IAEA CRP: Development of a Database for NAA

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November 4, 2009

Comparison of Neutron Activation Analysis k_0 and σ_0 Data

Two independent "standard" cross section databases exist for physicists (σ_0) and chemists (k_0). They are related by

$$(k_{0,Au})x = [M_{Au}\theta_x\sigma_{0,x}P_x] / [M_x\theta_{Au}\sigma_{0,Au}P_{Au}]$$

Au = comparator 411.8 keV γ-ray
x = γ-ray from element of interest
M = atomic mass (M_{Au}=196.96655)
θ = isotopic abundance (θ_{Au}=100)
$\sigma_{0,x}$ = thermal radiative neutron cross section ($\sigma_{0,Au}$=98.65 b) P_γ = γ-ray transition probability (P_{Au}=0.9554)

Sources of Data

Total radiative thermal neutron cross sections (σ_0)

- Mughabghab, *Atlas of Neutron Resonances* (Elsevier, 2006) - evaluation
- CSISRS file, NNDC, Brookhaven Laboratory - compilation
- NSR reference database - references

Gamma-ray cross sections

k_0: De Corte and Simonits, ADNDT **85**, 47-67 (2003) - delayed γ-rays

σ_γ: EGAF, Budapest Reactor - prompt and delayed γ-rays

Gamma-ray emission probablilities (P_γ)

DDEP *Table of Radionuclides,* Bureau International des Poids et Measures

ENSDF decay datasets

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Preliminary Results

Data from all sources were evaluated to obtain a self-consistent set of k_0/s_0 values.

- σ_0 for 304 activation product isotopes were evaluated
- Self-consistent σ_γ/k_0 values for 6428 γ-rays were adopted

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Future Directions

- A k_0 Nuclear Data Committee headed by Zs. Revay (Budapest) has been formed to adopt k0 values for the INAA chemistry community.
- Discrepant k_0 values will be remeasured when possible
- Self consistent k_0/σ_0 data will be included in the EGAF database.
- Final results will be included in EGAF-2

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Preliminary Results

Target	Isotope	Energy	Half-life	$\sigma_0 \pm \Delta\sigma_0$(b)-Atlas	$\sigma_0 \pm \Delta\sigma_0$(b)-Adopted
2H	3H	0.0	12.312±0.025 y	0.3326±0.0007	0.3326±0.0007
7Li	8Li	0.0	839.9±0.9 ms	0.0454±0.0027	0.0452±0.0014
9Be	10Be	0.0	1.51±0.04 My	0.00849±0.00034	0.0088±0.0004
11B	12B	0.0	20.2±0.02 ms	0.0055±0.0033	0.00906±0.0002
13C	14C	0.0	5730±40 y	0.00137±0.00004	0.0015±0.00003
14N	14C	0.0	5730±40 y	1.86±0.03	1.92±0.05
15N	16N	0.0	7.13±0.02 s	0.000024±0.000008	0.000039±0.000003
18O	19O	0.0	26.88±0.05 s	0.00016±0.00001	0.000175±0.000008
19F	20F	0.0	11.163±0.008 s	0.00951±0.00009	0.00935±0.00009
22Ne	23Ne	0.0	37.24±0.12 s	0.0455±0.006	0.033±0.005
23Na	24Na	0.0	14.9574±0.002 h	0.517±0.004	0.541±0.004
23Na	24Na	472.2	20.18±0.1 ms	0.4±0.03	0.478±0.004
26Mg	27Mg	0.0	9.458±0.012 m	0.0384±0.0006	0.0379±0.0008
27Al	28Al	0.0	2.2414±0.0012 m	0.231±0.003	0.232±0.003
30Si	31Si	0.0	157.3±0.3 m	0.107±0.002	0.116±0.003
31P	32P	0.0	14.284±0.036 d	0.165±0.003	0.168±0.005
34S	35S	0.0	87.32±0.16 d	0.256±0.009	0.262±0.004
36S	37S	0.0	5.05±0.02 m	0.236±0.006	0.249±0.008
35Cl	36Cl	0.0	301±3 ky	43.6±0.4	43.48±0.18
37Cl	38Cl	0.0	37.23±0.014 m	0.433±0.006	0.433±0.006
37Cl	38Cl	671.4	715±3 ms	0.047±0.01	0.0537±0.0013
36Ar	37Ar	0.0	35.04±0.04 d	5.2±0.5	6.1±0.8
38Ar	39Ar	0.0	269±3 y	0.8±0.2	0.8±0.2
40Ar	41Ar	0.0	109.61±0.04 m	0.66±0.01	0.643±0.013
39K	40K	0.0	1.265±0.013 Gy	2.1±0.2	2.21±0.03
41K	42K	0.0	12.36±0.012 h	1.46±0.03	1.523±0.022
40Ca	41Ca	0.0	1.03±0.03 ky	0.41±0.02	0.416±0.007
44Ca	45Ca	0.0	162.61±0.09 d	0.88±0.05	1.11±0.03
46Ca	47Ca	0.0	4.536±0.003 d	0.74±0.07	0.7±0.03

^{12}C, ^{2}H Cross Sections

^{12}C Author (Year)	σ_0	$\Delta\sigma$ (mb)
Prestwich (1981)	3.50	0.16
Jurney (1982)	3.53	0.07
Nichols (1960)	3.57	0.03
Sagot (1963)	3.72	0.15
Jurney (1963)	3.8	0.4
Starr (1962)	3.83	0.06
Hennig (1967)	3.85	0.15
Matsue (2004)	3.81	0.11
EGAF (2007)	3.90	0.06
Atlas	3.53	0.07
Adopted	**3.84**	**0.06**

^{2}H Author (Year)	σ_0	$\Delta\sigma$ (mb)
Trail (1964)	0.36	0.03
Alfimenkov (1980)	0.476	0.020
Jurney (1982)	0.508	0.015
Merritt (1968)	0.521	0.009
Silk (1969)	0.523	0.029
Ishikawa (1973)	0.55	0.01
Kaplan (1952)	0.57	0.01
Jurney (1963)	0.60	0.05
Sargent (1947)	0.92	0.22
Atlas	0.508	0.015
Adopted	**0.549**	**0.010**

The $\sigma_0(^{12}C)$ measurement by Jurney is discrepant by 10%. Jurney used this value to standardize the $\sigma_0(^{2}H)$ measurement.

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$^{23}Na(n,\gamma)^{24}Na$ cross section balance

Level	JPI	σ_{in} (mb)	σ_{out} (mb)	σ_{in}-σ_{out}	Level	JPI	σ_{in} (mb)	σ_{out} (mb)	σ_{in}-σ_{out}
0	4+	540.29±4.07		540.29±4.07	4206.991	2+	59.69±1	64.75±0.32	-5.06±1.05
472.234	1+	500.57±3.61	501.24±4	-0.66±5.39	4441.453	2-	73.71±0.7	71.08±0.38	2.63±0.8
563.158	2+	254.81±1.22	259.78±3.01	-4.97±3.24	4561.862	1-	7.05±0.09	6.38±0.16	0.66±0.18
1341.498	2+	117.77±0.5	117.62±1.5	0.15±1.59	4621.4		0.57±0.02	0.35±0.1	0.22±0.1
1344.501	3(+)	42.32±3.04	38.55±0.22	3.77±3.05	4690.84			5.220.58	-5.220.58
1346.598	1+	80.45±0.55	79.6±1.3	0.85±1.41	4750.854	2-	26.82±0.24	25.59±0.21	1.24±0.32
1845.932	2+	33.13±0.15	32.91±0.28	0.22±0.32	4891.22			1.70.7	-1.70.7
1885.478	3+	7.25±0.14	9.79±0.06	-2.54±0.15	5030.56			1.560.02	-1.560.02
2513.248	3+	9.24±0.09	10.01±0.1	-0.77±0.13	5044.825	(1,2,3)-	6.02±0.06	6.42±0.13	-0.4±0.14
2562.22	4+,(2+)		1.50.2	-1.50.2	5059.449	2-	0.16±0.01	4.49±0.13	-4.33±0.13
2903.87	3+	5.22±0.19	1.57±0.03	3.66±0.19	5117.16	1-	2.46±0.19	1.87±0.04	0.59±0.19
2977.691	2+,3+	79.54±0.94	78.21±0.39	1.33±1.02	5192.28		0.32±0.01	0.26±0.02	0.06±0.02
3371.694	2-	74.31±1.7	70.45±0.39	3.86±1.75	5252.01	2-	0.19±0.06	0.19±0.04	0±0.07
3413.186	1+	11.8±0.13	12.28±0.08	-0.48±0.16	5338.94	2-	2.97±0.03	3.15±0.06	-0.18±0.07
3589.199	1+	16±0.21	24.23±0.38	-8.24±0.43	5396.86	(1,3)-	2.57±0.03	0.76±0.12	1.81±0.12
3628.26	3+	1.34±0.03	1.63±0.04	-0.29±0.05	5478.9	1-	1.8±0.02	1.34±0.12	0.46±0.12
3655.77	(2+,1+)	4.91±0.34	2.13±0.05	2.79±0.34	5809.4		5.8±0.08	12.08±0.7	-6.28±0.71
3681.68	0+	4.14±0.06	3.78±0.05	0.36±0.08	5863.06		0.22±0.1	0.12±0.02	0.1±0.1
3744.957	3-	7.54±0.17	4.95±0.07	2.58±0.18	5918.074		1.53±0.02	1.16±0.03	0.38±0.04
3865.89		1.63±0.04	3.22±0.04	-1.59±0.06	5953.322	0+	0.76±0.15	0.76±0.15	0±0.21
3935.15	(0+ to 4+)	0.46±0.15	1.54±0.03	-1.08±0.15	5966.81	1+	0.1±0.01	0.07±0.01	0.03±0.01
3977.174	(1-,2+)	23.6±0.71	14.8±0.11	8.8±0.72	6072.53	1+	4.08±0.04	3.9±0.09	0.18±0.1
4048.67	4-,(5-)	0.64±0.02	0.51±0.04	0.14±0.05	6222.05		0.11±0.03	0.7±0.03	-0.59±0.04
4143	2+		0.410.14	-0.410.14	6247.374		4.69±0.04	6.66±0.43	-1.97±0.43
4186.7	(1,2)-	0.42±0.14	0.39±0.12	0.03±0.19	6959.257	1+,2+		527.61±3.95	-527.613.95
4195.98	(1,2)-	2.81±0.14	2.57±0.05	0.24±0.14					

^{23}Na

^{23}Na Author (year)	σ_0	$\Delta\sigma$ (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
Budapest-PGAA	0.540	0.004
Budapest-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
Adopted	**0.541**	**0.004**

^{23m}Na Author (year)	σ_0	$\Delta\sigma$ (mb)
Alexander	0.40	0.03
Groshev	0.39	0.06
Matsue	0.476	0.011
Budapest-PGAA	0.478	0.004
Atlas	0.40	0.03
Adopted	**0.478**	**0.004**

New measurement planned by Simonits.

^{41}K

^{40}K	Author (Year)	σ_0	$\Delta\sigma$ (mb)
	Asghar (1978)	30	
	Beckstrand (1971)	30	8
	Pomerance (1952)	66	20
	Gillette (1966)	70	
	Krusche (1984)-EGAF*	90	3
	Atlas	30	8
	Adopted	**90**	**3**

* ^{40,41}K(n,γ) data of Krusche *et al* were renormalized to EGAF σ_γ data.

^{41}K	Author (Year)	σ_0	$\Delta\sigma$ (mb)
	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
	Gleason (1975)	1.43	0.03
	Heft (1978)	1.43	0.03
	Lyon (1960)	1.45	
	Ryves (1970)	1.46	0.03
	Kappe (1966)	1.49	0.03
	Kaminishi (1982)	1.57	0.17
	Krusche(1985)-EGAF*	1.523	0.022
	Atlas	1.46	0.03
	Adopted	**1.523**	**0.022**

Discrepancy between EGAF PGAA data and other NAA measurements may be resolved if P_γ(1524.7)=0.1808(9) is revised to P_γ=0.173(3).

New NAA measurements are in progress.

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^{186}W

^{186}W	Author (Year)	σ_0	$\Delta\sigma$ (mb)
	Gillette (1966)	33	
	Pomerance (1952)	34.1.0	2.7
	Seren (1947)	34.2	7
	Beitins (1992)	34.8	0.3
	De Corte (2003)	34.72	0.18
	Szentmiklosi (2006)	35.2	0.3
	Damle (1967)	35.4	0.8
	Bondarenko (2008)	35.9	1.1
	Heft (1978)	36.6	0.8
	Gleason (1977)	37.0	1.5
	Anufriev (1981)	37	3
	Nguyen (2008)	37.2	2.1
	Friesenhahn (1966)	37.8	1.2
	Knopf (1987)	38.5	0.8
	Uddin (2008)	38.7	2.3
	Karadag (2004)	39.5	2.3
	Hogg (1970)	40.0	1.5
	Lyon (1960)	41.3	
	Lyon (1960)	51.0	
	EGAF	28.8	0.2*
	Atlas	38.1	0.5
	Adopted	**34.9**	**0.2**

The ^{186}W(n,γ) cross section has changed considerably due to a new decay scheme normalization.

New statistical model calculations are in progress to determine a better value from the EGAF data.

* Does not included statistical feeding correction

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EGAF-2 Updates

- The prompt γ-ray database will be updated where discrepancies exist
- DICEBOX statistical model calculations will be performed for all elements. Pd completed, K, Fe, Eu, Gd, W in progress
- New RIPL library will be constructed
- Complete thermal neutron activation database
- Self-consistent set of $\sigma_\gamma/k_0/\sigma_0/P_\gamma$ values

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