Flux Profiling Using a Neutron Absorbing Cocktail

Donald Wall

Washington State University

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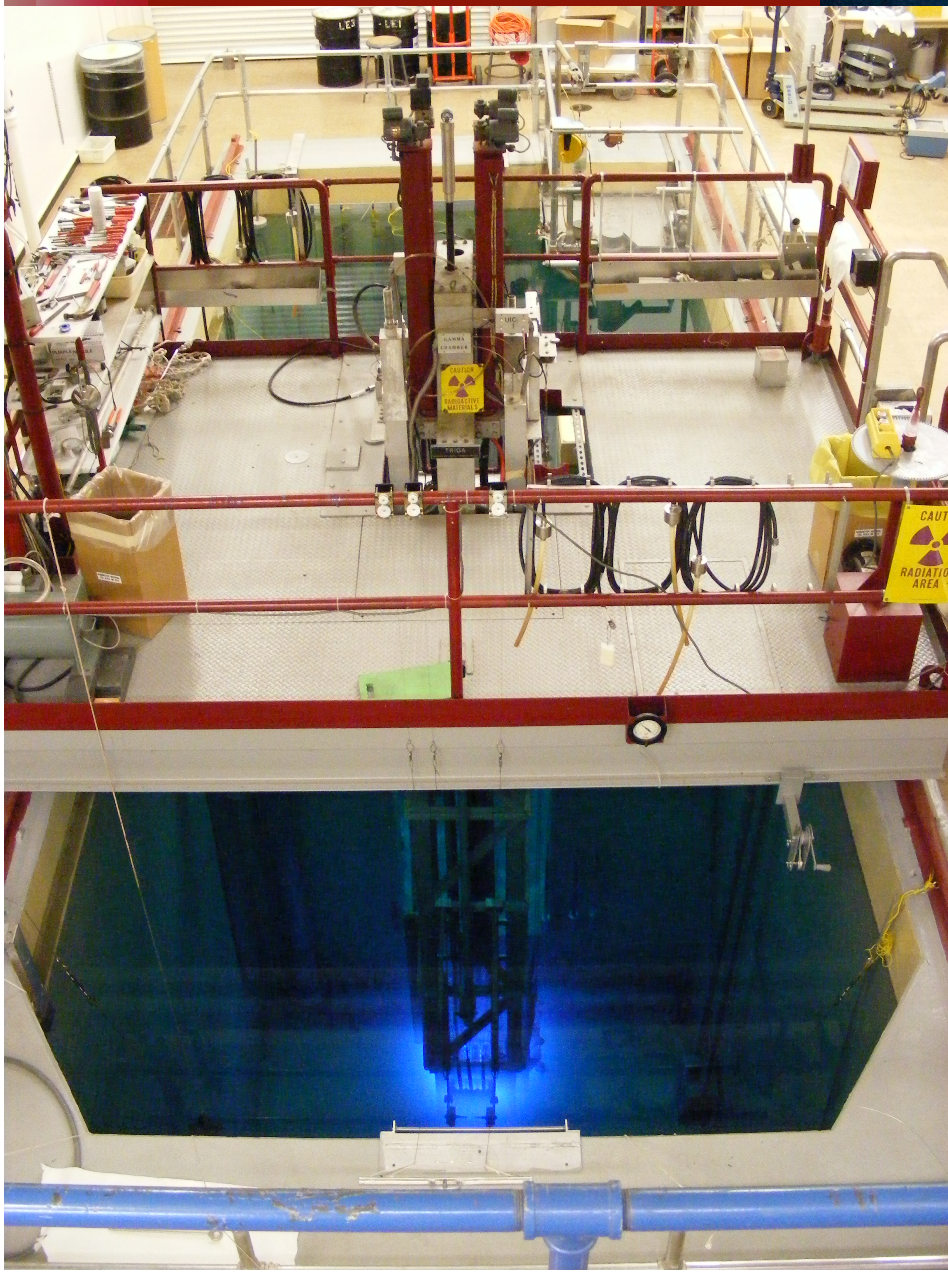
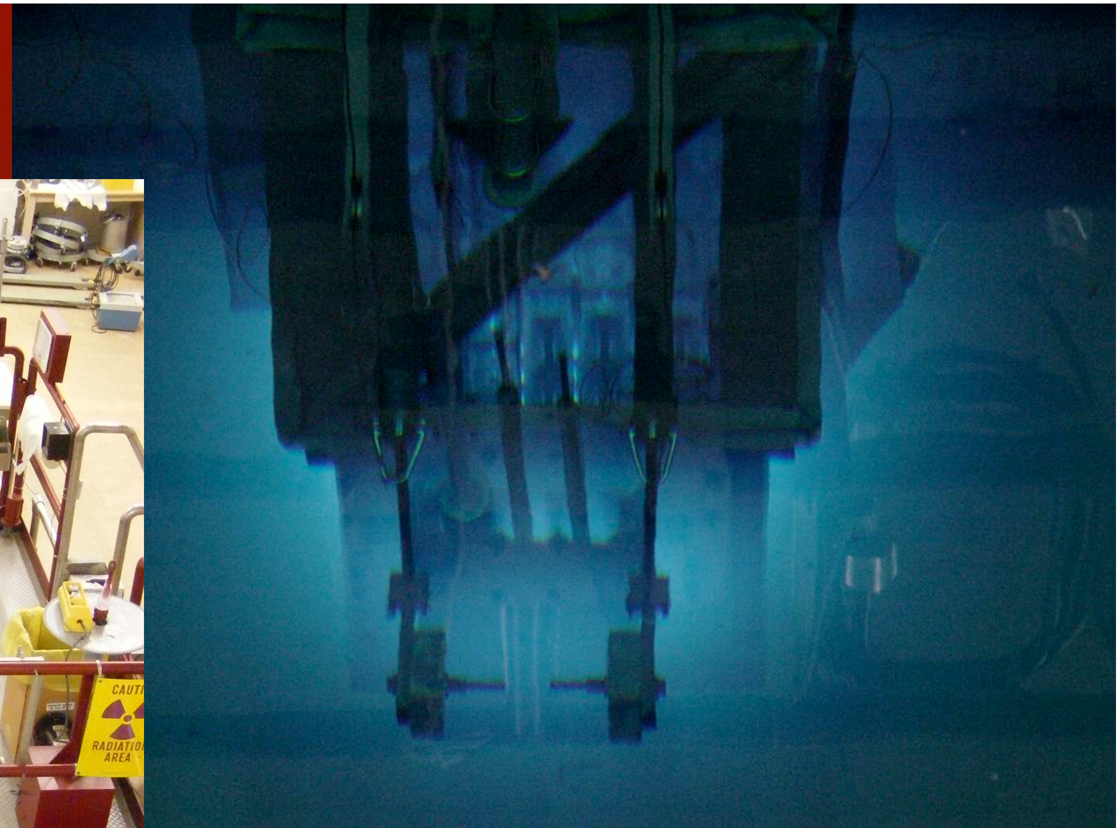
Rationale:

The WSU 1 MW TRIGA conversion reactor was converted from HEU to LEU in 2008.

The core has been extensively modeled at GA, PNNL and WSU, but experimental measurements of flux profiles and neutron energy distribution were unavailable.





Use of multiple flux monitors allows deconvolution of the neutron energy spectrum into three general energy bins: thermal, epithermal, and fast (>1 MeV) since each reaction is sensitive to a different range of neutron energies.

The thermal cross sections and resonance integrals for the reactions also have different ratios.

Reaction	Cross section	Resonance integral
$^{58}Fe(n,\gamma)^{59}Fe$	1.3	1.2
$^{59}Co(n,\gamma)^{60}Co$	37	74
$^{63}Cu(n,\gamma)^{64}Cu$	4.5	5.0
$^{197}Au(n,\gamma)^{198}Au$	98.7	1550
^{235}U fission average (barns)		
$^{46}Ti(n,p)^{46}Sc$	0.001211	
$^{47}Ti(n,p)^{47}Sc$	0.02812	
$^{48}Ti(n,p)^{48}Sc$	0.0004696	
$^{54}Fe(n,p)^{54}Fe$	0.1146	
$^{56}Fe(n,p)^{56}Fe$	0.001645	

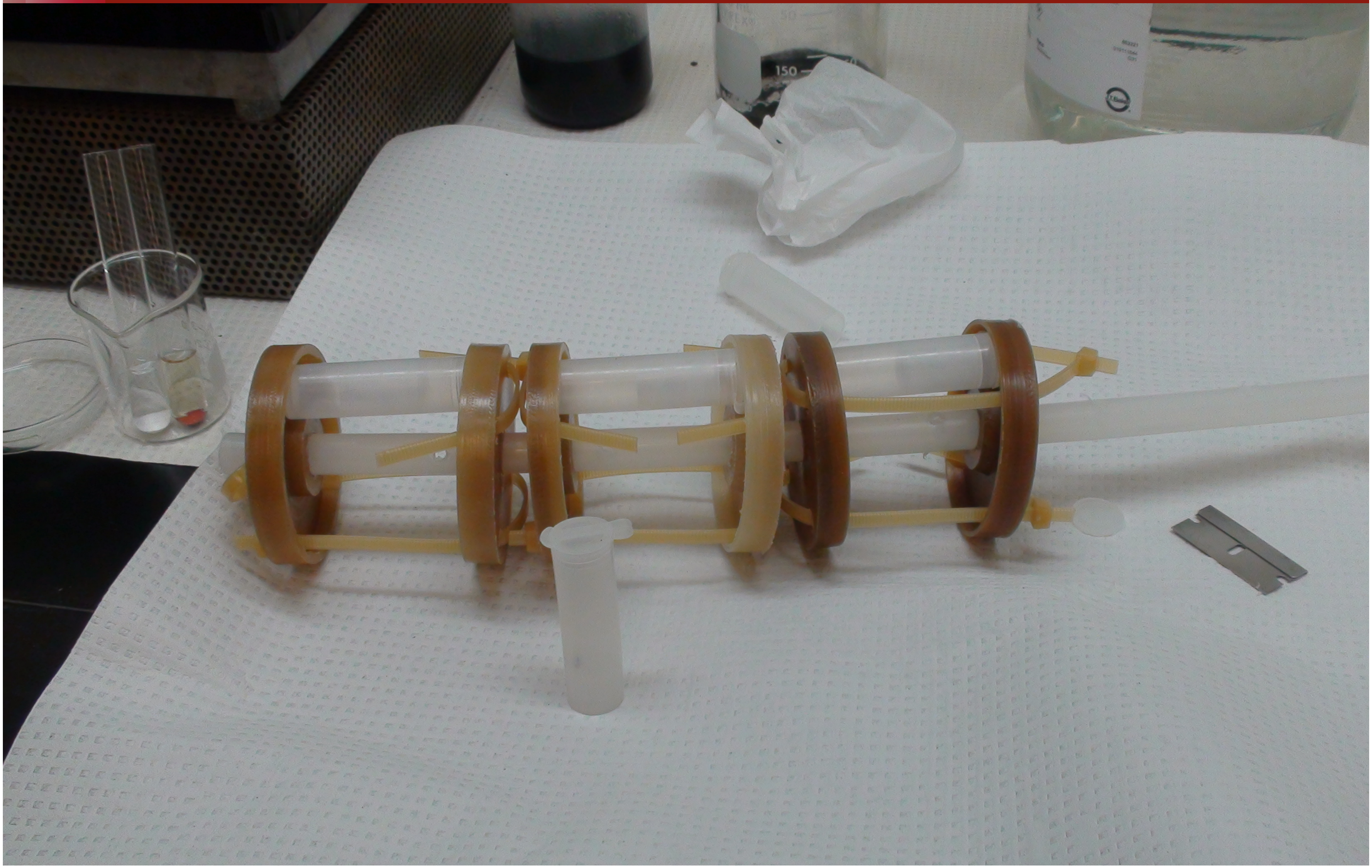
Procedure:

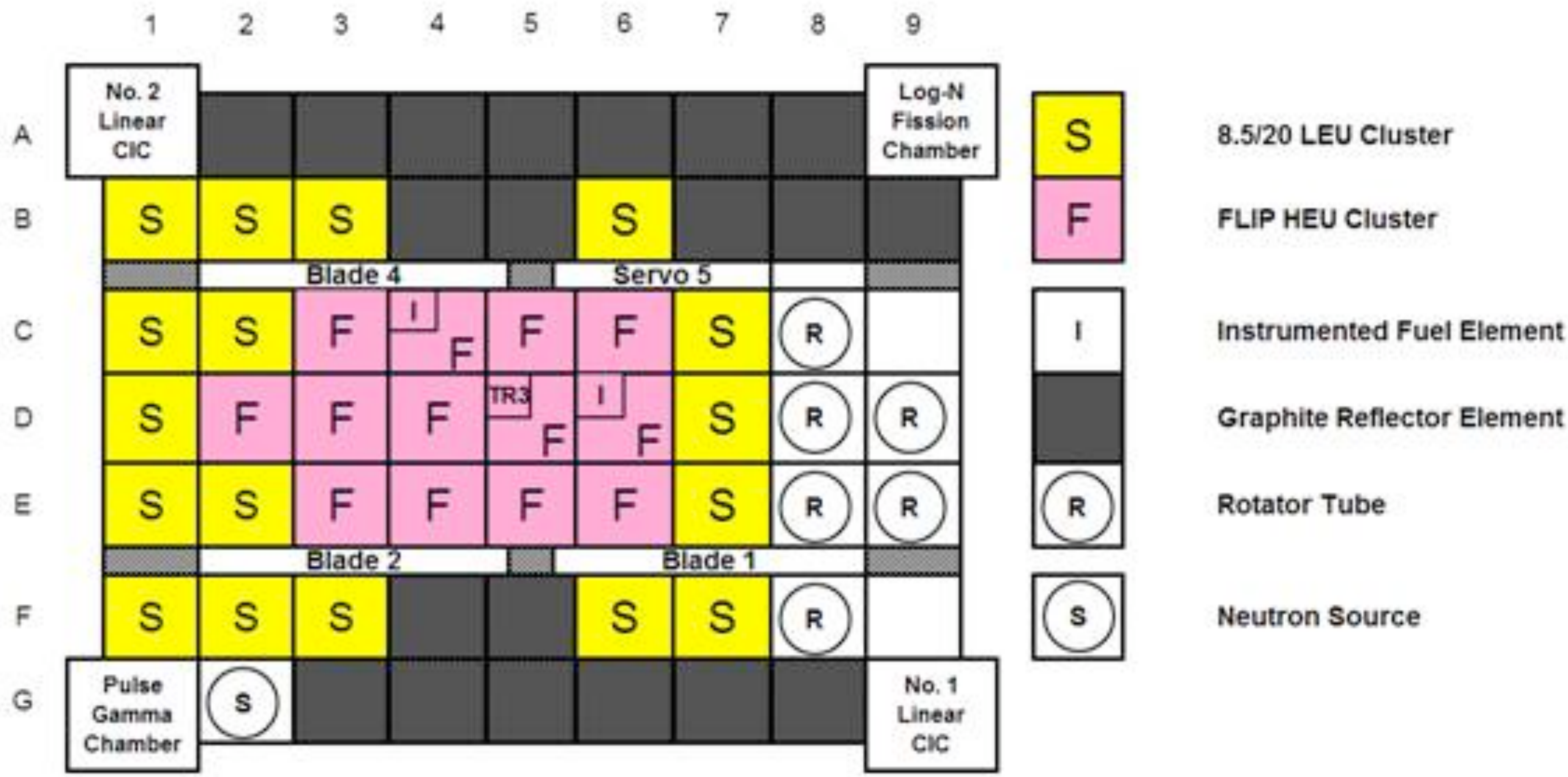
Ti, Fe, Co, Cu, and Au standards were packaged in 1.5 mL heat sealed polyethylene vials, which were placed inside 18.5 mL vials.

The samples were irradiated at measured distances from the bottom of the core.

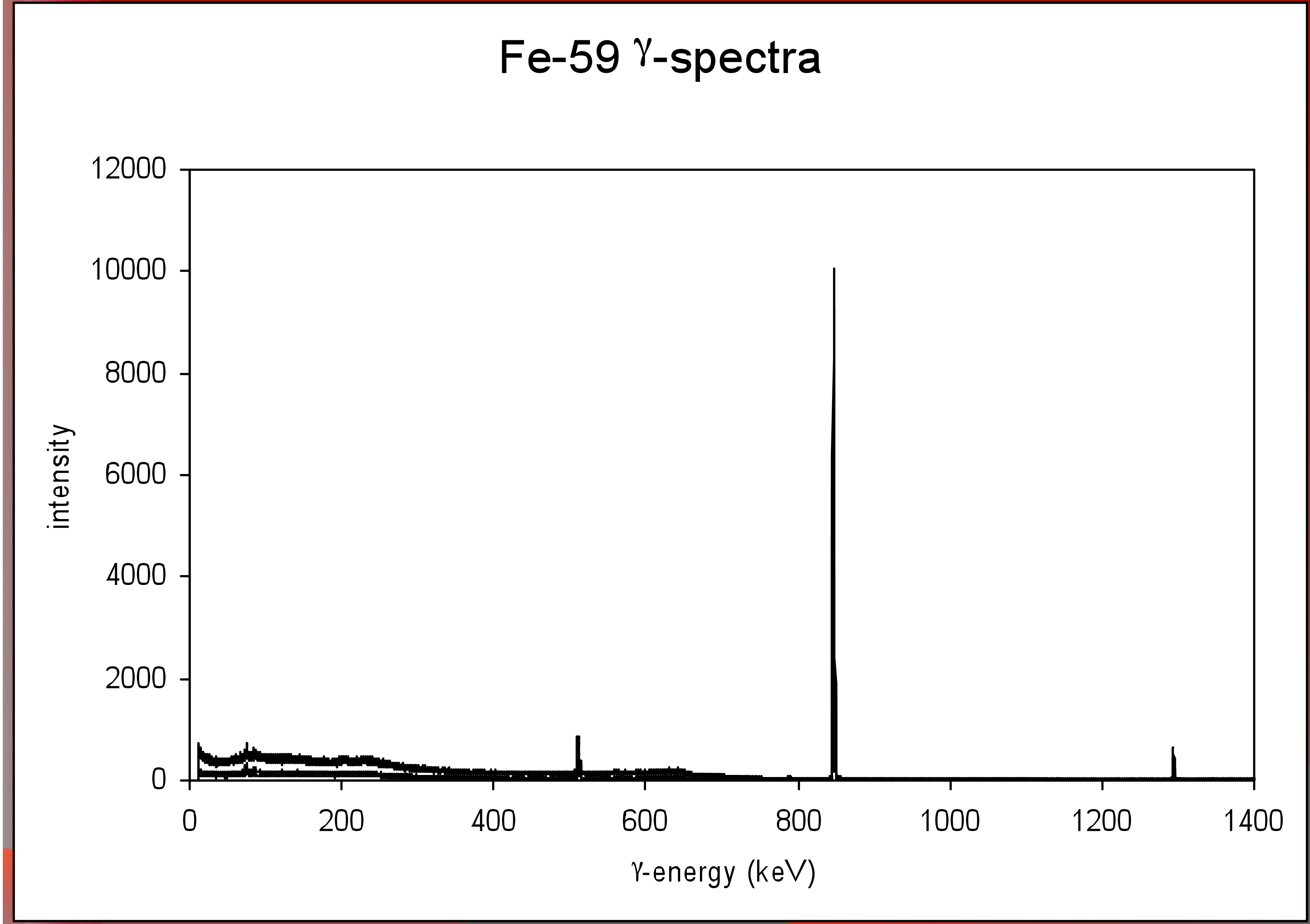
- Samples were irradiated for 30 minutes in core position D8 or subjected to a $2.00 pulse
- Cooling time of 4 hours to 24 hours
- Samples were counted for 2 – 15 minutes on an energy and efficiency calibrated Canberra HpGe

Flux monitors consisted of Ti, Fe, Co, Cu, and Au.



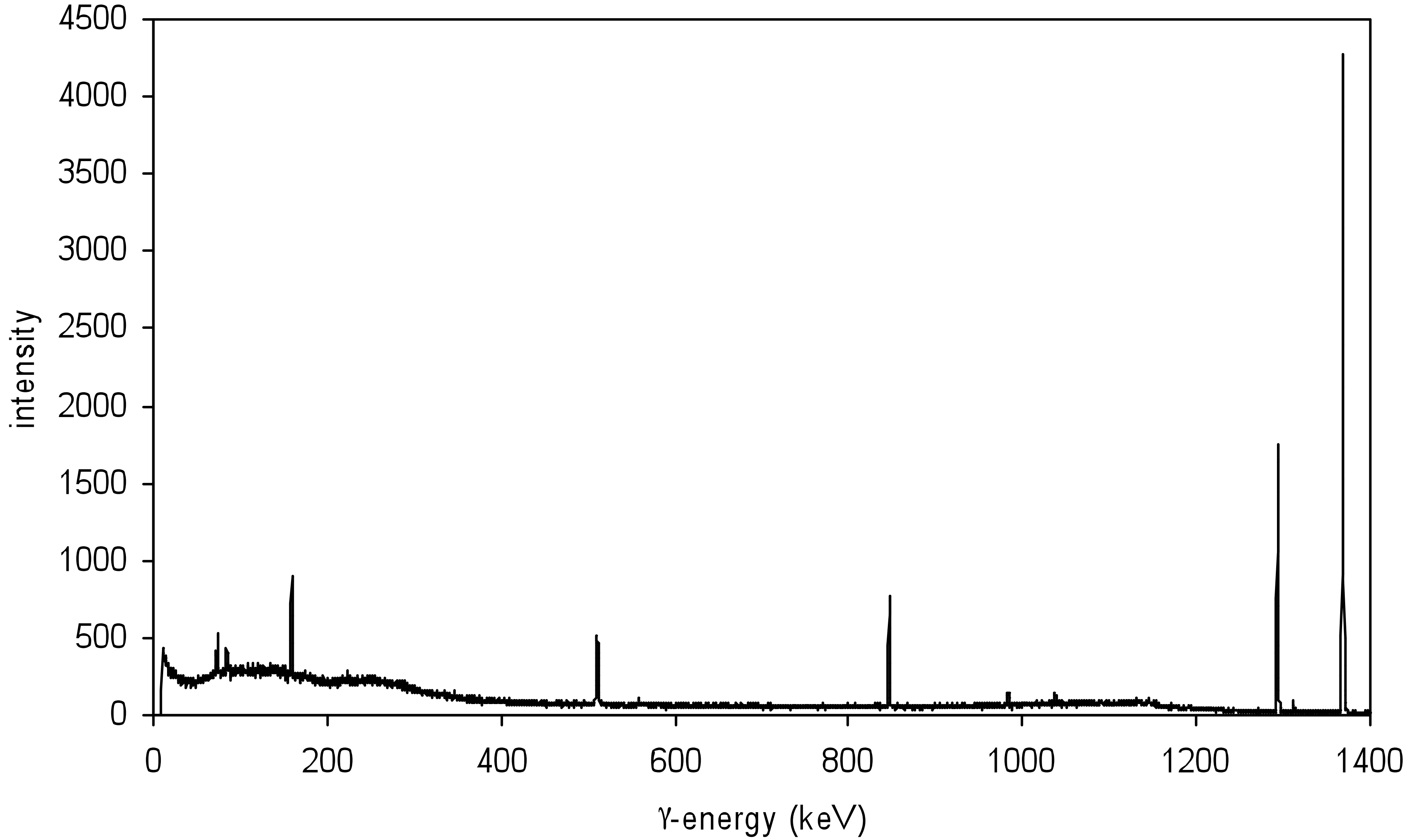


1
2
3
4
5
6
7
8
9
A
B
C
D
E
F
G
No. 2 Linear CIC
Log-N Fission Chamber
Pulse Gamma Chamber
No. 1 Linear CIC
Blade 4
Servo 5
Blade 2
Blade 1
TR3
S
F
I
R
8.5/20 LEU Cluster
FLIP HEU Cluster
Instrumented Fuel Element
Graphite Reflector Element
Rotator Tube
Neutron Source

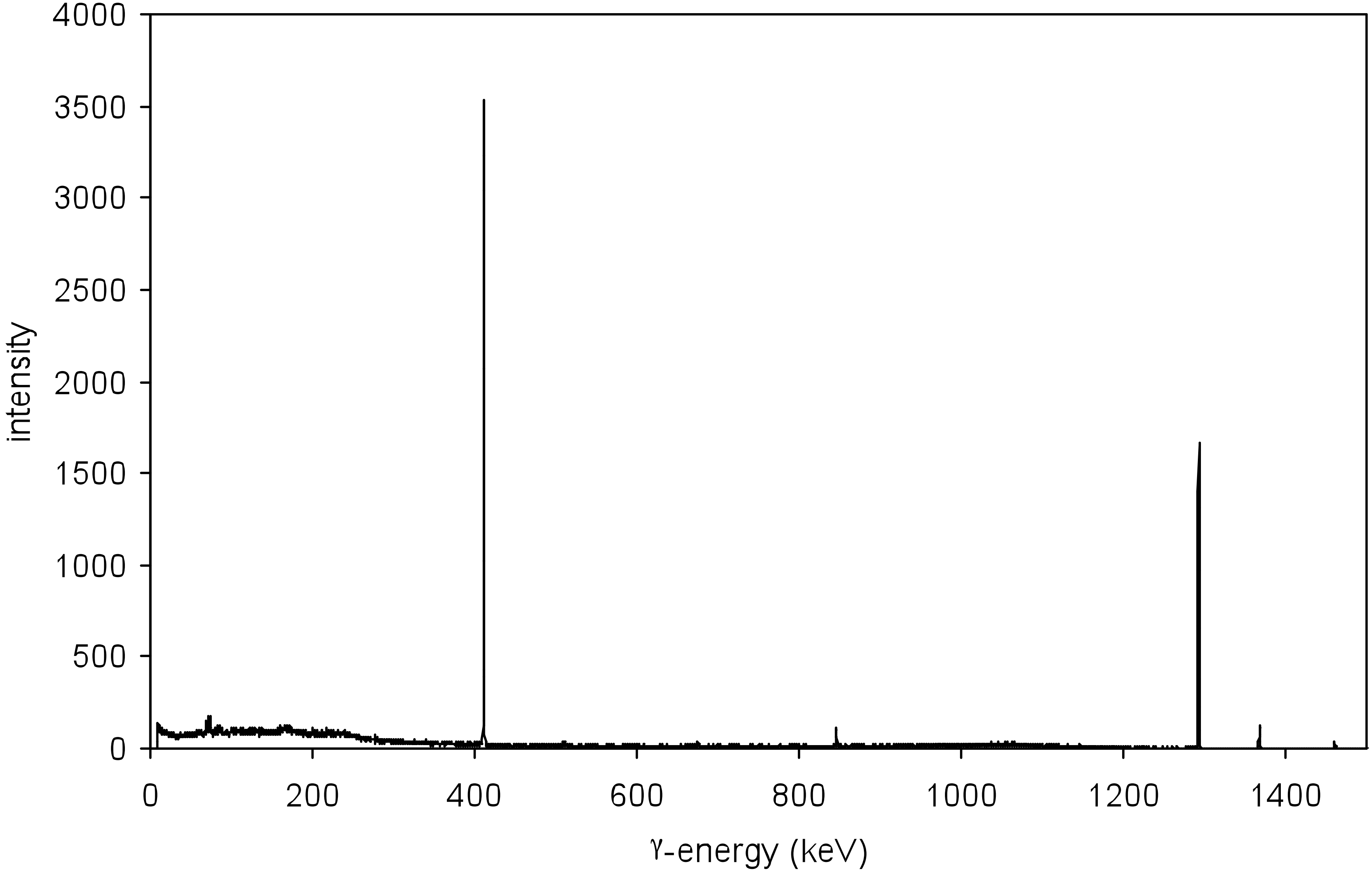


Fe-59 γ-spectra
12000
10000
8000
6000
4000
2000
0
intensity
0
200
400
600
800
1000
1200
1400
γ-energy (keV)

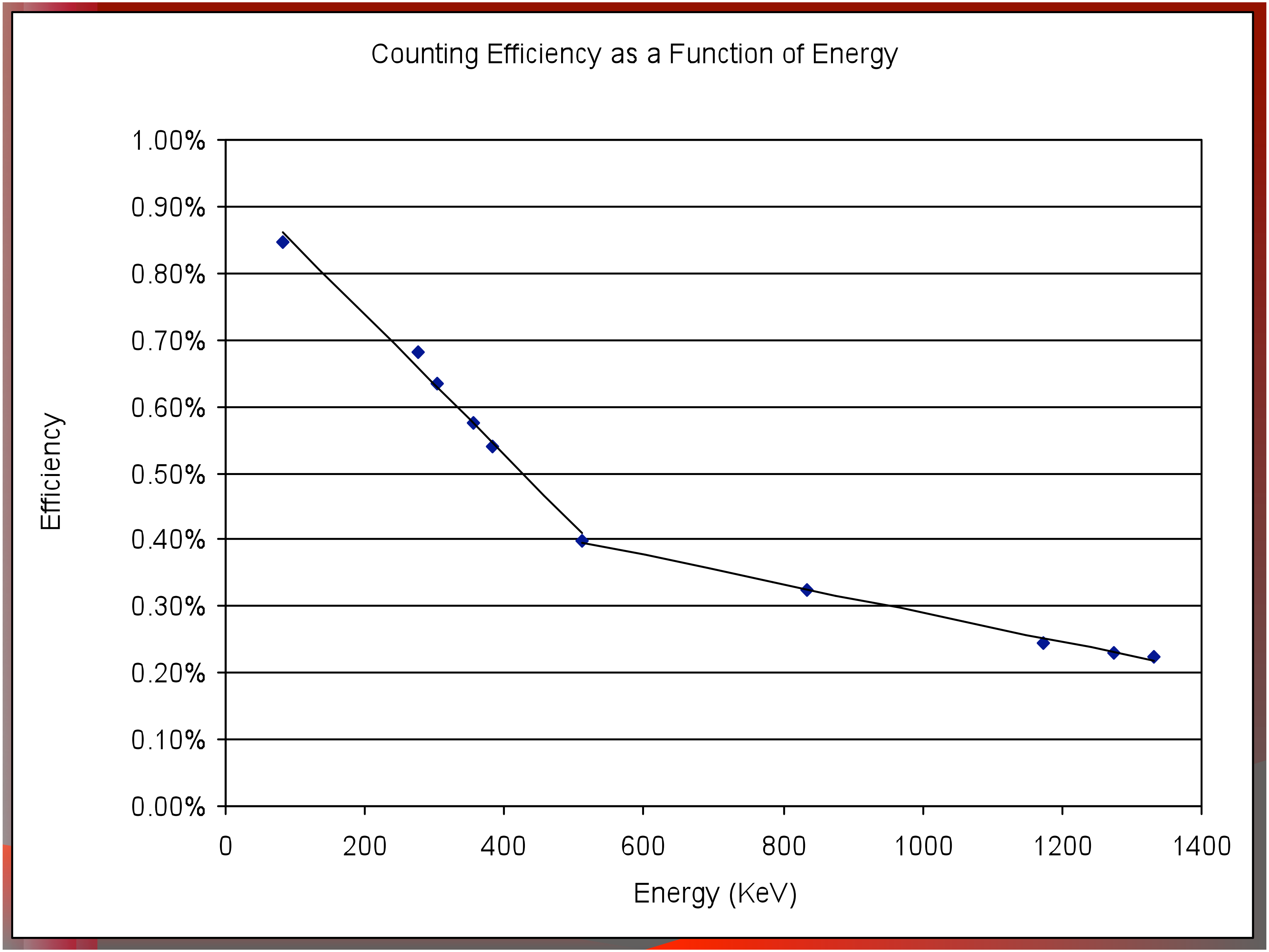
Ti (n,p) Sc Reaction



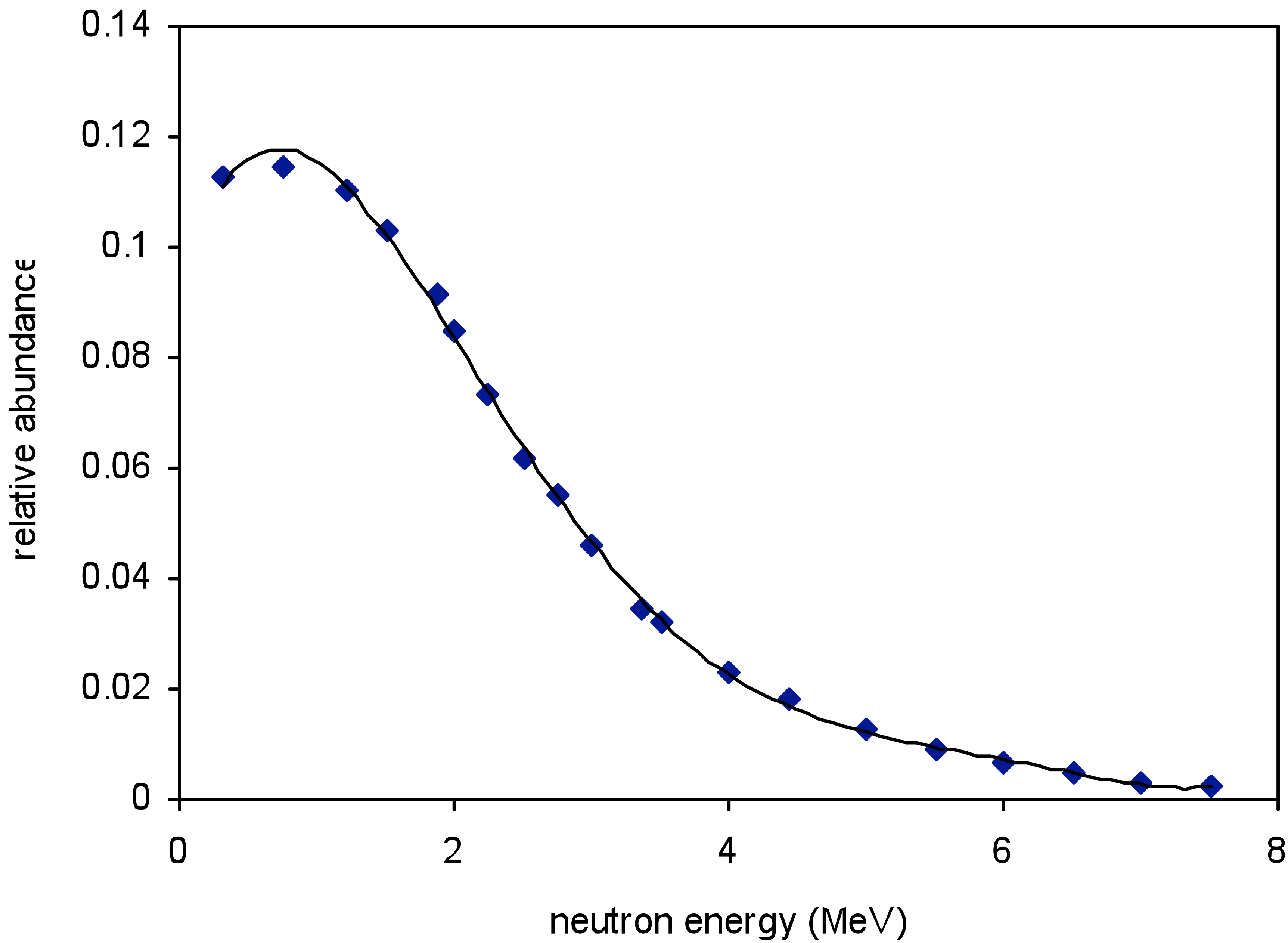
Au-198



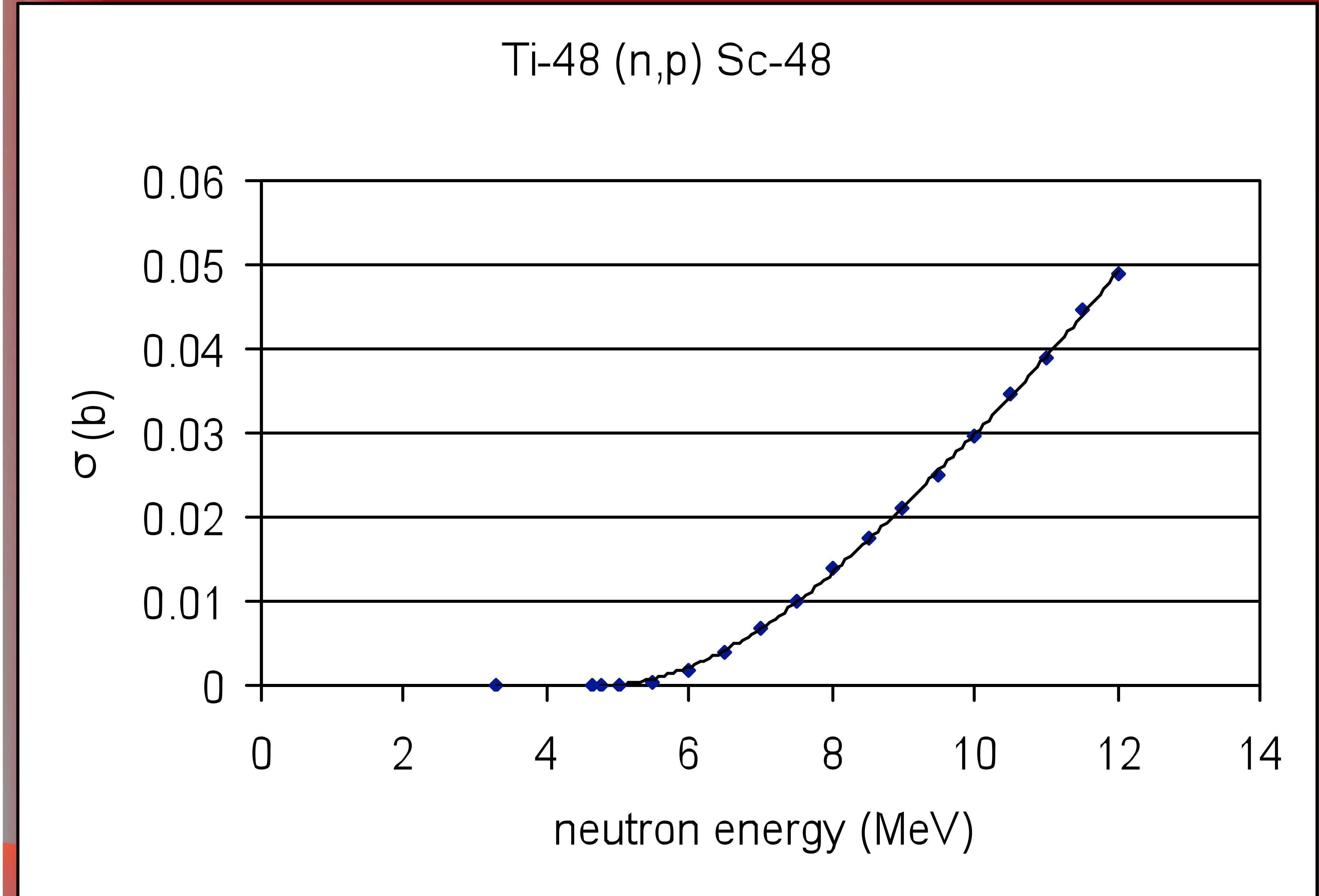
4000
3500
3000
2500
2000
1500
1000
500
0
intensity
0
200
400
600
800
1000
1200
1400
γ-energy (keV)

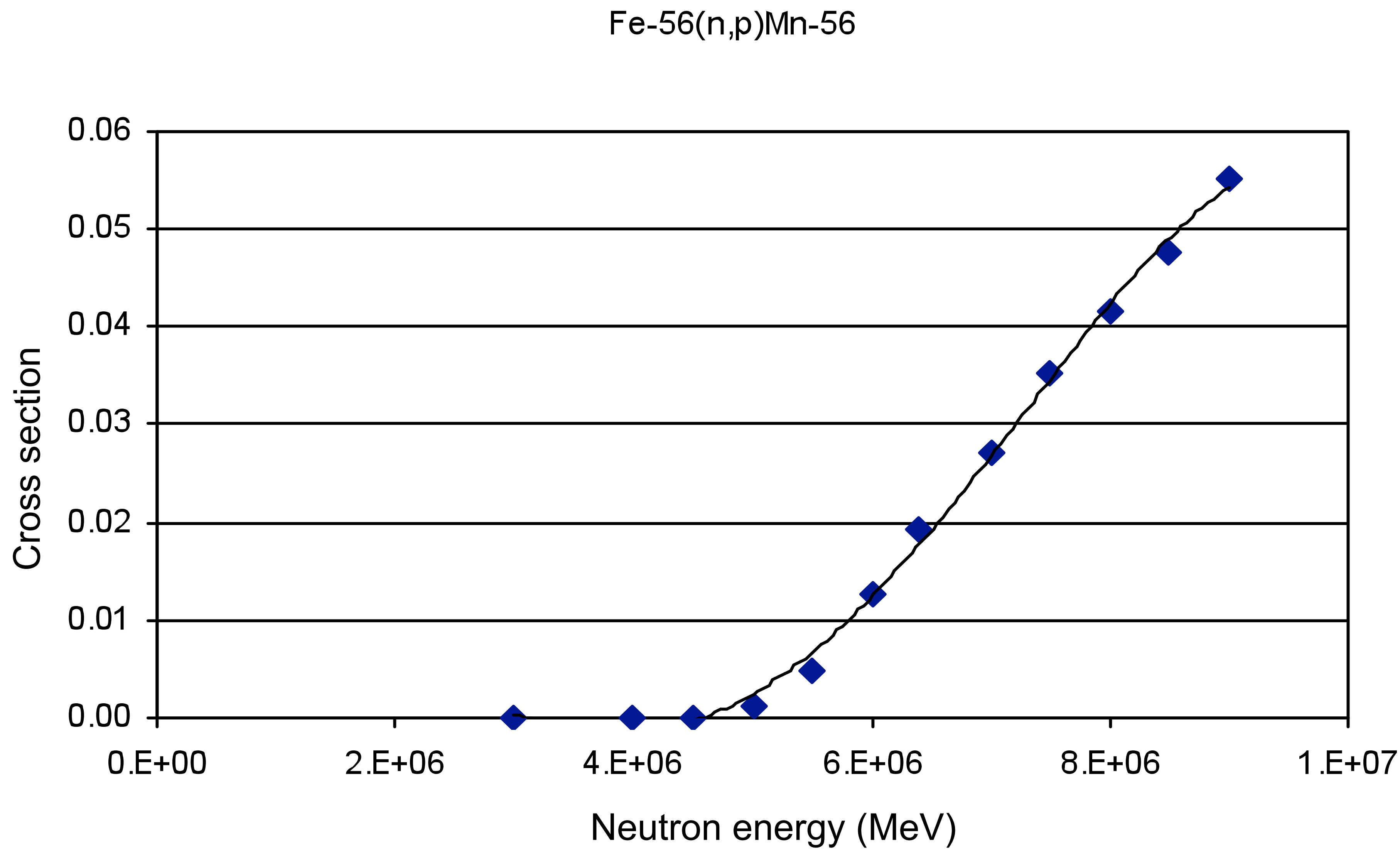


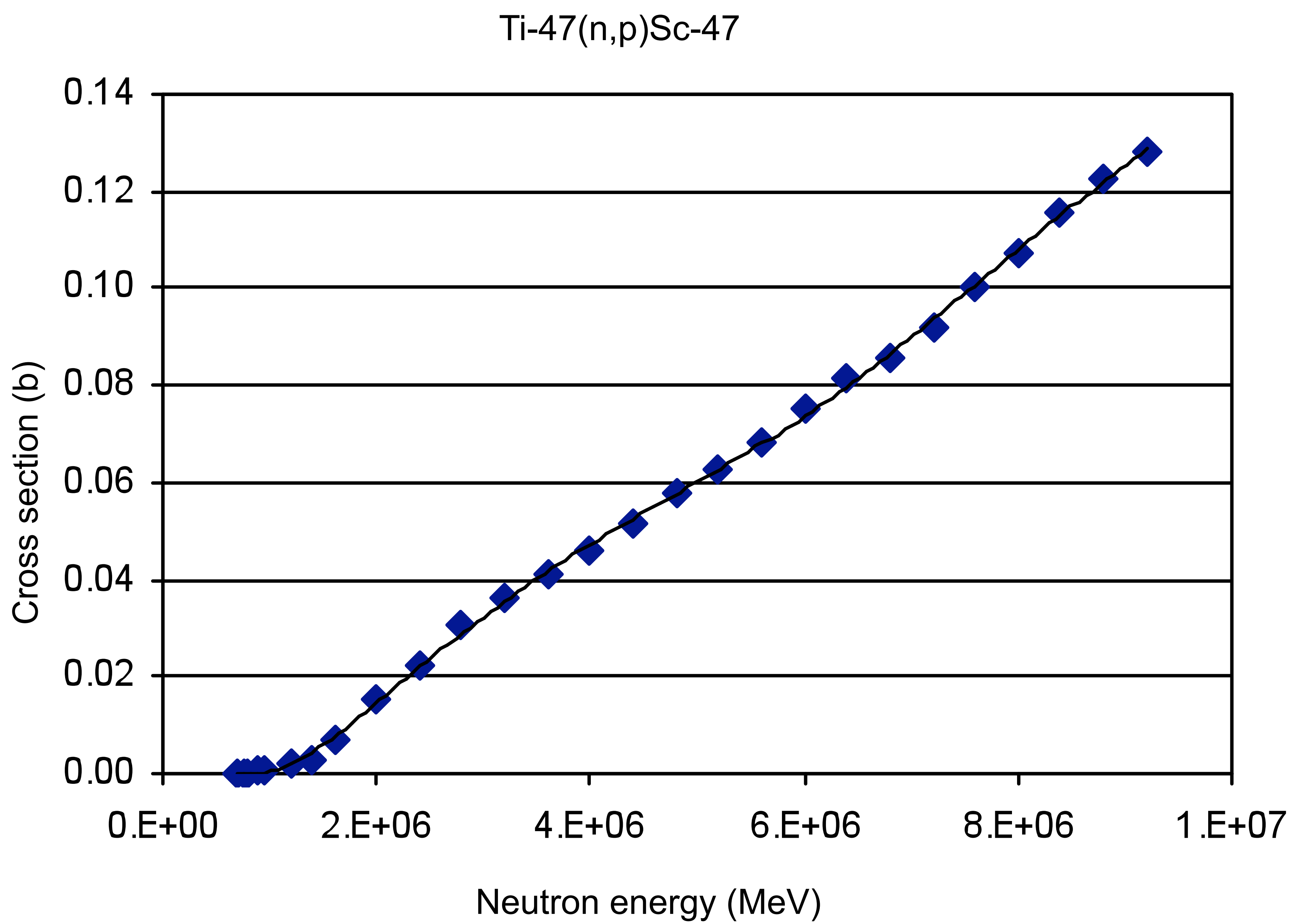
Counting Efficiency as a Function of Energy
1.00%
0.90%
0.80%
0.70%
0.60%
0.50%
0.40%
0.30%
0.20%
0.10%
0.00%
Efficiency
0
200
400
600
800
1000
1200
1400
Energy (KeV)

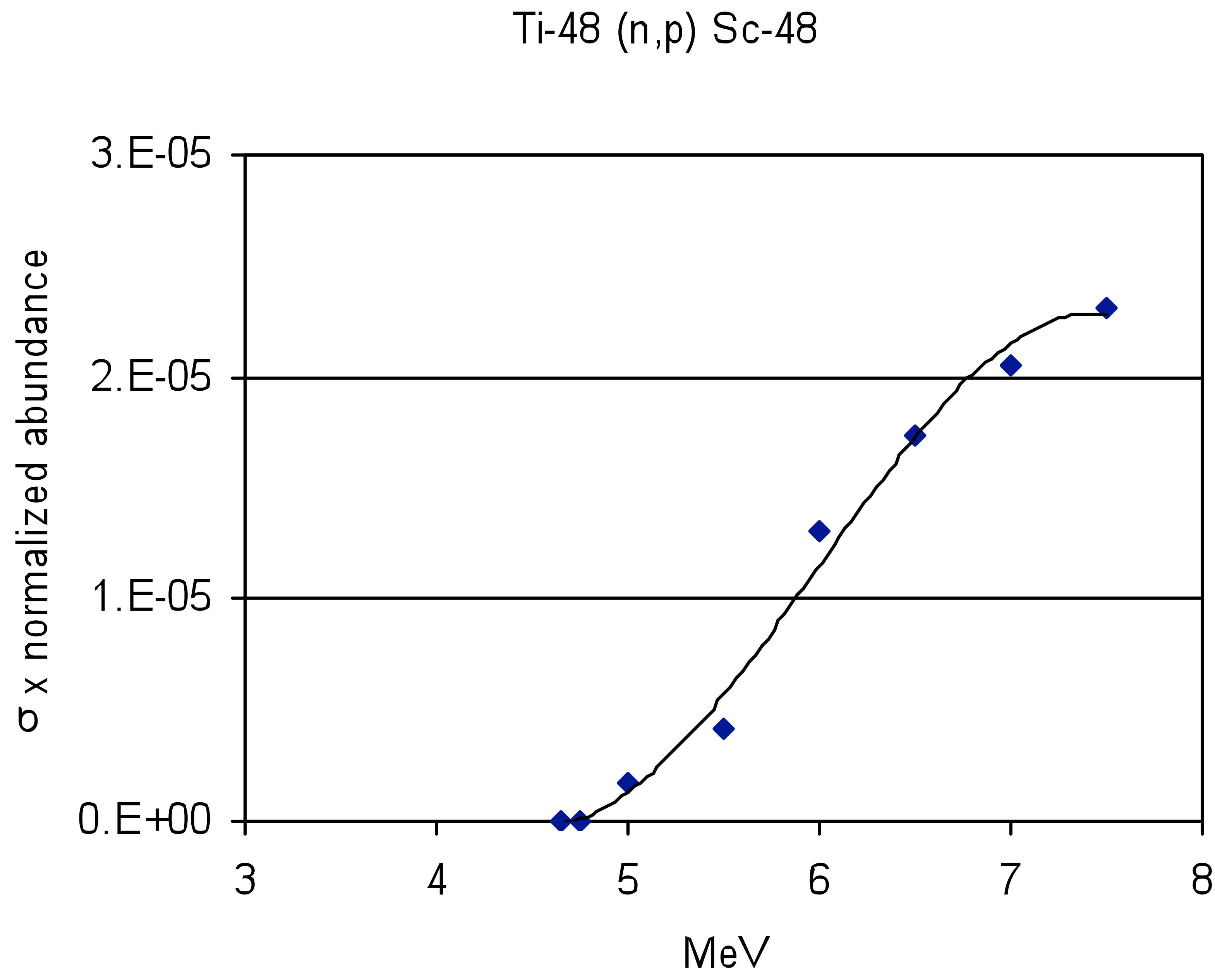


0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
relative abundance
0
2
4
6
8
neutron energy (MeV)


Ti-48 (n,p) Sc-48
σ (b)
0.06
0.05
0.04
0.03
0.02
0.01
0
0
2
4
6
8
10
12
14
neutron energy (MeV)

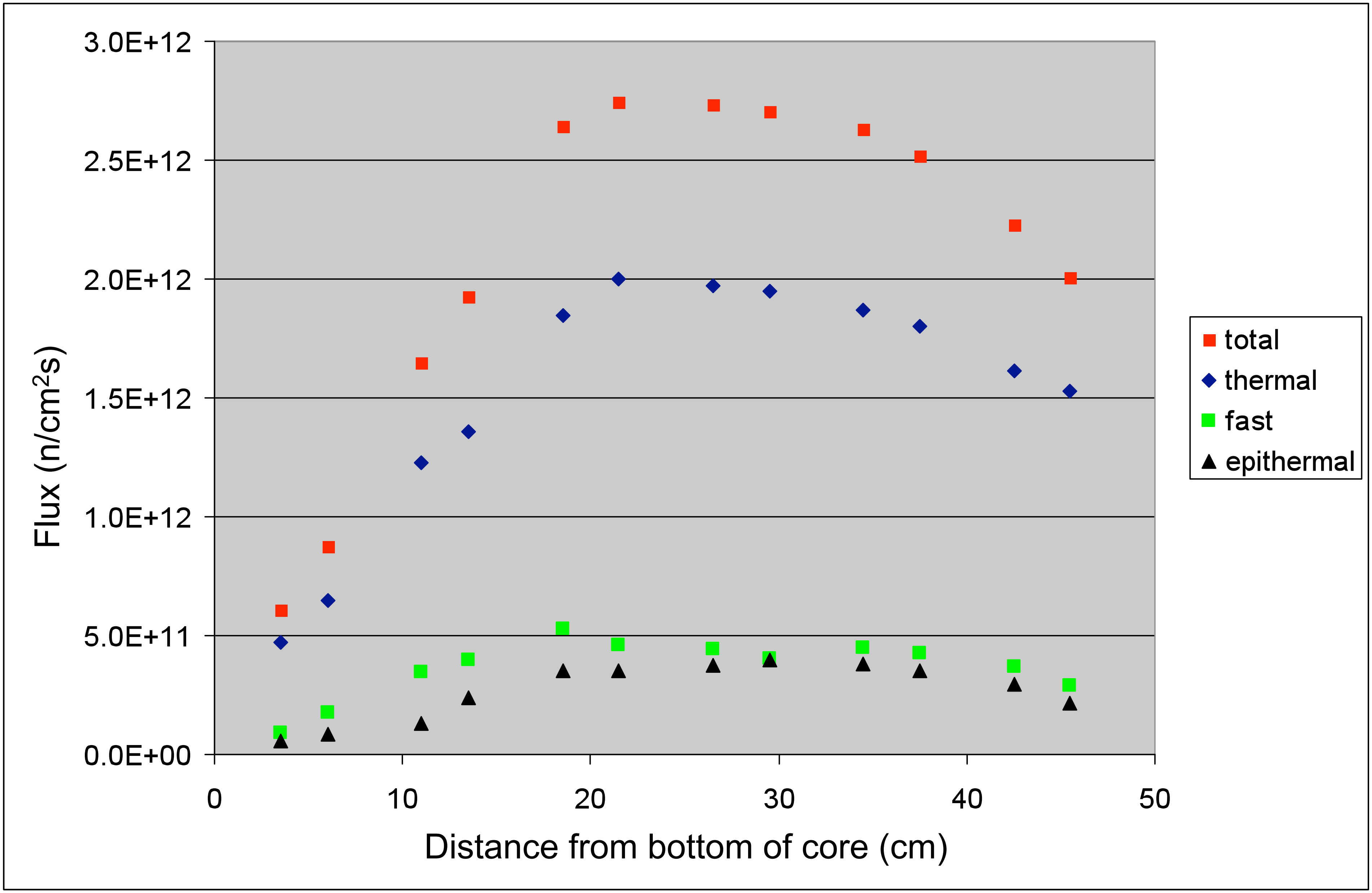

Fe-56(n,p)Mn-56
Cross section
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.E+00
2.E+06
4.E+06
6.E+06
8.E+06
1.E+07
Neutron energy (MeV)


Ti-47(n,p)Sc-47
Cross section (b)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.E+00
2.E+06
4.E+06
6.E+06
8.E+06
1.E+07
Neutron energy (MeV)

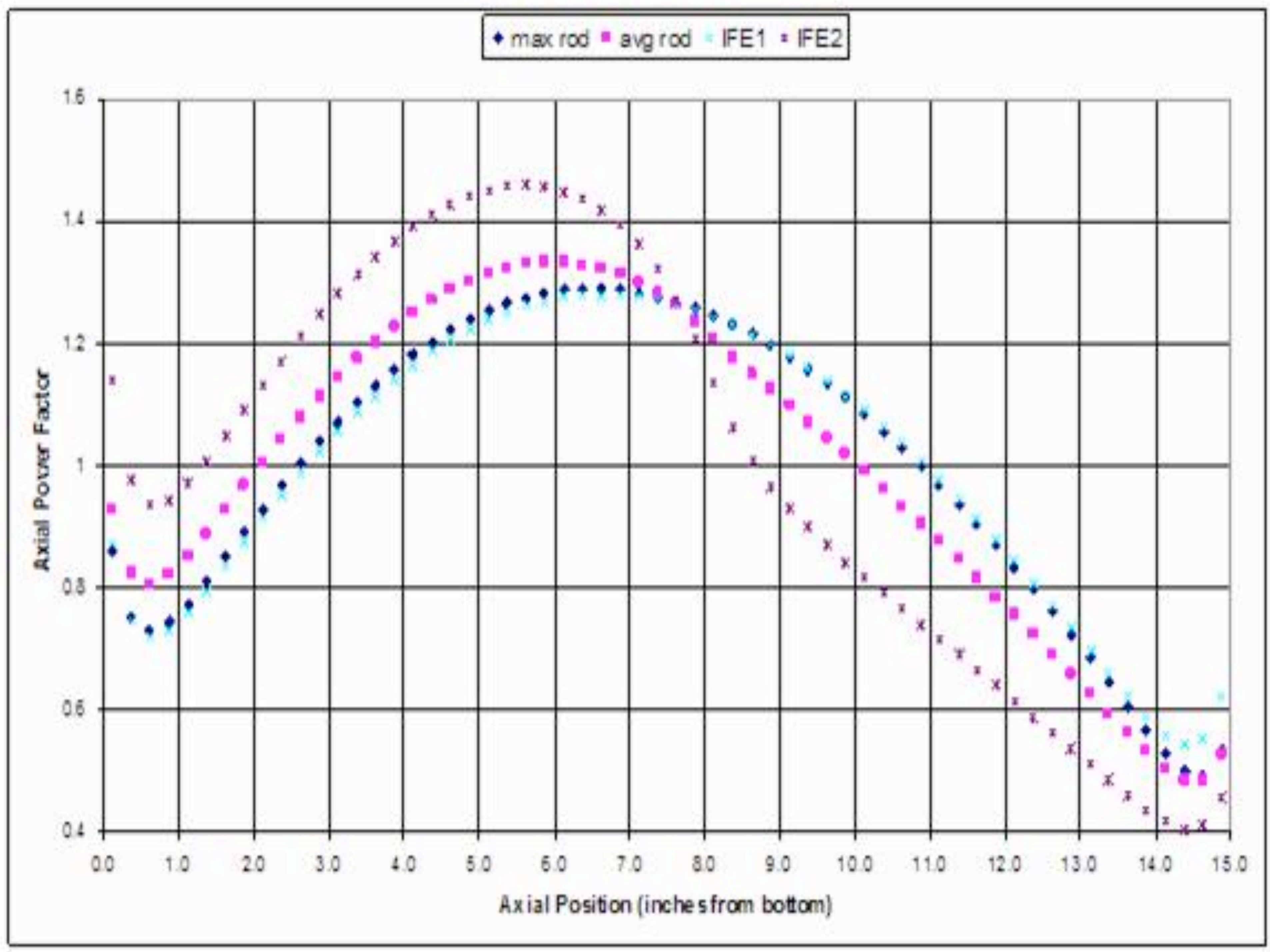

Ti-48 (n,p) Sc-48
3.E-05
2.E-05
1.E-05
0.E+00
σ x normalized abundance
3
4
5
6
7
8
MeV

		Power	1.00E+06	watts						
		total flux	5.30E+11	0.53						
		epi fraction	0.11							
		fast fraction	0.15							
						theoretical			product	
Product nuclide	Target nuclide	grams	thermal activity	epi activity	fast activity	total	therm %	epi %	half life	
Fe-59	Fe-58	0.0481	285	33		318	89.8%	10.2%	45.1	days
Co-60	Co-59	0.000505	676	167		843	80.2%	19.8%	5.27E+00	years
Cu-64	Cu-63	1.29E-05	4816	661		5477	87.9%	12.1%	12.701	hours
Au-198	Au-197	8.53E-07	649	1259		1908	34.0%	66.0%	2.695	days
Sc-46	Ti-46	0.1413			2.43				83.81	days
Sc-47	Ti-47	0.1413			1271.9				3.349	days
Sc-48	Ti-48	0.1413			1620.6				43.7	hours
Mn-54	Fe-54	0.0481			12.8				312.1	days
Mn-56	Fe-56	0.0481			333068.8				2.578	hours

- Fast neutron cross sections were set at the 7 MeV values for best fit for the $^{56}Fe(n,p)^{56}Mn$ reaction

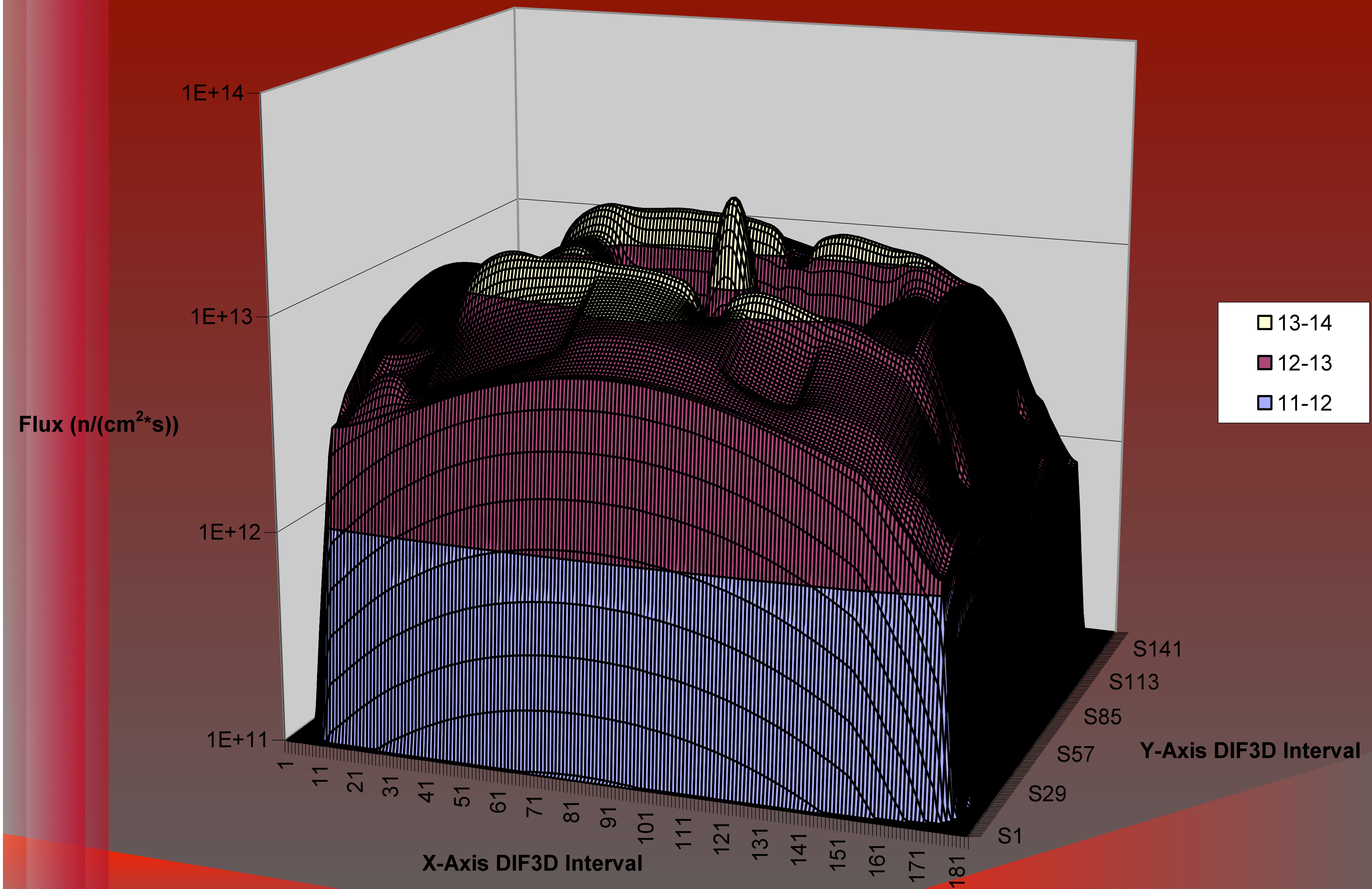


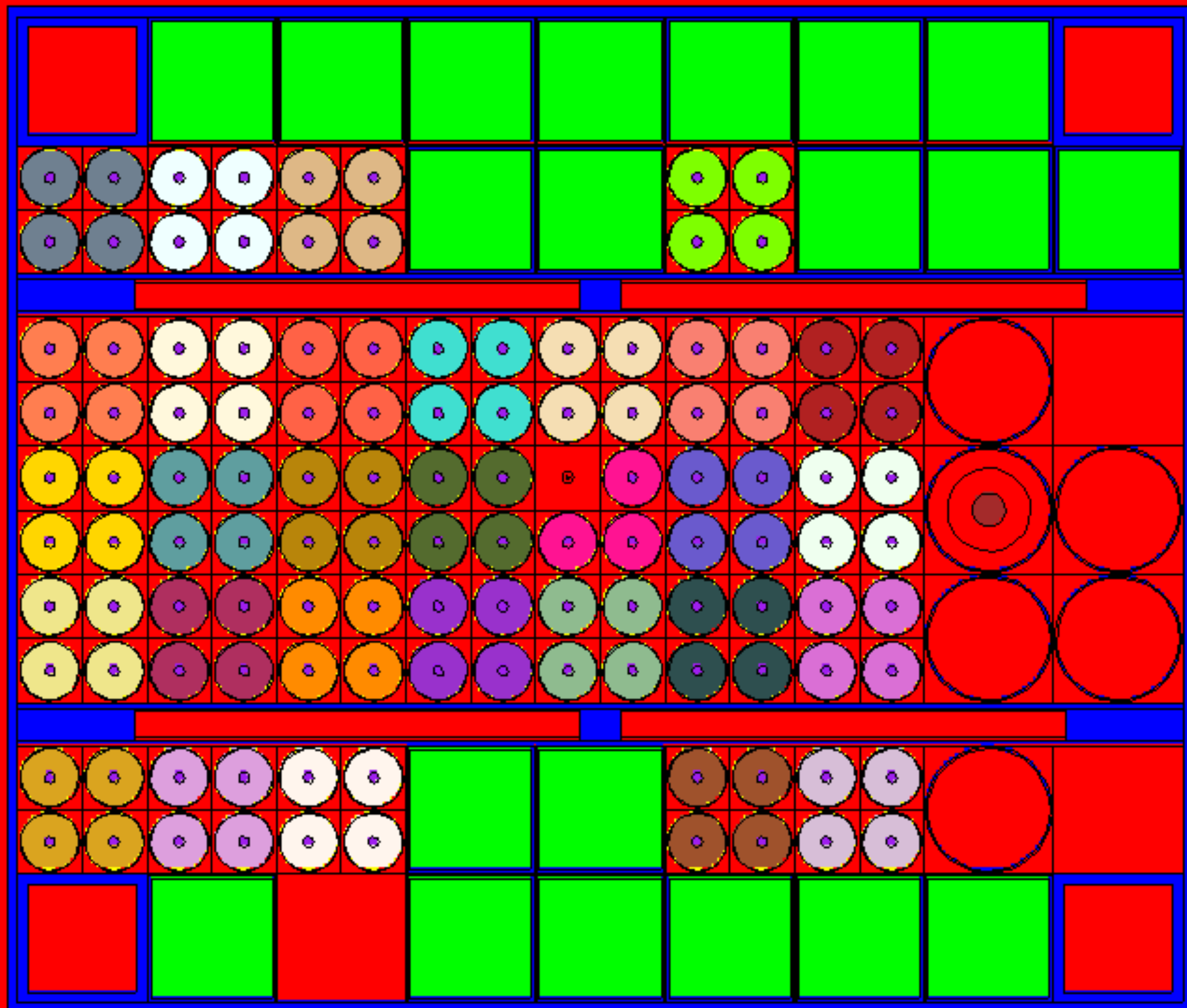
3.0E+12
2.5E+12
2.0E+12
1.5E+12
1.0E+12
5.0E+11
0.0E+00
Flux (n/cm2s)
0
10
20
30
40
50
Distance from bottom of core (cm)
total
thermal
fast
epithermal



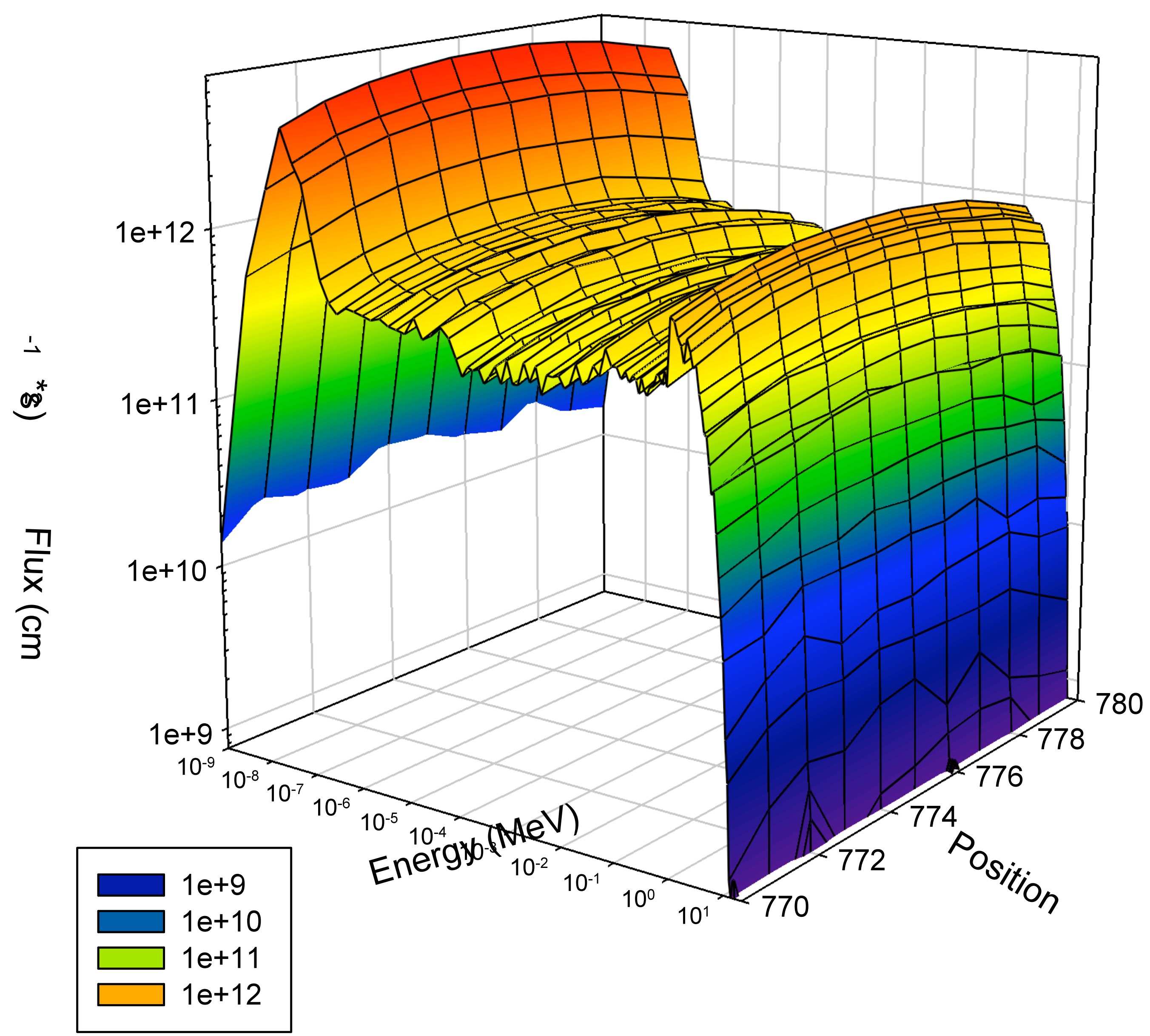
max rod
avg rod
IFE1
IFE2
1.6
1.4
1.2
1
0.8
0.6
0.4
Axial Power Factor
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
Axial Position (inches from bottom)

Thermal Neutron Flux (E < 0.42 eV) at Fuel Axial Centerline





Axial Flux Profile (Total)



Pulse Fluence*

Thermal neutron fluence	
Reaction	Fluence
$^{58}Fe(n,\gamma)^{59}Fe$	2.28×10^{14}
$^{59}Co(n,\gamma)^{60}Co$	2.44×10^{14}
$^{63}Cu(n,\gamma)^{64}Cu$	2.38×10^{14}
$^{197}Au(n,\gamma)^{198}Au$	2.37×10^{14}

Epithermal fluence	7.51×10^{13}

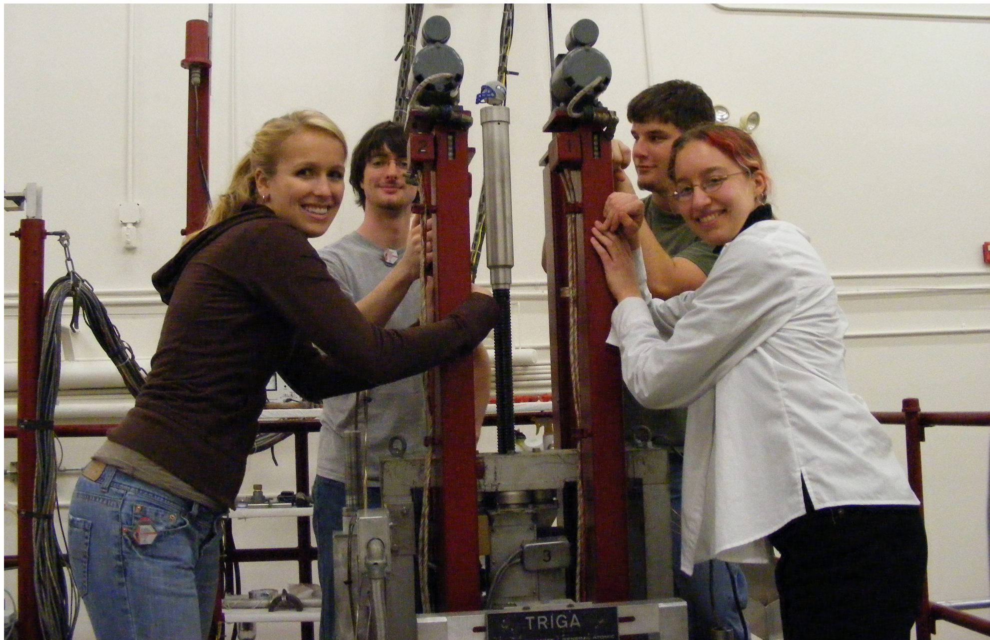
* $2.00 pulse

Pulse Fluence

Thermal neutron fluence	
Reaction	Fluence
$^{47}Ti(n,p)^{47}Sc$	2.53×10^{13}
$^{48}Ti(n,p)^{48}Sc$	2.96×10^{13}
$^{54}Fe(n,p)^{54}Fe$	2.78×10^{13}
$^{56}Fe(n,p)^{56}Fe$	3.00×10^{13}

Conclusions and Future Work

- Fast fluences during pulsing represent about 10% of the thermal fluence value, vs. about 15% for steady-state operation. The difference is likely due to choice of fast reaction cross-sections. This will be reevaluated.
- Pulsing epithermal ratios were determined with cadmium shielding. Examination of the ratio method vs. Cd shield is ongoing.


TRIGA


EXIT
CAUTION