Overview of the LBNL Na, K, Eu and Gd thermal (n,γ) σ_0 measurements

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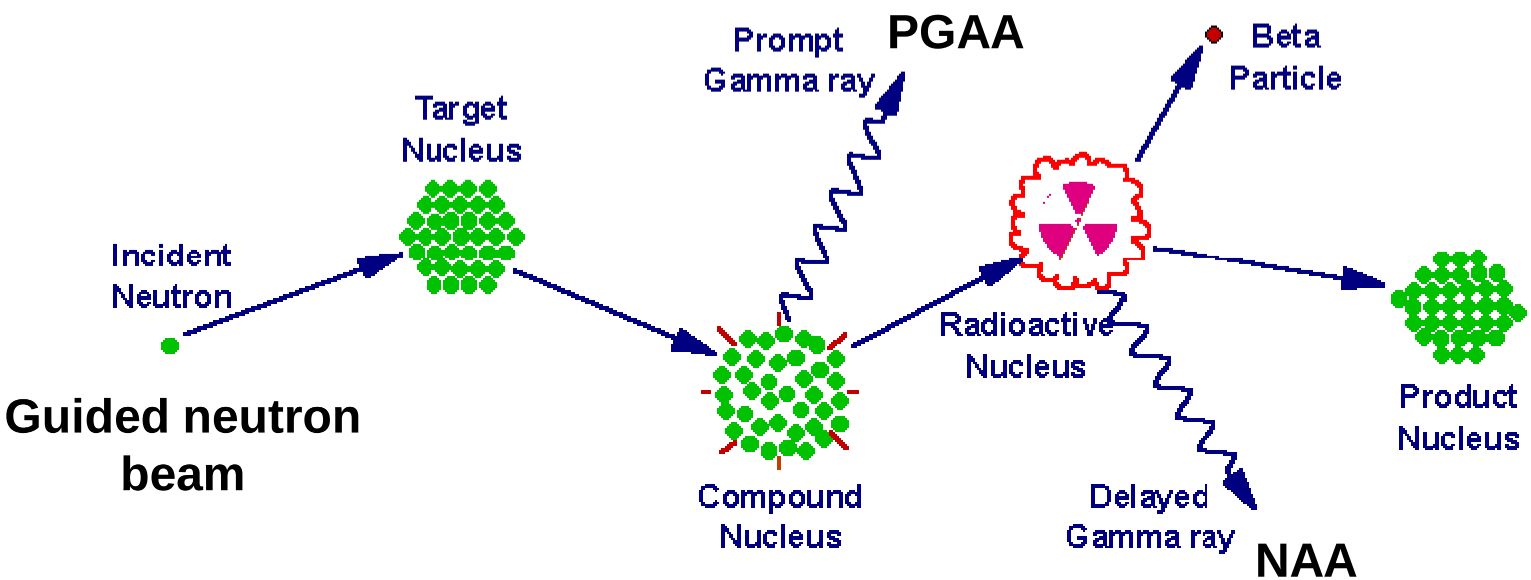
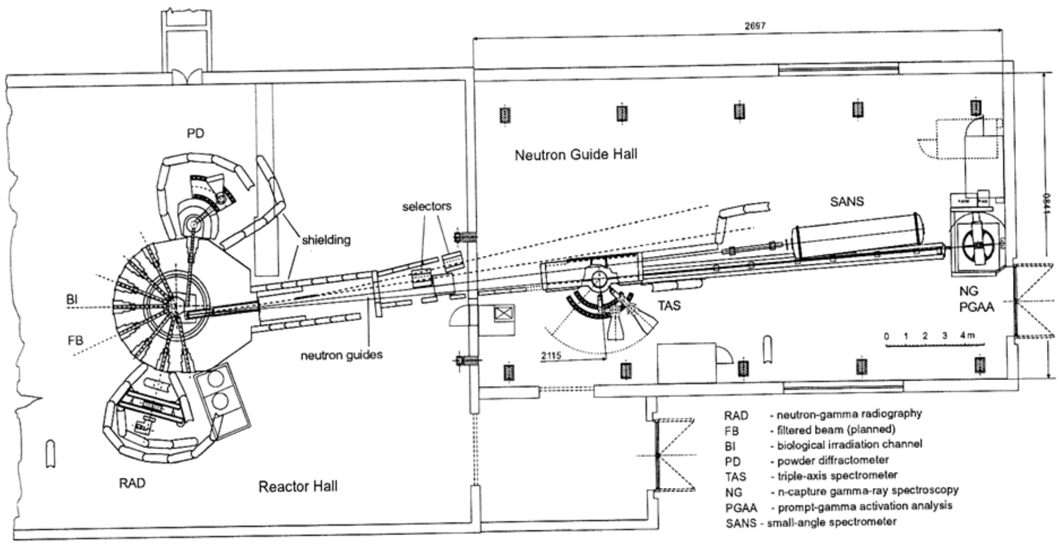


Cross section measurements



Budapest Reactor guided neutron beam produces prompt and delayed γ-rays on targets ~30 m from the reactor.

Standardization:

H, N, Cl, S, Na, Ti, Au

Stoichmetric compounds

Homogenous mixtures

Activation P_γ

Compton-suppressed γ-ray detector efficiency calibrated to <1% 0.5-6 MeV and <3% at other energies.

Thermal (n,γ) σ_0 determination

Light elements: $\sigma_0=\Sigma\sigma_\gamma(GS)=\Sigma\sigma_\gamma(CS)$

Heavy elements: $\sigma_0=\Sigma\sigma_\gamma(GS)^{expt}+\Sigma\sigma_\gamma(GS)^{stat}$

$\Sigma\sigma_\gamma(GS)^{stat}$ from DICEBOX calculation

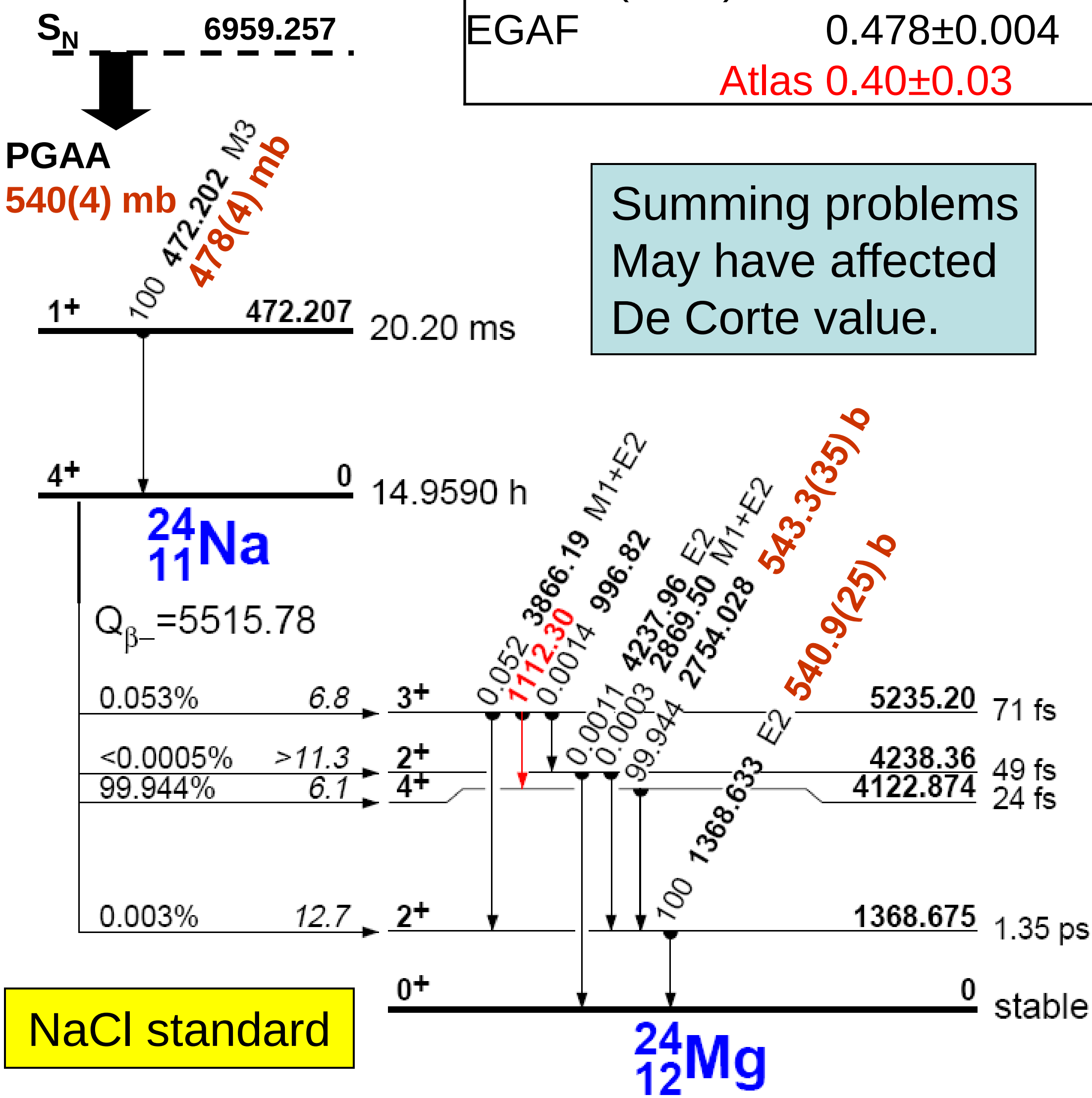
Level, gamma data below E_{crit} from RIPL, primary γ-ray data to levels below E_{crit} from EGAF

$^{23}Na(n,\gamma)$

^{24m}Na	
Author (year)	**$\sigma_0 \pm \Delta\sigma$ (mb)**
Alexander (1963)	0.40±0.03
Groshev (1955)	0.39±0.06
Matsue (2004)	0.476±0.011
EGAF	0.478±0.004
Atlas	0.40±0.03

^{24g}Na	
Author (year)	**$\sigma_0 \pm \Delta\sigma$ (mb)**
Coltman (1946)	0.47±0.04
Pomerance (1951)	0.470±0.024
Meadows (1961)	0.47±0.06
Brooksbank (1955)	0.50±0.05
Koehler (1963)	0.50±0.02
Yamamuro (1970)	0.50±0.03
Harris (1953)	0.503±0.005
Grimeland (1955)	0.51±0.03
De Corte (2003)	0.513±0.006
Kennedy (2003)	0.515±0.021
Heft (1978)	0.523±0.005
Ryves (1970)	0.527±0.005
Szentmiklosi (2006)	0.527±0.008
Bartholomew (1953)	0.530±0.032
Wolf (1960)	0.531±0.008
Cocking (1958)	0.536±0.006
Jowitt (1959)	0.536±0.008
Rose (1959)	0.539±0.008
EGAF-PGAA	0.540±0.004
EGAF-NAA	0.542±0.003
Gleason (1975)	0.54±0.02
Kaminishi (1963)	0.577±0.008
Seren (1947)	0.63±0.13
Atlas	0.517±0.004

Summing problems
May have affected
De Corte value.



NaCl standard

$^{39}K(n,\gamma)$

KCl standard calibration

E_γ(Cl) (keV)	Elemental σ_γ^a (barns)	$\sigma_\gamma(770.3)^b$ (barns)
517.1	7.80±0.07	1.009±0.016
787	9.09±0.09[c]	1.020±0.016
1164.9	9.17±0.08	1.023±0.016
1951.1	≡6.51±0.02	1.012±0.013
2863.8	1.871±0.017	1.011±0.021
4979.8	1.261±0.013	1.025±0.023
5715.2	1.871±0.021	1.024±0.021
6110.8	6.78±0.08	1.024±0.020
Adopted Value[d]		1.017±0.013

$$\sigma_0=2.252(16)^{expt}+0.028(28)^{stat}=2.28(4)\ b$$

^{39}K	
Author (year)	**$\sigma_0\pm\Delta\sigma$ (b)**
Hansen (1949)	3.0(15)
Pomerance (1952)	1.9(2)
Gillette (1966)	2.1(2)
EGAF	**2.28(4)**
Atlas	2.1(2)

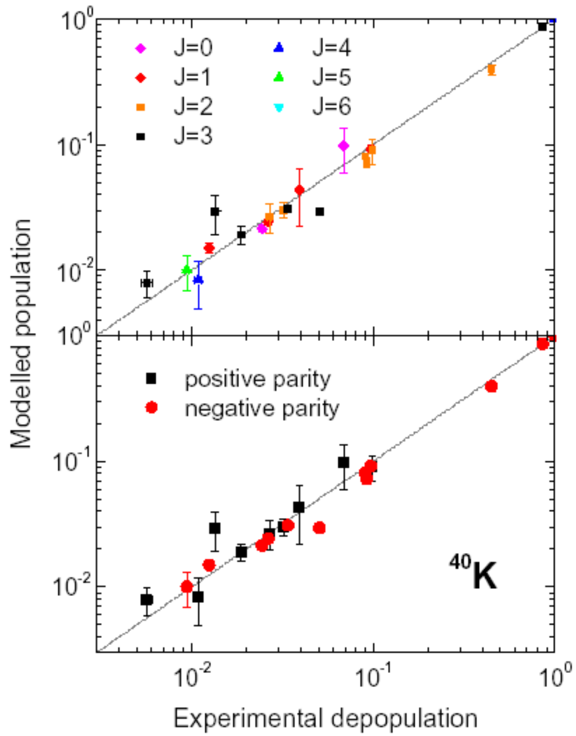
Experimental cross section balance* below E_{crit}

Level Energy (keV)	J^π	In (b)	Out (b)	Net[a] (b)
0	4^-	0.314(4)		{2.252(16)[b]
29.8299(5)	3^-	1.938(15)		
800.124(14)	2^-	0.992(11)	1.020 13	0.028(17)
891.55(3)	5^-	0.0195(11)	0.0216 6	0.0021(12)
1643.608(19)	0^+	0.165(4)	0.1567 24	-0.008(4)
1959.007(18)	2^+	0.1638(24)	0.225 3	0.061(4)
2047.375(20)	2^-	0.191(6)	0.2096 25	0.019(6)
2069.752(23)	3^-	0.098(3)	0.1153 21	0.018(3)
2103.544(22)	1^-	0.195(3)	0.217 3	0.022(5)
2260.49(4)	3^+	0.0228(14)	0.0306 13	0.0078(19)
2289.856(23)	1^+	0.0902(23)	0.0897 13	0.000(3)
2290.57(3)	3^-	0.0561(15)	0.0772 16	0.0211(22)
2397.14(4)	4^-	0.0256(15)	0.0253 10	0.000(2)
2419.111(23)	2^-	0.172(5)	0.201 3	0.029(6)
2575.92(4)	2^+	0.0427(17)	0.0622 14	0.0194(22)
2625.91(3)	0^-	0.0547(18)	0.0575 12	0.0028(21)
2730.30(3)	$1^{(-)}$	0.0486(19)	0.040 7	-0.009(7)
2746.75(3)	$(2,3)^-$	0.0058(4)	0.0131 9	0.0074(10)
2756.63(3)	2^+	0.0578(20)	0.0731 16	0.0153(25)
2786.60(3)	3^+	0.0354(15)	0.0461 17	0.0106(22)
2807.83(4)	$(1,2)^-$	0.0556(18)	0.0628 17	0.0071(25)

* Extensive (n,γ) data of von Egidy et al (1984) were also considered

$^{40}K(n,\gamma)$

Experimental cross section below E_{crit}. Most data come from Krusche et al* renormalized to EGAF data



$\sigma_0=86(7)^{expt}+4(4)^{stat}=90(7)$ b

^{39}K	
Author (year)	**$\sigma_0 \pm \Delta\sigma$ (b)**
Gillette (1966)	30(8)
Pomerance (1952)	66(30)
Beckstrand (1971)	≈70
EGAF	90(7)
Atlas	30(8)

Level Energy (keV)	J^{π}	In^{a} (b)	Out^{a} (b)	Net^{b} (b)
0	$3/2^+$	95(5)		95(5)
980.476(8)	$1/2^+$	3.4(3)	3.2(6)	0.2(7)
1293.609(8)	$7/2^-$	41(3)	37.1(18)	4(3)
1559.903(12)	$3/2^+$	4.9(3)	4.6(4)	0.3(5)
1582.001(11)	$3/2^-$	4.05(19)	4.1(3)	-0.0(4)
1593.107(12)	$1/2^+$	0.60(3)	0.52(8)	0.08(8)
1677.235(11)	$7/2^+$	17.3(10)	18.2(18)	-0.9(21)
1698.005(15)	$5/2^+$	5.3(3)	7.5(7)	-2.2(8)
2143.82(2)	$5/2^+$	4.46(19)	5.8(5)	-1.4(5)
2166.70(2)	$3/2^-$	1.43(11)	1.26(16)	0.17(19)
2316.62(2)	$5/2^-$	12.2(6)	11.1(23)	1.1(24)
2447.83(7)	$3/2^{+(c)}$	0.57(6)	0.42(4)	0.15(7)
2494.91(3)	$9/2^+$	3.76(18)	4.3(5)	-0.5(6)
2507.93(3)	$7/2^+$	4.37(23)	6.6(6)	-2.2(7)
2527.66(3)	$11/2^+$	2.53(12)	2.8(6)	-0.3(6)
2593.97(3)	$1/2^-,3/2^-$	0.51(3)	0.40(7)	0.11(7)

EGAF data	
E_{γ} (keV)	**σ_{γ} (b)**
1293.82(11)	37.1(19)
1677.5(3)	13(3)

* B. Krusche et al, Nucl. Phys. A**417**, 231 (1984)

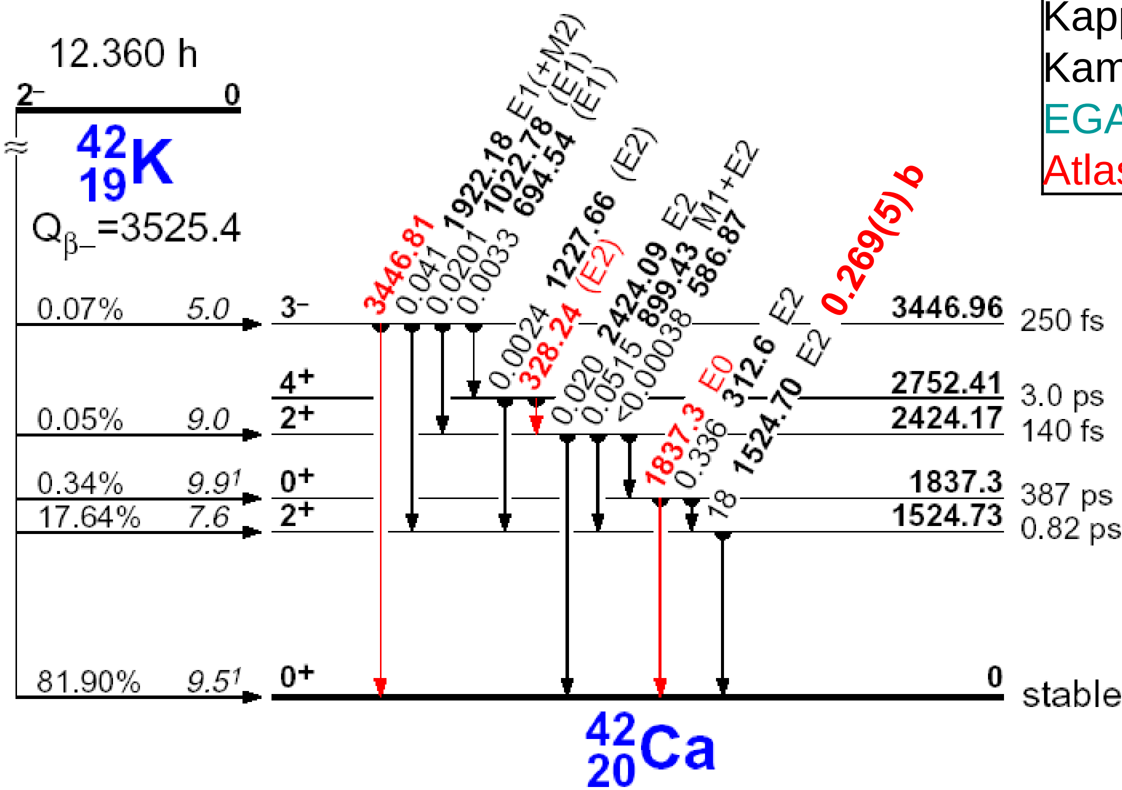
^{41}K(n,γ)

S_N 7533.80

PGAA

1.62(3) b

A significant problem may exist with P_γ values measured by 4πβ–γ. Many σ_0 values were measured this way



Author (Year)	$\sigma_0 \pm \Delta\sigma$ (mb)	σ_γ(1525)
Seren (1947)	1.0±0.2	
Pomerance (1952)	1.19±0.10	
Koehler (1967)	1.2±0.1	
Gryntakis (1976)	1.28±0.06	
De Corte (2003)	1.42±0.02	0.263(2)
Gleason (1975)	1.43±0.03	0.257(5)
Heft (1978)	1.43±0.03	0.252(5)
Lyon (1960)	1.45	
Ryves (1970)	1.46±0.03	
Kappe (1966)	1.49±0.03	0.266(8)
Kaminishi (1982)†	1.57±0.17	
EGAF	1.62±0.03	0.269(5)
Atlas	1.46±0.03	

† 4πβ–γ measurement corrected for self-absorption in the target.

Author (Year)	P_γ(1525)
Miyahara (1990)*	0.1808(9)
Simoes (2001)*	0.1813(14)
EGAF	0.164(4)

* 4πβ–γ measurements uncorrected for self-absorption in the target.

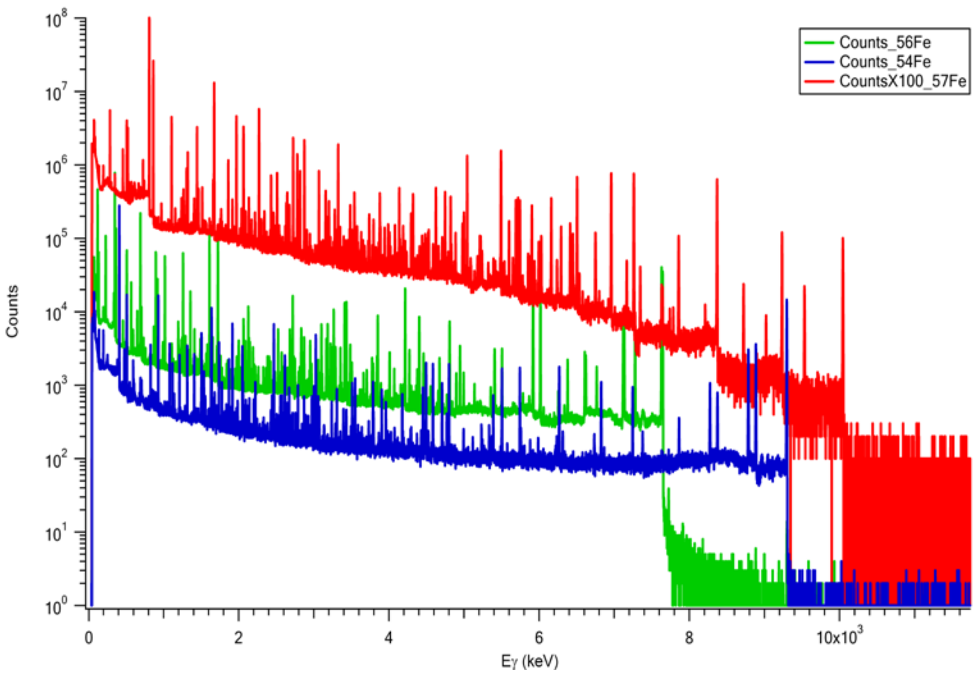
$^{54,56,57}Fe(n,\gamma)$

Tamas Belgya, Budapest Neutron Centre

Sample	^{54}Fe %	^{56}Fe %	^{57}Fe %	^{58}Fe %
Enriched in ^{54}Fe	99.77	0.2(1)	<0.05	<0.05
Enriched in ^{56}Fe	0.04(1)	99.94	0.02(1)	-
Enriched in ^{57}Fe	<0.1	0.7(1)	96.06	3.2(3)

Standardization

		Emental				Isotopic	
$Fe_2(SO_4)_3$		This work		PGAA Handbook		This work	
Isotope	E_γ keV	σ_γ (b)	Unc.	σ_γ (b)	Unc.	σ_γ (b)	Unc.
Fe-54	411	0.0262	0.0004	0.022	0.005	0.448	0.007
Fe-56	352	0.2737	0.003	0.273	0.003	0.298	0.003
Fe-57	810	0.0273	0.0004	0.0274	0.0009	1.286	0.021

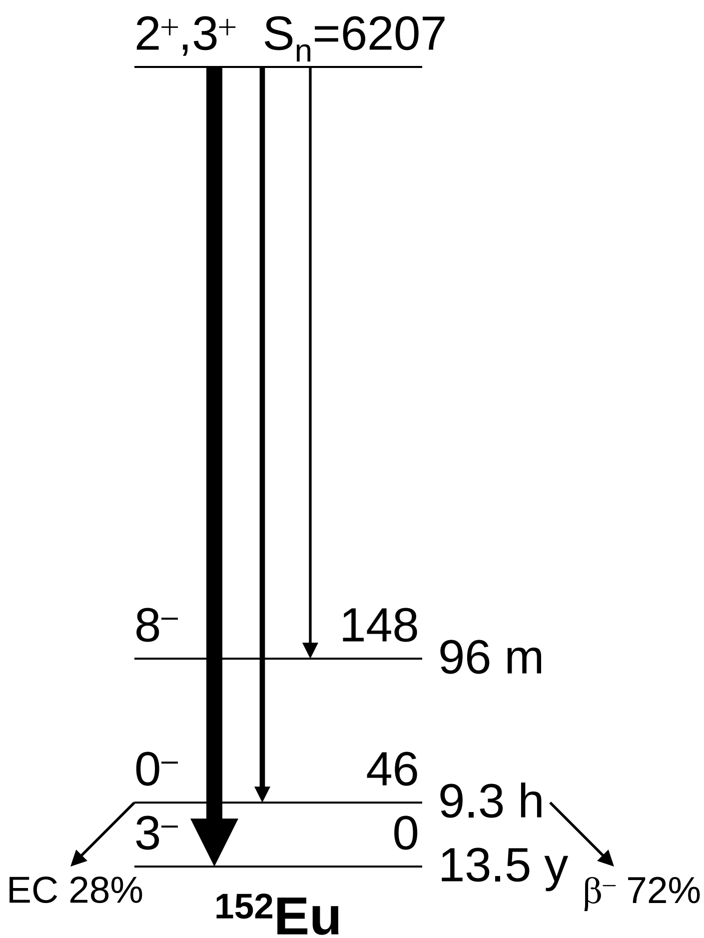


Spectra of $^{54,56,57}Fe$ neutron capture γ-rays

Reaction	Author (year)	σ_0 (b)
$^{54}Fe(n,\gamma)$	Wallner (2010)	2.33(10)
	EGAF	2.13(4)
	Atlas	2.25(18)
$^{56}Fe(n,\gamma)$	EGAF	2.47(2)
	Atlas	2.59(14)
$^{57}Fe(n,\gamma)$	EGAF	1.65(3)
	Atlas	2.48(30)

^{151,153}Eu(n,γ)

Shamsu Basunia, LBNL



^{151}Eu(n,γ)^{152}Eu^{g}	
Author (Year)	**σ_0 (b)**
Alian (1973)	4056(127)
Sims (1967)	4410(66)
Hayden (1949)	5200
Kafala (1997)	5915(51)
Kim (1975)	5935(73)
Heft (1978)	6290(25)
De Corte (2003)	6885(15)
EGAF	**6900(300)**
Atlas	**5900(200)**
^{151}Eu(n,γ)^{152}Eu^{m}	
Seren (1947)	1380(276)
Hans (1960)	1700(250)
EGAF	**2265(300)**
Ryves (1971)	2620(24)
Sims (1967)	2951(85)
Kim (1975)	3211(82)
De Corte (2003)*	3219(2)
Poortmans (1971)	3236(20)
Heft (1978)	3490(30)
Atlas	**3300(200)**
^{151}Eu(n,γ)^{152}Eu^{m+g}	
Tattersall (1960)	8790(90)
EGAF	**9165(400)**
Widder (1975)	9170(300)
Poortmans (1971)	9184(140)
Atlas	**9200(100)**

All measurements from activation assume that $P_\gamma(344\gamma)=0.024(3)$ from ^{152}Eu β^- decay (1957Na01) $\beta\gamma$ coinc (NaI, mag. Spec).

From this work

$P_\gamma(344\gamma)=0.0327(14)$

^{153}Eu(n,γ)^{152}Eu^{g}	
Author (Year)	**σ_0 (b)**
Hayden (1949)	240
EGAF	**292(12)**
Heft (1978)	295(5)
Kafala (1997)	313(8)
De Corte (2003)	316(4)
Tattersall (1959)	319(5)
Lucas (1977)	325(38)
Widder (1975)	391(14)
Pattenden (1958)	448(16)
Gryntakis (1975)	603(23)
Sims (1967)	639(7)
Atlas	**316(8)**

- Assuming $P_\gamma(344\gamma)=0.024(3)$
- Experiemt: $\sigma_\gamma(344)=75.7(15)$ b

^{155,157}Gd(n,γ)

Heedong Choi, Seoul University, S. Korea

Westcott g-factor	
^{155}Gd(n,γ)	0.895(16)
^{157}Gd(n,γ)	0.861(16)

GdB_6 standardization

Self absorption correction needed for 88.97-keV γ-ray (^{156}Gd) and 79.51-keV γ-ray (^{158}Gd) deexciting first excited states. EGAF σ_0 cross sections will increase.

DICEBOX calculations suggests that expected feeding to 79.5-kev level gives

$\sigma_0(^{157}\text{Gd})=284000$ b

Tune in next year for "final" result.

^{155}Gd(n,γ)^{156}Gd	
Author (year)	**σ_0 (b)**
Walker (1956)	25000
Inghram (1950)	41400
Tattersall (1960)	49800(600)
EGAF	**56300(1900)**
Groshev (1962)	61000(5000)
Pattenden (1958)	66000(2000)
Atlas	**60900(500)**
^{157}Gd(n,γ)^{158}Gd	
Tattersall (1960)	213000(2000)
Leinweber (2006)	226000
EGAF	**239000(6800)**
Groshev (1962)	240000(12000)
Pattenden (1958)	264000(4500)
Atlas	**254000(815)**

Future Plans

- Submit elemental evaluation papers to refereed journals (Na, K, Eu, W, …)
- New measurements of ^{2}H, ^{3}He, Zr cross sections at Garching Reactor
- New measurements of ^{180}W and other separated isotopes TBD
- Continued development of EGAF elemental publications in Nuclear Data Sheets
- Evaluated RIPL data for (n,γ) on stable and selected radioactive targets