

$$\varepsilon = \frac{CPS}{A_0 e^{-\lambda t} \times I_\gamma}$$





Formula of Cross sections calculations

Reaction Rate

$$R = \frac{\lambda C}{\varepsilon I_\gamma NQ(1-e^{-\lambda t_m})e^{-\lambda t_c}(1-e^{-\lambda t_i})}$$

R = Reaction rate
λ = decay constant, s^{-1}
C = total counts of gamma-ray peak area
N = number of target atoms, atom
ε = peak efficiency
I_γ = branching ratio of gamma-ray
t_c, t_m, t_{irr} = cooling time, measuring time, irradiation time (s)
Q = proton beam current, coulomb.

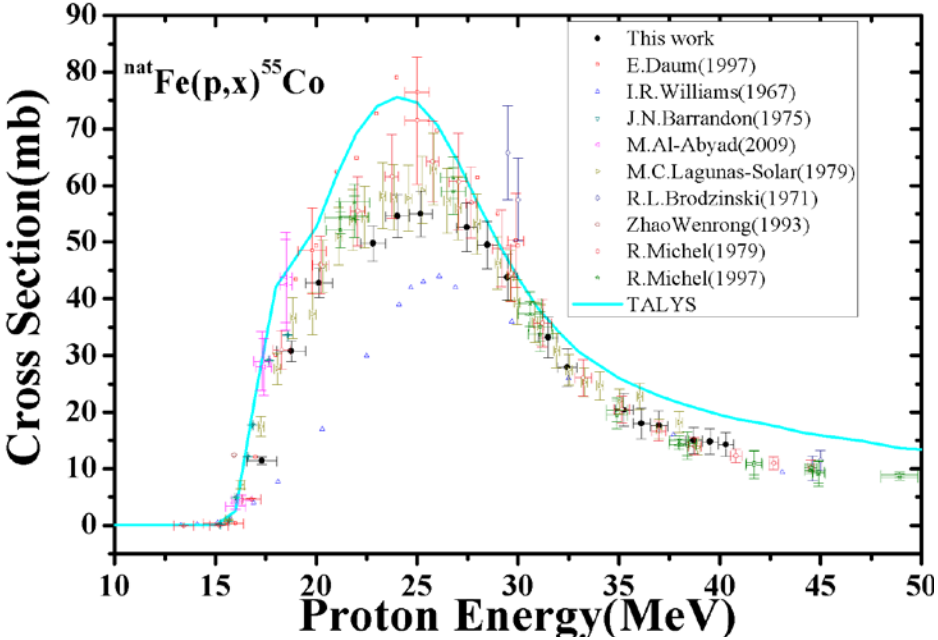
Cross-Sections

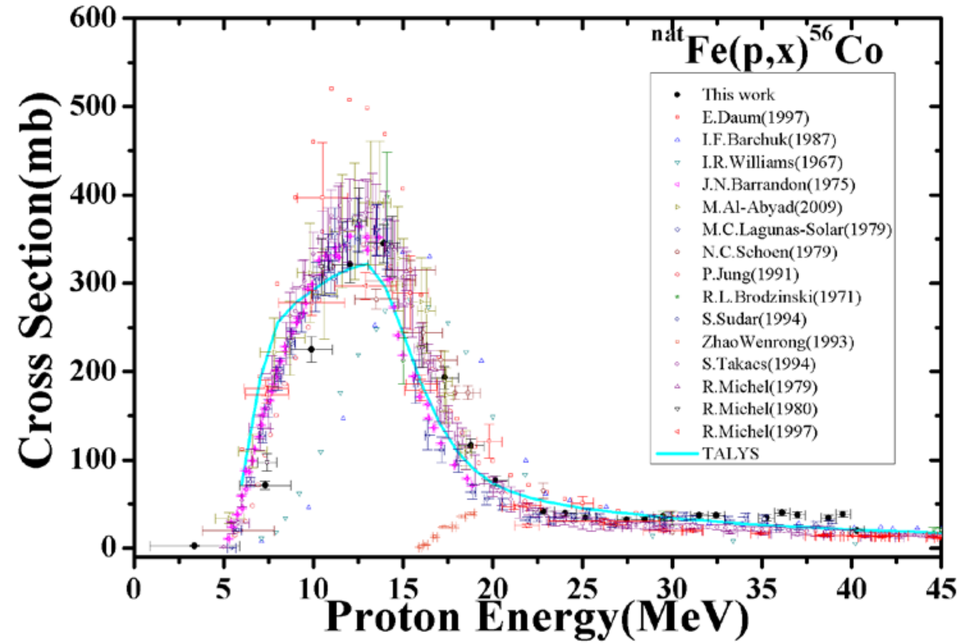
$$\sigma = \frac{RQN}{\phi N_d l}$$

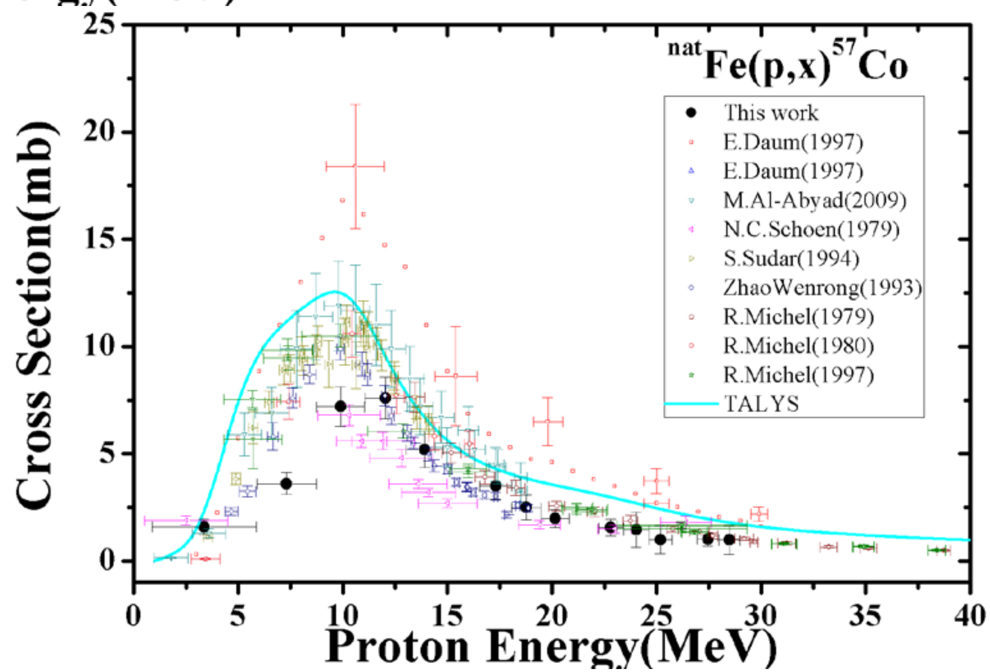
σ = cross section, cm^{-2}
N_d = atomic density, $atom/cm^3$
l = foil thickness, cm
ϕ = beam intensity, $p/cm^2/sec$

$$\sigma = \frac{\lambda C}{\varepsilon \times I_\gamma \times N_d \times t \times \phi (1-e^{-\lambda t_m})e^{-\lambda t_c}(1-e^{-\lambda t_i})}$$

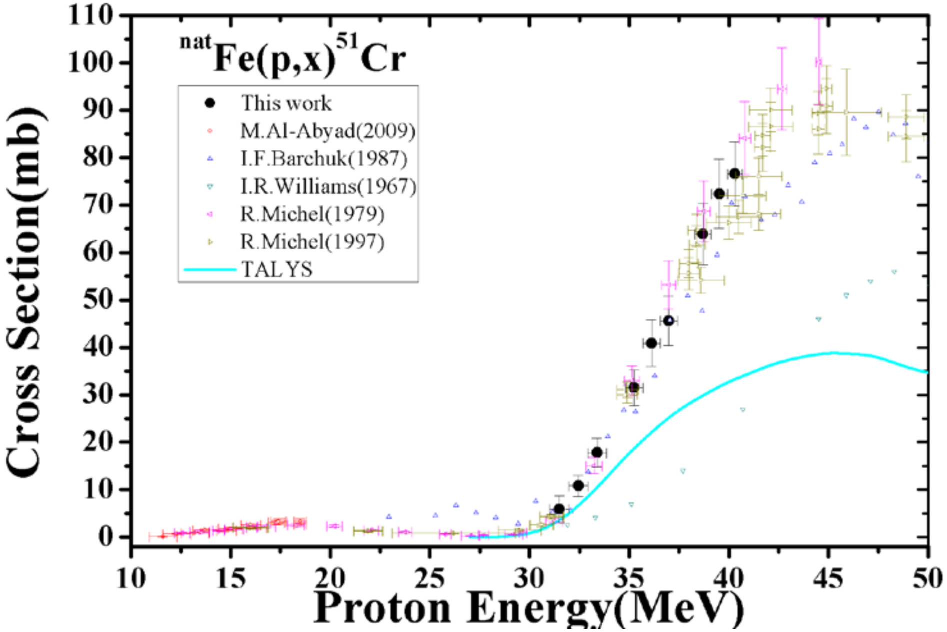
Measured Cross sections of $^{nat}Fe(p,x)$

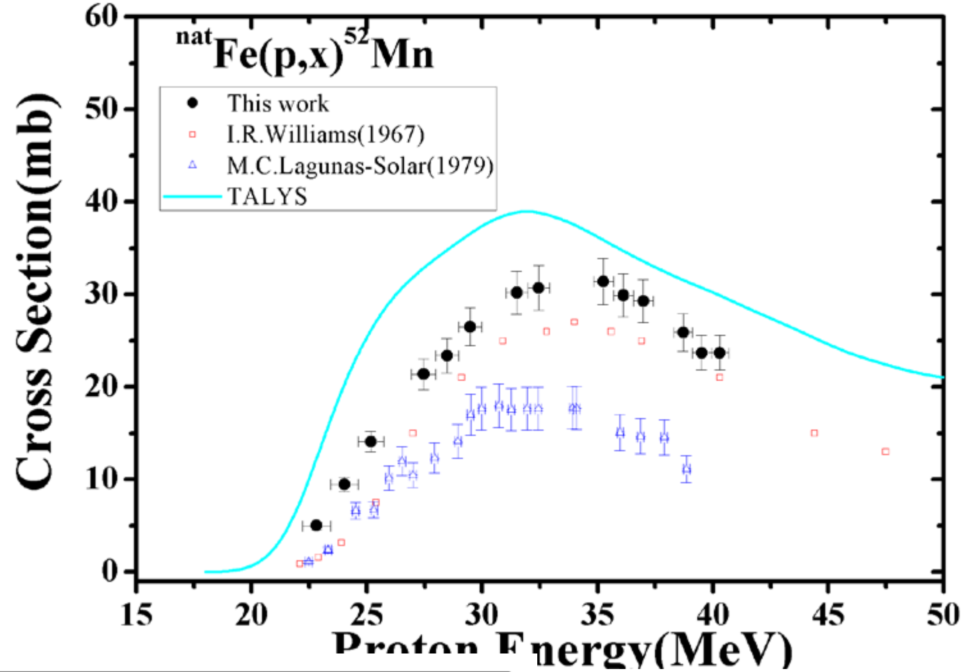


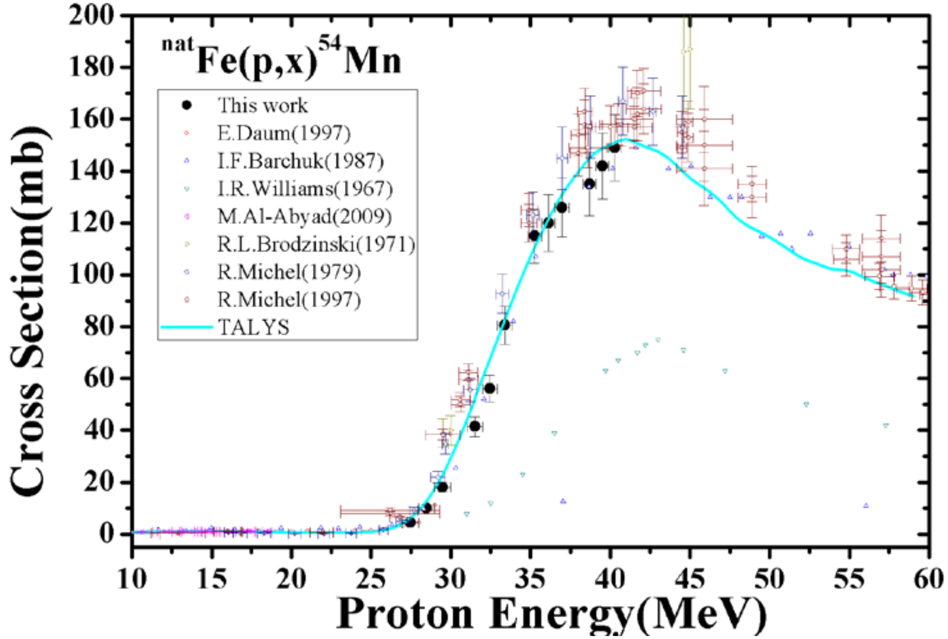




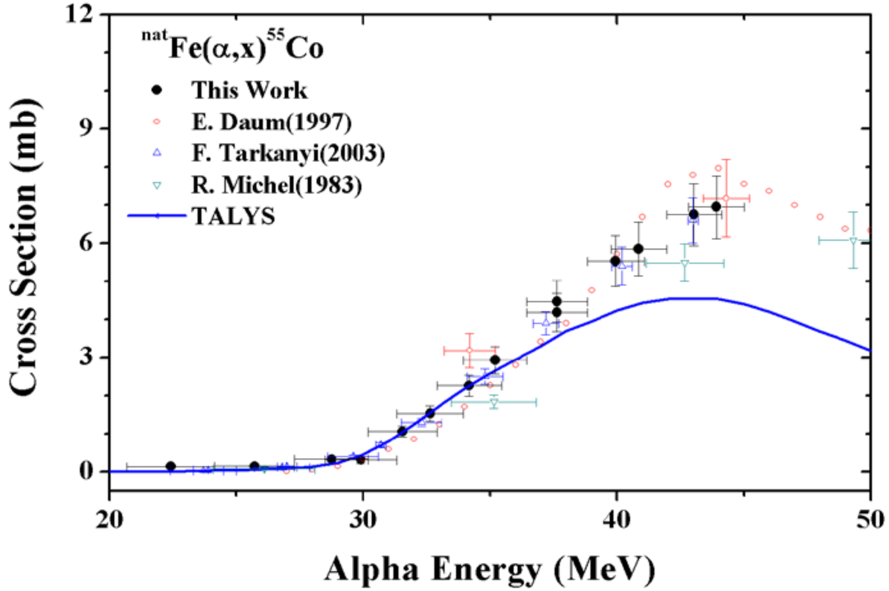
Measured Cross sections of $^{nat}Fe(p,x)$

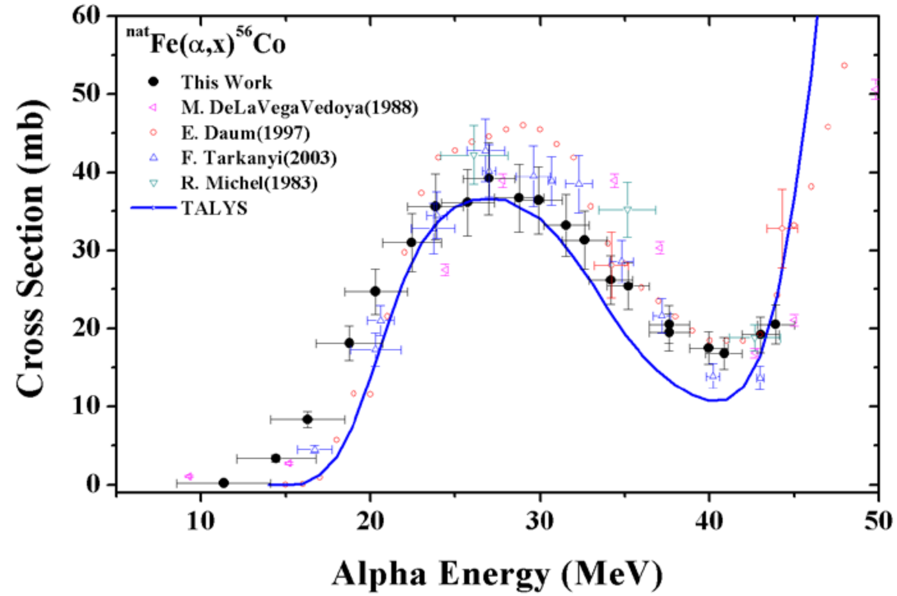


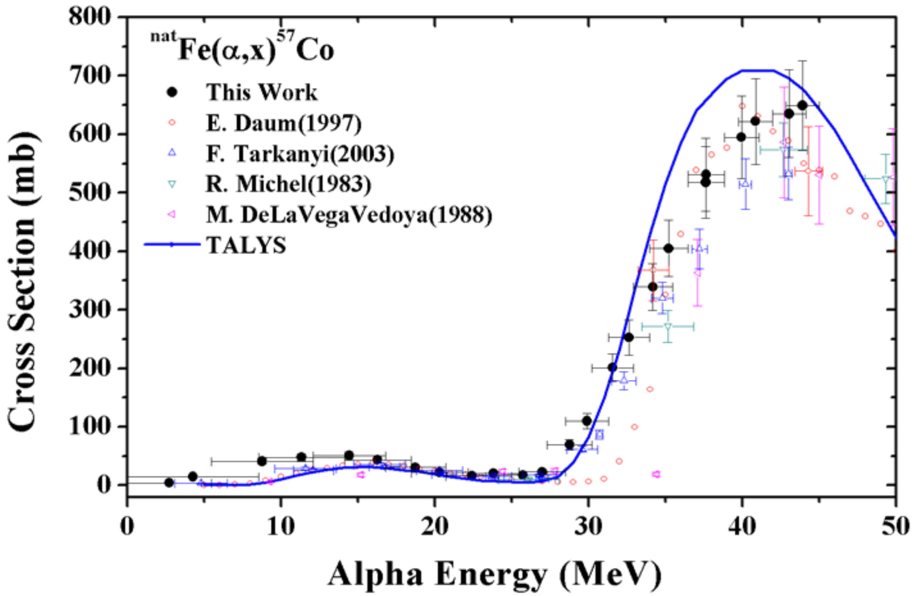


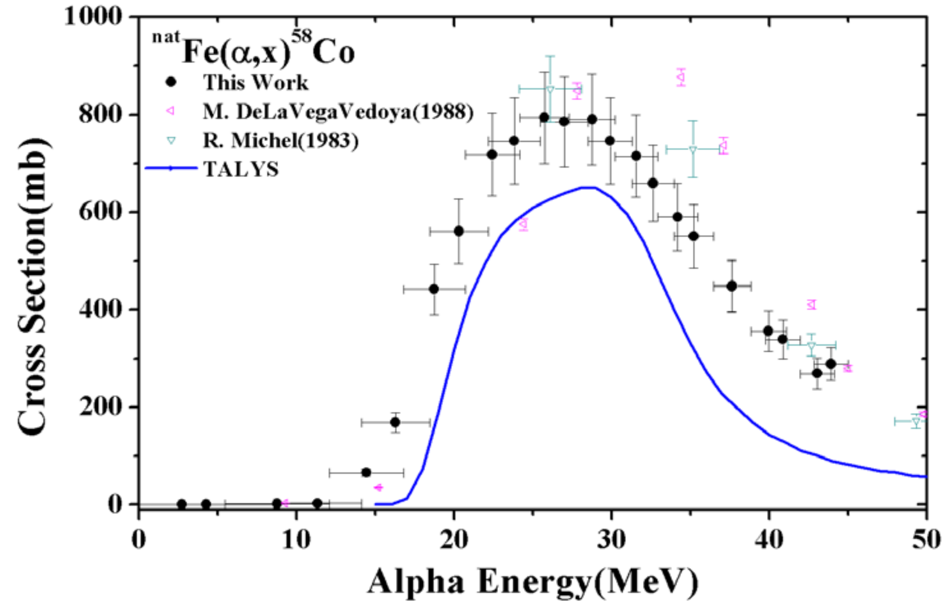


Measured Cross sections of $^{nat}Fe(\alpha,x)$

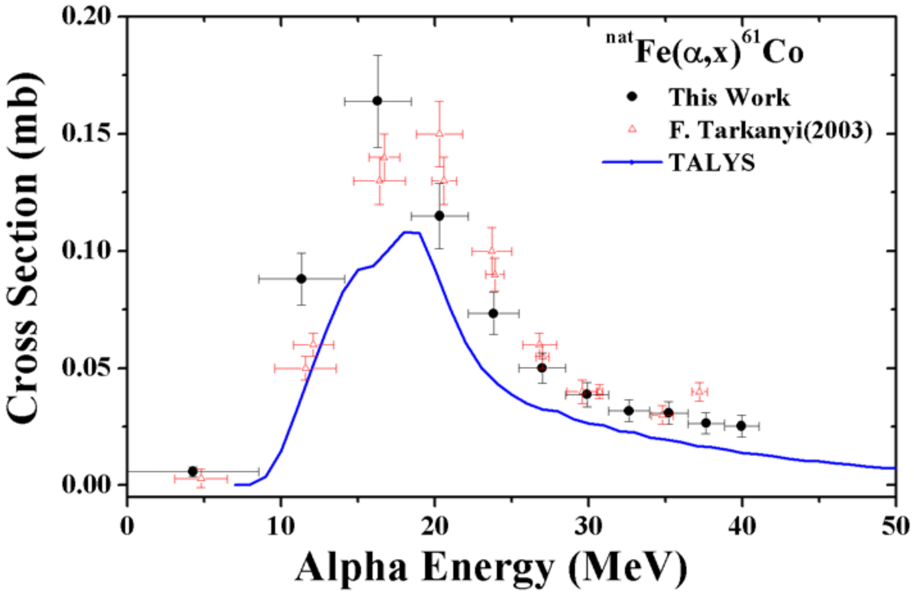


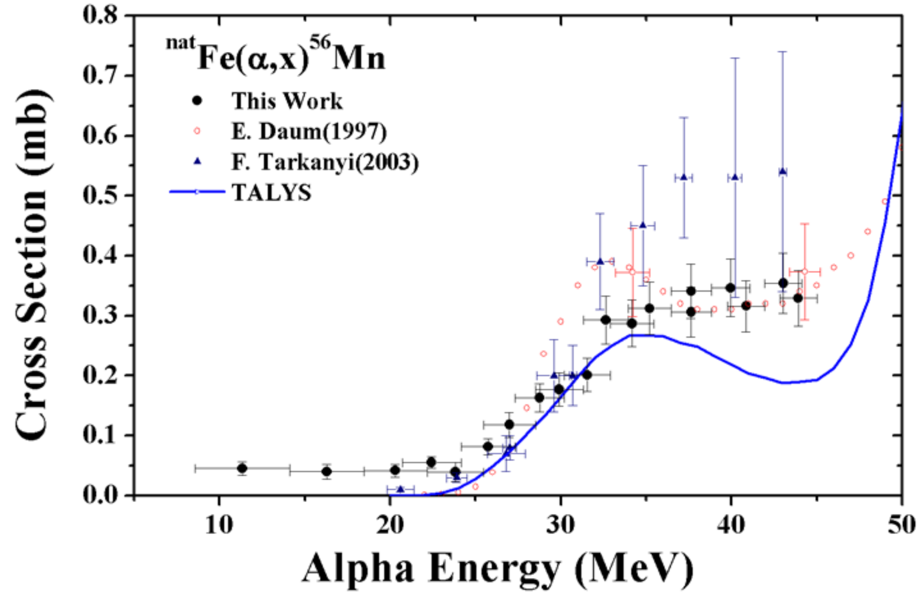


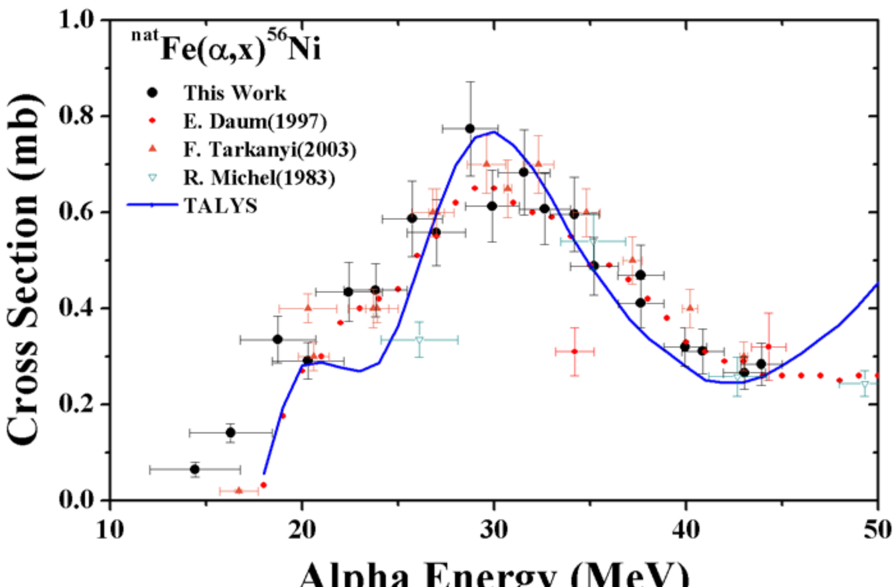


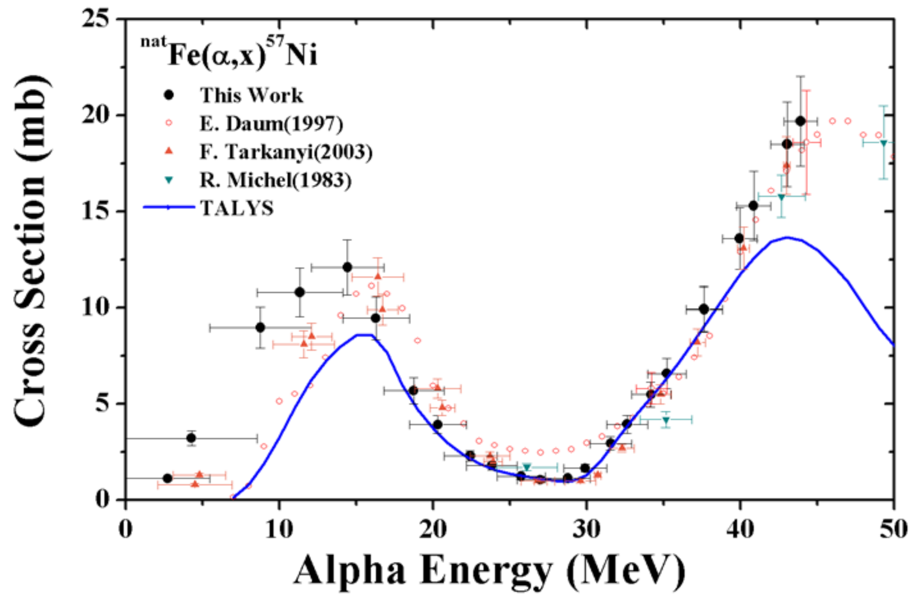


Measured Cross sections of $^{nat}Fe(\alpha,x)$

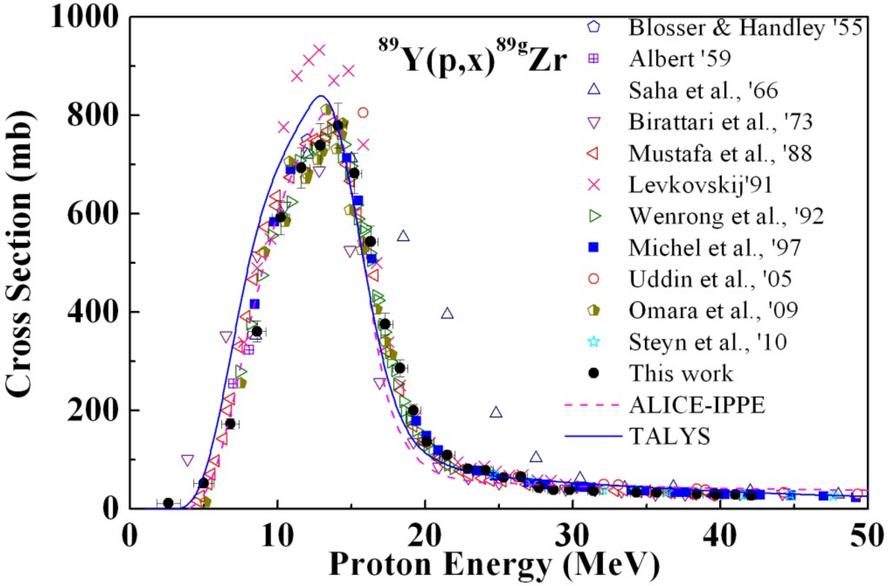


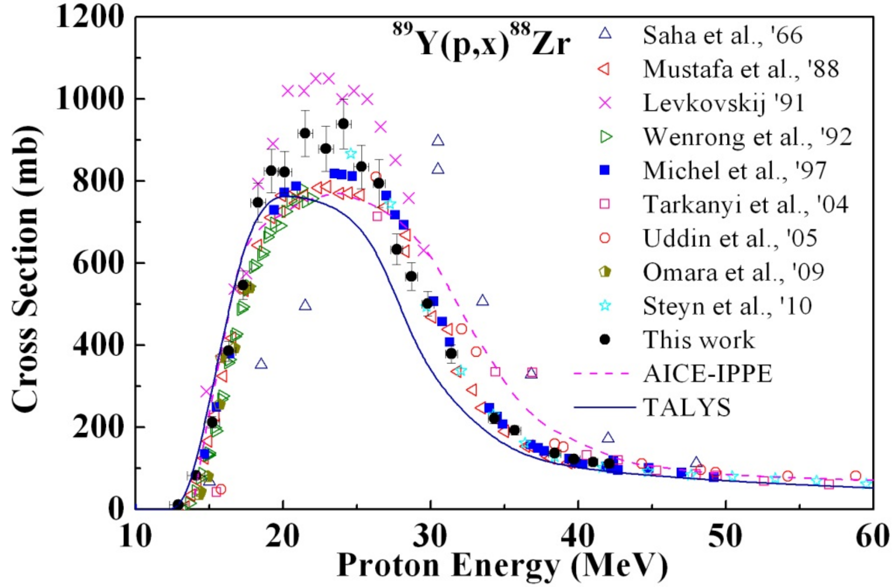


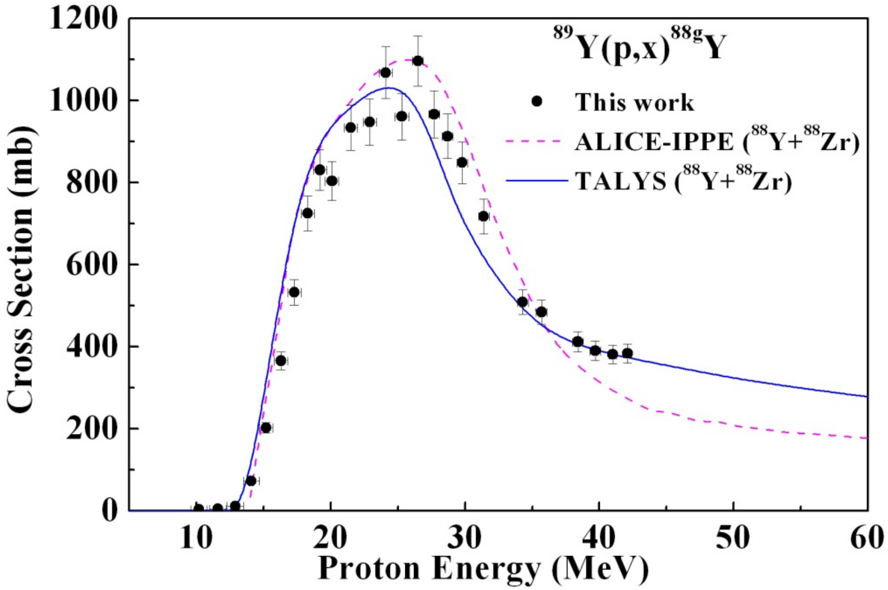


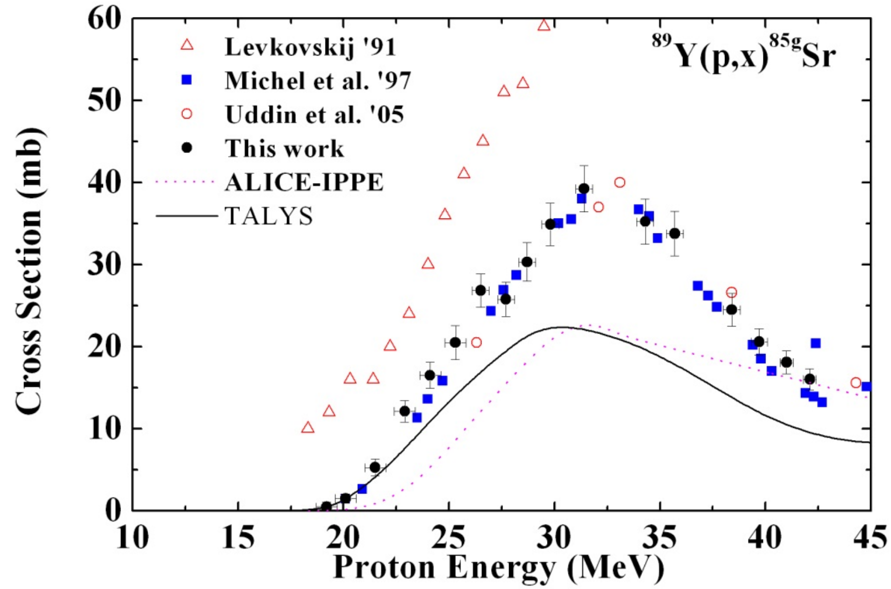


Measured Cross sections of $^{nat}Y(p,x)$

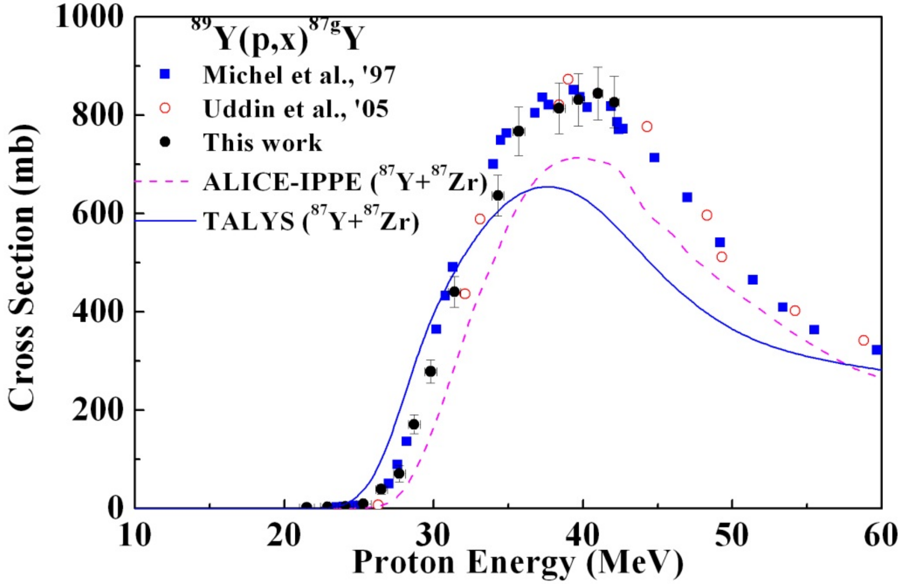


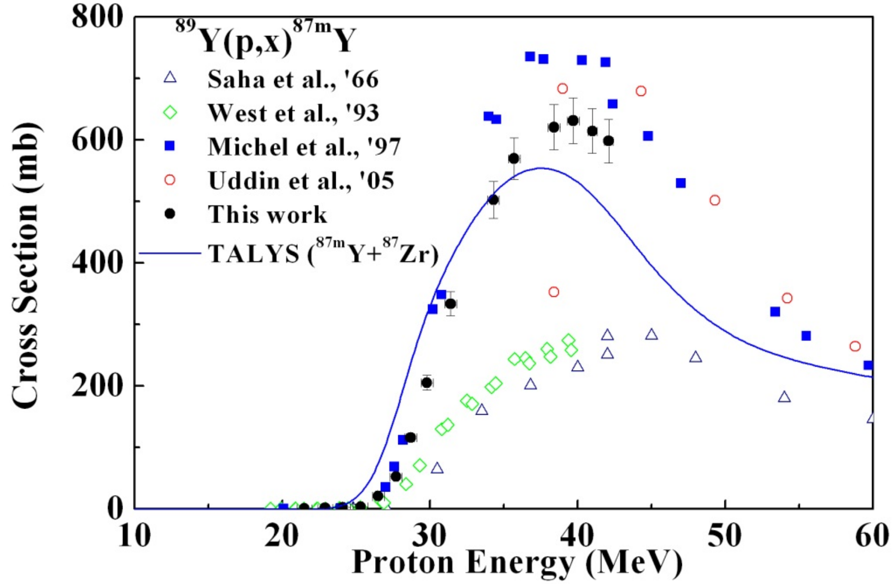


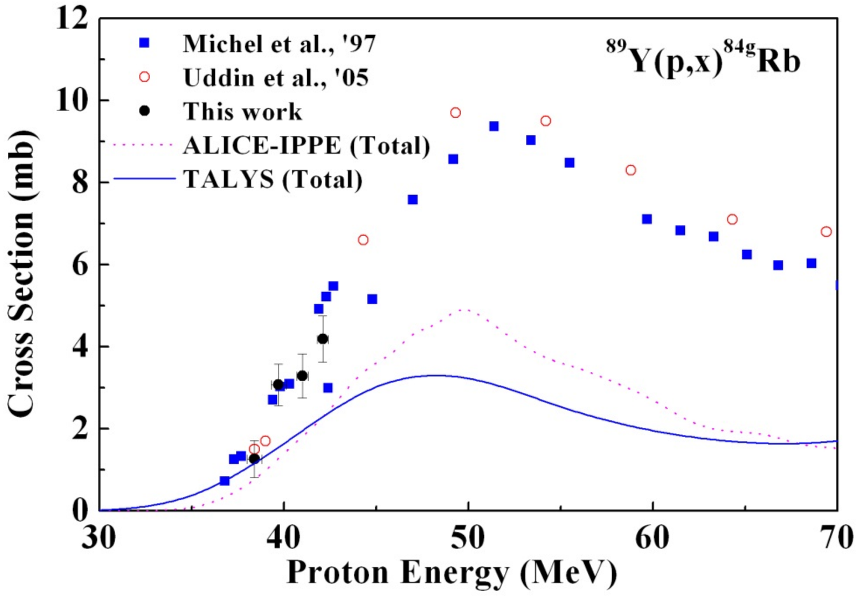


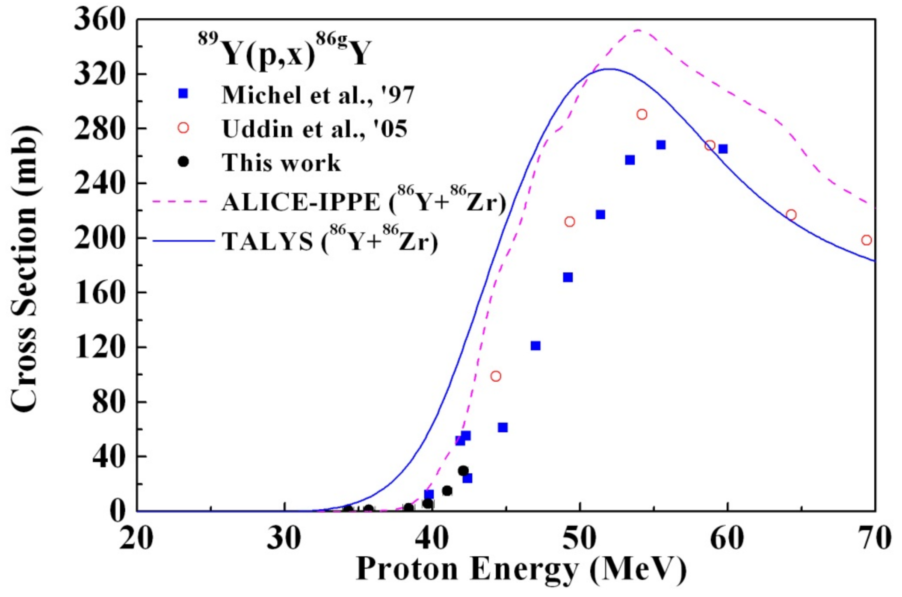


Measured Cross sections of $^{nat}Y(p,x)$

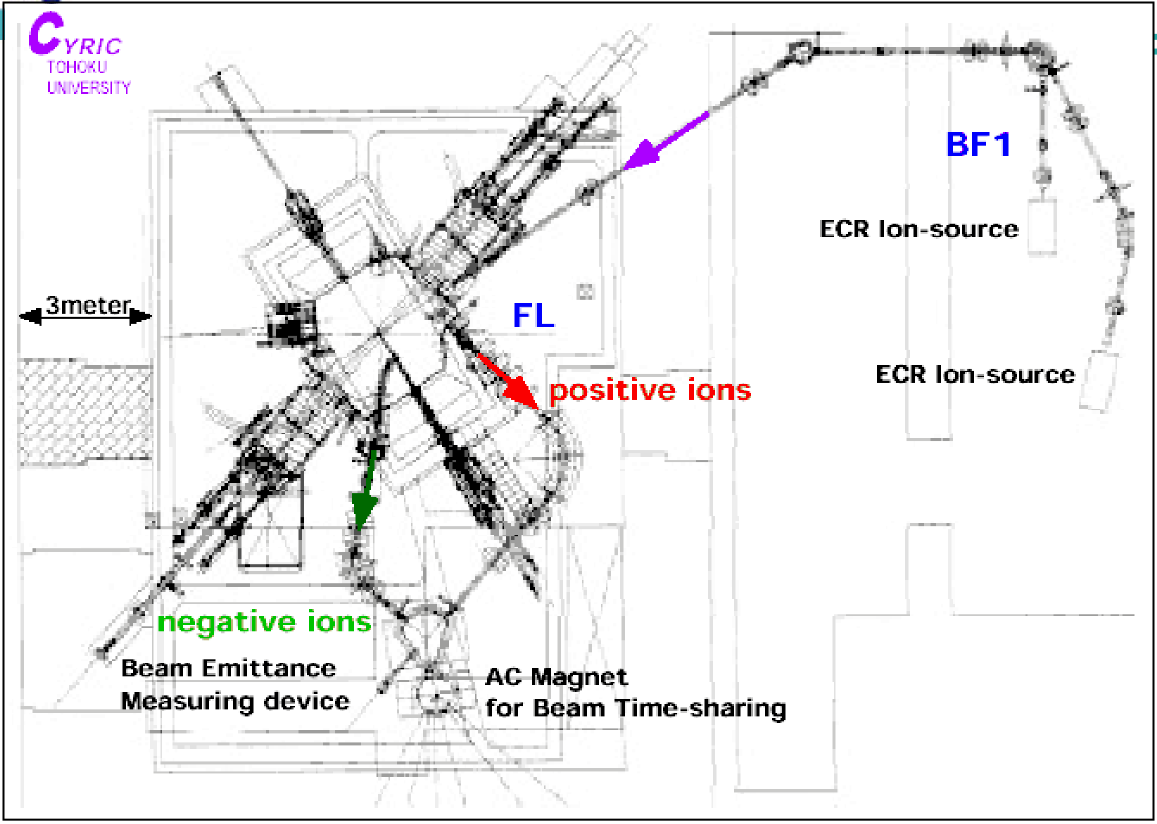








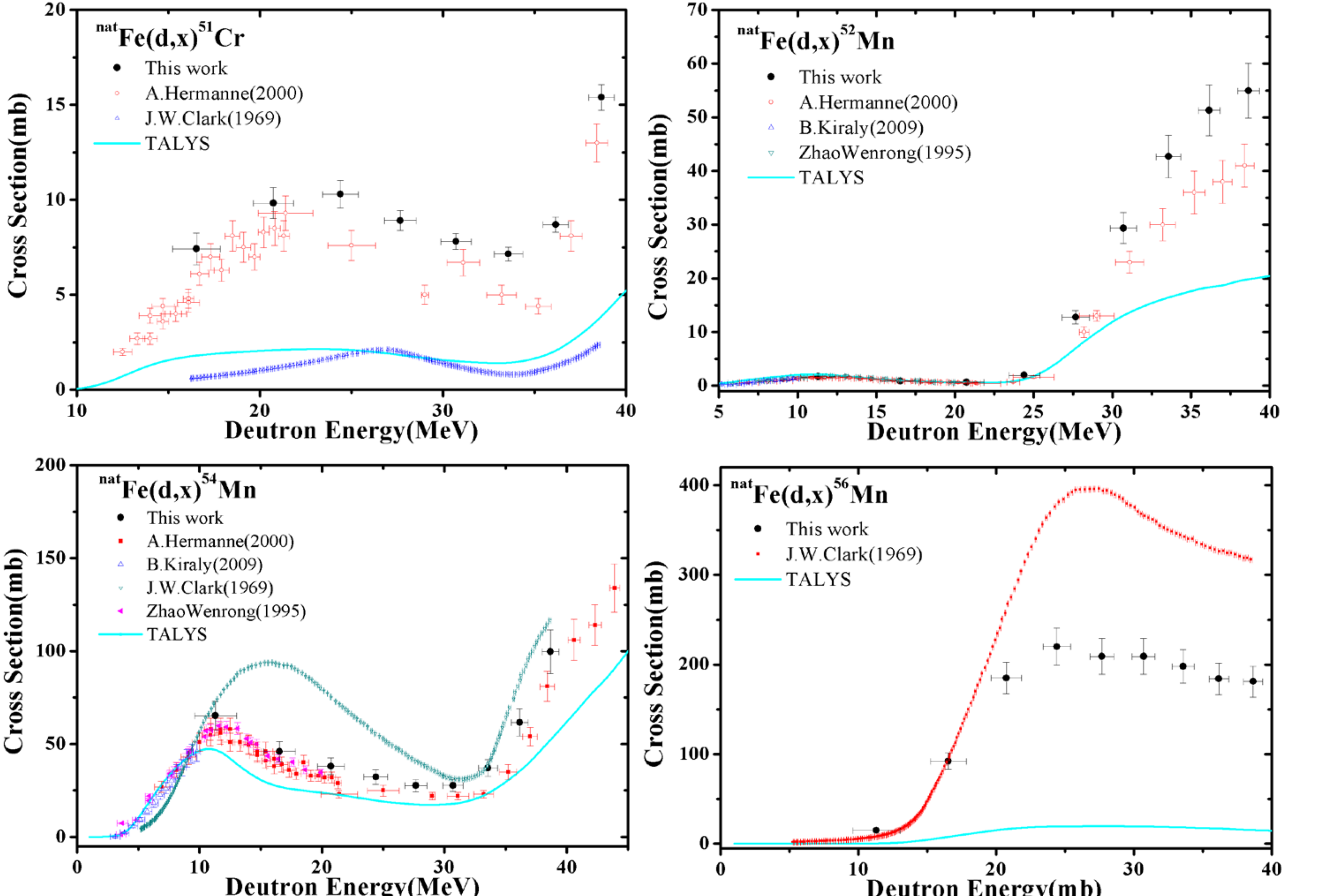
Cyclotron at CYRIC, Tohoku Univ.



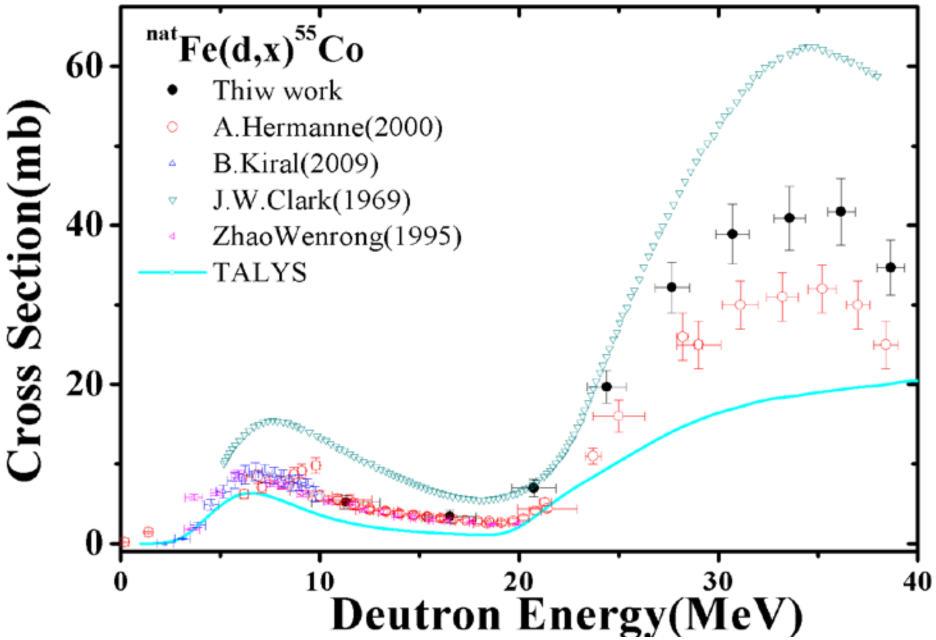
http://www.cyric.tohoku.ac.jp/english/cyric/avfproe/avfproe1.html

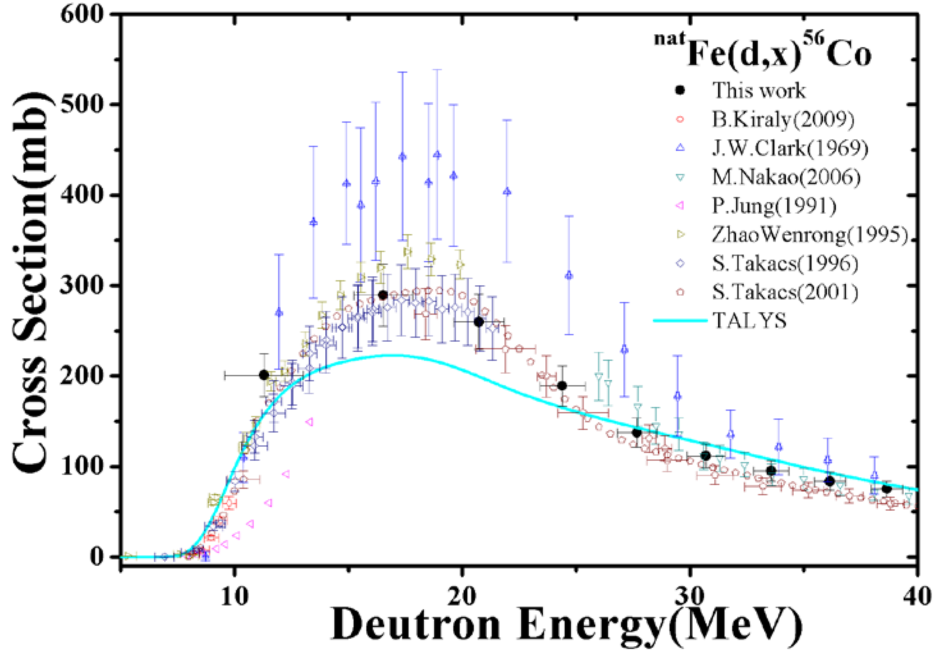
Deutron Beam Energy	maximum	This work
	65 MeV	40 MeV
Current	50μA	100nA

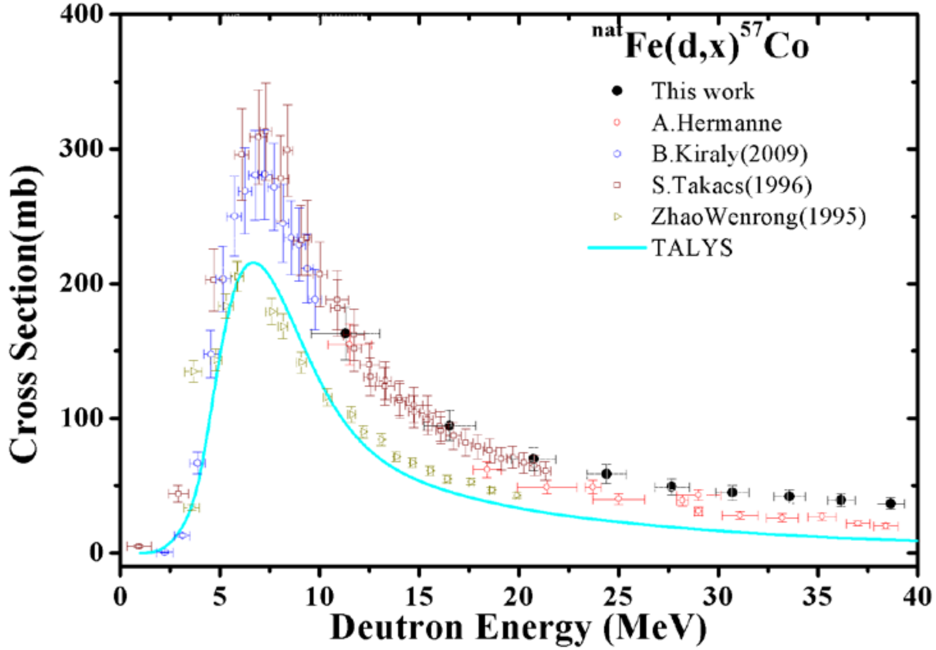
Measured Cross sections of $^{nat}Fe(d,x)$

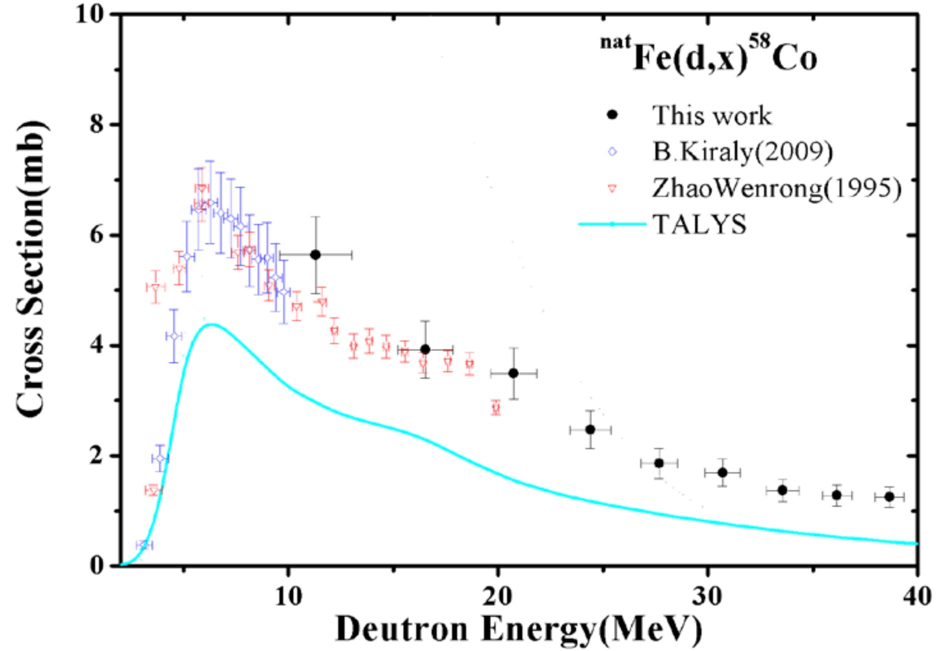


Measured Cross sections of $^{nat}Fe(d,x)$

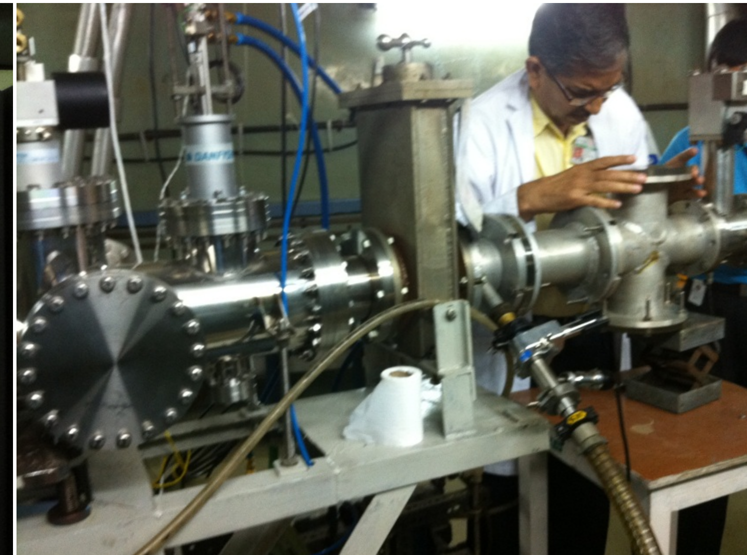








Cyclotron at VECC, KOLKATA



Alpha Beam : 65 MeV, 1 μA

Summary and Discussion

- **Reported the recent activities at Pohang neutron facility :**

- ➢ **Neutron Total Cross Section Measurement**

  - 12 m TOF path length

  - New DAQ system based on FADC was developed

  - Resonance parameter determination with SAMMY code

- ➢ **Neutron Activation measurements with thermal neutrons of PNF**

- ➢ **Photo-nuclear Reaction Measurements with 50-70 MeV and 2.5 GeV Bremsstrahlung**

- ➢ **Charged Particle Induced Reaction Cross-section Measurements**

- ➢ **Collaboration with Domestic and Foreign Users**
  - Vietnam, India, Russia, China, Poland, Mongol