EGAF Publication in NDS

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The Evaluated Gamma-ray Activation File (EGAF) was published with the IAEA* in 2007. We propose that future, more detailed updates of EGF be published in Nuclear Data Sheets.

* *Database of Prompt Gamma Rays from Slow Neutron Capture for Elemental Analysis*, R.B. Firestone, et al, IAEA STI/PUB/1263, 251 pp(2007)

EGAF Publication

EGAF Publication Considerations

1. Publication of Budapest σ_γ data in refereed journals
2. Detailed EGAF evaluation publication in NDS
   a. Adopted EGAF dataset – E_γ, σ_γ, k_0, σ_0, S_n, RIPL levels
   b. Supporting datasets – E_γ, I_g
   c. Activation decay datasets – E_γ, P_γ, σ_γ, k_0
3. Database update provided to IAEA

Why Nuclear Data Sheets?

1. Existing NDS production procedures are satisfactory
2. Only journal suitable for nuclear data publication
3. Detailed information on EGAF evaluation considerations

Comments

EGAF Comments Dataset for Na

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Abstract: Evaluated thermal capture prompt and delayed γ-ray energies, σγ cross sections and k_0 valueswere determined for the ^{23}NA(n,γ) reaction. A revised version of the RIPL library for ^{24}Na was generated and a new, more precise value for S_n was determined.

General Policies and Organization of Material: See the January issue of the *Nuclear Data Sheets* or http://www.nndc.bnl.gov/nds/NDSPolicies.pdf.

Acknowledgments: This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

General Comments: Neutron capture γ-ray σγ data from the cold neutron beam at the Budapest Reactor were combined with capture γ-ray data from ENSDF to determine an evaluated set of energies, σ_γ cross sections, and k_0 values for the ^{23}Na(n,γ)^{24}Na E=thermal reaction. The decay scheme is nearly complete with 0.540 3 b observed populating the ground state and 0.537 3 b deexciting the capture state. The activation cross section for ^{24}Na β− decay (14.997 h) was determined as 0.542 3 b and the activation cross section for ^{24}Na IT decay was determined as 0.501 3 b. A new Reaction Input Parameter Library was prepared with definite spins and parities determined for the first 30 levels. The neutron separation energy was determined as S_n=6959.527 8 keV in good agreement with S_n=6959.58(8) (2003Au03) adopted by Audi et al.

General comments

^{23}Na(n,γ) E=thermal

EGAF thermal neutron capture adopted E_γ, σ_0, and k_0 data.

σ_0=0.60 5 (Coltman, PR 69, 411, 1946). Original value σ_0=0.47 4 b corrected for monitor σ_0(B)=600 b.
σ_0=0.63 13 b (Seren, 1947Se33). Activation method.
σ_0=0.490 25 b (Pomerance,PR83,641,1951), Pile oscilator method. Corrected from original value σ_0=0.470 24 b calibrated assuming σ_0(^{197}Au)=95 b.
σ_0=0.560 32 b (Bartholomew, Can J. Chem 31, 204, 1953). Measured value σ_0=0.530 32 corrected for monitor value σ_0(^{197}Au)=93 b.
σ_0=0.511 5 b (Harris, ANL–5031 Report, p 68, 1953). Pile oscillator method. Corrected from original value σ_0=0.503 5 b assuming σ_0(B)=755 b.
σ_0=0.50 5 b (Brooksbank, ANS Transactions, 203, 1955). Activation cross section, monitor σ_0^{55}Mb=13.3 b.
σ_0=0.513 30 b (Grimeland, J. Nucl. En. 1, 231, 1955). Thermal column method. Corrected from original value σ_0=0.51 3 b calibrated assuming σ_0(B)=750 b.
σ_0=0.536 6 b (Cocking, J. Nucl. En. 4, 33, 1957). Measured by 4πβγ coincidence counting. Monitor σ_0(^{197}Au)=98.6 b.
σ_0=0.536 8 b (Jowitt, Prog. Nucl. En. 3, 242, 1959). Method dimple oscillator reactivity modulation. Monitor σ_0(B)=766.6 b.
σ_0=0.536 8 b. (Rose, Prog. Nucl. En. 3, 242, 1959). Pile oscillator method assuming σ_0(B)=771 b.
σ_0=0.531 8 b (Wolf, 1960Wo07). Measured by 4πβγ coincidence counting. Monitor σ_0(^{197}Au)=98.70 35 b.
σ_0=0.47 6 b (Meadows, 1961Me02) Pulse die away method. Monitor ^{197}Au.
σ_0=0.50 2 b (Koehler, Zeit. Nat. A18, 1339,1963). Activation cross section with ^{197}Au monitor.
σ_0=0.50 3 b (Yamamuro, Nucl. Sci. Eng. 41, 445 (1970). Measured neutron flux, natural Cd monitor.
σ_0=0.526 5 b (Ryves, 1970Ry05). Measured by 4πβγ coincidence counting. Monitor σ_0(^{197}Au)=98.8 3 b.
σ_0=0.54 2 b (Gleason, 1975Gl09). Activation method. Monitor σ_0(^{197}Au)=98.88 b.
σ_0=0.523 5 b (Heft, Conf. MAYAG, 1978). Activation with natural Sc flux monitor.
σ_0=0.577 8 b (Kaminishi, Jap. J. Appl. Phys. 21, 366 (1982). Activation method.
σ_0=0.513 6 b (De Corte, 2003De34). k_0 method.
σ_0=0.515 21 (Kennedy, J. Rad. Nucl. Chem. 257, 475, 2003). k0 method.
σ_0=0.527 8 b (Szentmillosi, 2006Sz05). Activation with neutron beam.
σ_0=0.540 3 b (Budapest prompt γ–ray data to ground state).
σ_0=0.534 3 b (Budapest prompt γ–ray data primaries).
σ_0=0.542 3 b (Budapest activation γ–ray data).
σ_0=0.517 4 b (Mughabghab, 2006MuZX). Evaluation.

Summary of σ_0 values from the literature (CSISRS) and this evaluation

Levels

^{24}Na Levels

E(level)§	Jπ#	$T_{1/2}$@	σγ(in)†	σγ(out)‡	Comments
0.0	4+	14.9590 h *12*	0.540_3		
472.2082 *8*	1+	20.20 ms *7*	0.508_4	0.501 *3*	
563.1974 *15*	2+	36 ps *6*	0.257_1	0.260 *3*	
1341.457 *5*	2+	60 fs *20*	0.120_1	0.118 *2*	
1344.644 *7*	(3)+	26 fs *6*	0.0388_3	0.0386 *22*	
1346.623 *5*	1+	4.4 ps *3*	0.0828_7	0.0805 *13*	
1515.70 *22*	5+		0.00013_3	0.00010 *2*	E(level): Level energy 3-keV higher than Adopted Level (2007Fi14) but consistent with energy shift in 2562.37 adopted level.
1846.021 *5*	2+	180 fs *25*			
1885.581 *4*	3+	26 fs *5*	0.0097_3	0.00979 *6*	
2513.413 *10*	3+	10 fs *3*	0.0103_1	0.0102 *1*	
2564.90 *18*	4+		6.4E-5_10	2.2×10^{-4} *4*	E(level): Level energy 3-keV higher than adopted level (2007Fi14) but consistent with energy shift in 1514.7 4 adopted level.
2904.025 *13*	3+	35 fs *6*	0.0054_2	0.0055 *1*	
2977.807 *12*	(2+)	<17 fs	0.0760_8	0.0775 *4*	Jπ: Adopted Jπ is (2+,3+). Strong popuation by (n,γ) favors 2+.
3216.7 *5*	(4+)		1.0E-4_1	7.5×10^{-5} *11*	Jπ: Adopted Jπ is (4+,2+). Weak population by (n,γ) favors 4+.

Cross section balance through the (n,γ) level scheme.

Justification of RIPL J^{π} assignments.

Gammas

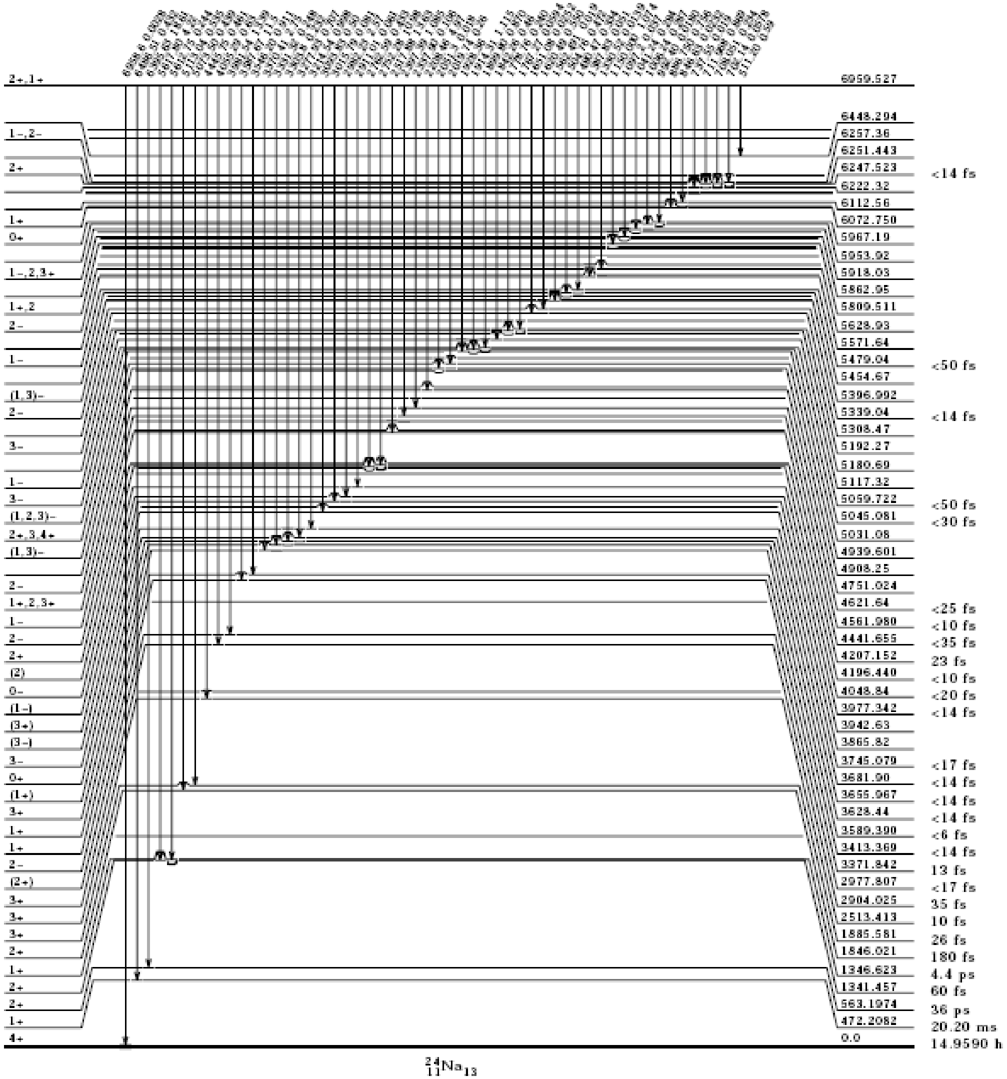
$\gamma(^{24}Na)$

Iγ normalization: Normalization to per 100 neutron captures assuming σ_0=0.540 b.

Eγ†	E(level)	σγ‡@	Mult.	α	Comments
90.9921 *14*	563.1974	0.250 *3*	M1	0.00213	k_0=0.0329 *4*.
242.30 *9*	3655.967	0.000110 *11*			$k_0=1.45\times10^{-5}$ *14*.
340.8 *3*	4527.3	0.000033 *9*			$k_0=4.3\times10^{-6}$ *12*.
373.24 *6*	3589.390	0.000075 *7*			$k_0=9.9\times10^{-6}$ *9*.
	3745.079	0.000075 *6*			$k_0=9.9\times10^{-6}$ *8*.
387.98 *18*	3977.342	0.000028 *6*			$k_0=3.7\times10^{-6}$ *8*.
472.2027 *11*	472.2082	0.501 *3*	M3	0.00047	k_0=0.0660 *4*.
499.383 *5*	1846.021	0.01474 *22*			k_0=0.00194 *3*.
501.30 *3*	1846.021	0.00308 *12*			k_0=0.000406 *16*.
504.57 *4*	1846.021	0.00140 *8*			$k_0=1.85\times10^{-4}$ *11*.
511.20 *2*	6959.527	0.0032 *2*			k_0=0.00042 *3*. Eγ,σγ: Expected primary γ-ray, Iγ from the intensity balance. Observed transition with E=510.94 9 keV, σγ=0.00552 23 b includes annihilation radiation from pair production.
543.94 *13*	4751.024	0.000042 *7*			$k_0=5.5\times10^{-6}$ *9*.
551.21§ *4*	4207.152	0.000348 *13*			$k_0=4.59\times10^{-5}$ *17*.
563.1974 *16*	563.1974	0.00925 *8*			k_0=0.001219 *11*.
605.51§ *3*	3977.342	0.000159 *10*			$k_0=2.10\times10^{-5}$ *13*.
617.84 *5*	4207.152	0.000143 *10*			$k_0=1.88\times10^{-5}$ *13*.
662.06 *25*	4527.3	0.00006 *4*			$k_0=8\times10^{-6}$ *5*.
665.14 *12*	5192.27	0.00042 *5*			$k_0=5.5\times10^{-5}$ *7*.
696.570 *20*	4441.655	0.000215 *17*			$k_0=2.83\times10^{-5}$ *22*.

Gamma ray cross sections and k_0 values

Level scheme drawing



Possibly too complex?

Budapest Data

$\gamma(^{24}Na)$

Iγ normalization: Normalization to per 100 neutron captures assuming σ0=0.540 b.

$E\gamma^{\dagger}$	E(level)	$\sigma_{\gamma}^{\dagger\&}$	Mult.	α	Comments
91.004 *15*	563.200	0.250 *3*	M1	0.00213	
242.30§ *9*	3655.889	0.000110§ *11*			
340.8§ *3*	4527.3	0.000033§ *9*			
373.24§ *6*	3589.209	0.000075§ *7*			
	3744.928	0.000075 *6*			
387.98§ *18*	3977.202	0.000028§ *6*			
472.205 *14*	472.197	0.501 *3*	M3	0.00047	
499.363 *22*	1845.976	0.01474 *22*			
501.35 *4*	1845.976	0.00308 *12*			
504.55 *5*	1845.976	0.00140 *8*			
511.20 *2*	6959.315	0.0032 *2*			$E\gamma,\sigma_{\gamma}$: Expected primary γ-ray, Iγ from the intensity balance. Observed transition with E=510.94 9 keV, σγ=0.00552 23 b includes annihilation radiation from pair production.
543.94§ *13*	4750.870	0.000042§ *7*			
551.21 *4*	4207.020	0.000348 *13*			
563.171 *11*	563.200	0.00925 *8*			
605.51 *3*	3977.202	0.000159 *10*			
617.84§ *5*	4207.020	0.000143§ *10*			
662.06§ *25*	4527.3	0.00006§ *4*			
665.14§ *12*	5192.13	0.00042§ *5*			
696.570‡ *20*	4441.525	0.000215‡ *17*			

Typically this is the only source of σ_{γ} data. Reference to the published form of this data will be included.

Second data set - levels

^{23}Na(n,γ) E=thermal 1983Hu11,1983Ti02

Thermal neutron capture γ-ray Intensity per 100 neutron captures.

Target Jπ=3/2+.

1983Hu11: Measured Eγ and Iγ with curved crystal (GAMS), Ge(Li), and pair spectrometers. Deduced neutron separation energy S_N=6959.73 keV 14.

1983Ti02: Measured Eγ and Iγ with Ge(Li)–NaI(Tl) AND Ge(Li) pair spectrometer. Deduced neutron separation energy S_N=6959.42 keV 8.

1987Zh12: Measured Eγ and Iγ with Ge(Li)–NaI(Tl) spectrometer. Deduced neutron separation energy S_N=6959.51 keV 21.

^{24}Na Levels

E(level)†	Jπ‡	$T_{1/2}$‡
0.0	4+	14.9590 h *12*
472.2069 *8*	1+	20.20 ms *7*
563.1974 *16*	2+	36 ps *6*
1341.441 *10*	2+	60 fs *20*
1344.646 *8*	(3)+	26 fs *6*
1346.627 *6*	1+	4.4 ps *3*
1846.020 *6*	2+	180 fs *25*
1885.506 *5*	3+	26 fs *5*
1960.89 *4*		
1977.05 *9*		
2513.414 *23*	3+	10 fs *3*
2562.37 *24*	(4+,2+)	<17 fs
2904.10 *6*	3+	35 fs *6*
2977.809 *16*	(2+,3+)	<17 fs
3371.853 *23*	2−	13 fs *3*
3413.298 *25*	1+	<14 fs
3589.42 *4*	1+	<6 fs
3628.35 *6*	3+	<14 fs
3655.91 *6*	(2+,1+)	<14 fs
3681.93 *12*	0+	<14 fs
3745.14 *3*	3−	<17 fs
3865.58 *8*		
3935.87? *18*		<14 fs
3943.48 *12*		<14 fs
3977.40 *3*	(1−,2+)	<14 fs
4048.34 *14*	0−	70 fs *30*
4143.1? *3*	(4−)	<20 fs
4186.8 *7*	2+	<14 fs
4196.54 *6*	(1+,2,3+)−	<10 fs
4207.205 *19*	2+	23 fs *6*
4441.68 *3*	2−	<35 fs
4562.056 *24*	1−	<10 fs
4621.60 *10*	(1+,2,3+)	<10 fs
4691.7 *4*		<25 fs
4751.086 *21*	2−	
4891.26? *5*		
5031.17? *4*	(2+,3,4+)	
5045.07 *3*	(1,2,3)−	<30 fs
5059.647 *21*	3−	<50 fs
5117.36 *7*	1−	
5192.41 *7*	3−	<7 fs
5252.28 *14*	3−	
5339.09 *4*	2−	<14 fs
5397.08 *3*	(1,3)−	
5479.07 *6*	1−	<50 fs
5809.579 *19*	1+,2	
5862.93 *16*		
5918.357 *24*	1−,2,3+	
5953.36? *5*		
5967.37? *19*	0+	<7 fs
6072.837 *16*	1+	
6222.35 *9*		
6247.644 *17*	2+	<14 fs
6959.623 *14*	1+,2+	

† from least squares fit to γ energies.

‡ From adopted levels.

Adopted Jπ data

Second data set - gammas

$\gamma(^{24}Na)$

Iγ normalization: Normalized to the intensity of the ^{24}Na decay lines at 1369– and 2754–keV. Systematic errors of 15%, 10% and 5 % were added to the GAMS, Ge(Li) and pair errors, respectively by 1983Hu11. Unplaced gamma intensity is 1.85 5.

Eγ†	E(level)	Iγ per 100 n†§	Mult.‡	δ‡	Comments
90.9921 *14*	563.1974	41.8 *63*			
x417.08 *21*		0.049 *20*			
x440.10 *11*		0.092 *17*			
472.2023 *8*	472.2069	93.9 *74*	M3		
499.383 *5*	1846.020	2.4 *7*			
501.30 *3*	1846.020	0.66 *6*			
504.57 *4*	1846.020	0.27 *3*			
552.44 *8*	2513.414	0.127 *18*			
563.186 *8*	563.1974	1.7 *3*			
614.26 *5*	1960.89	0.134 *16*			
711.968 *10*	6959.623	0.90 *8*			
737.55 *13*	6959.623	0.019 *6*			
773.9 *3*	4751.086	0.073 *3*			
778.22 *23*	1341.441	1.09 *10*			
781.402 *15*	1344.646	3.4 *3*			
793.84 *6*	4207.205	0.39 *5*			

I_γ per 100 neutron captures

Continued on next page (footnotes at end of table)

Activation decay data

^{24}Na β⁻ Decay (14.997 h)

Parent ^{24}Mg: E=0; Jπ=4+; $T_{1/2}$=14.997 h *12*; Q(g.s.)=5515.45 *8*; %β⁻ decay=100.

^{24}Mg Levels

E(level)†	Jπ†	$T_{1/2}$
0.0	0+	stable
1368.672 *5*	2+	
4122.889 *12*	4+	
4238.24 *3*	2+	
5235.12 *4*	3+	

† From adopted levels.

β⁻ radiations

Eβ⁻	E(level)	Iβ⁻†	Log *ft*	Comments
(280.33 *9*)	5235.12	0.076 *3*	6.60 *2*	av Eβ=89.24 *22*.
(1392.56 *8*)	4122.889	99.855 *5*	6.11 *1*	av Eβ=554.1 *3*.
(4146.78 *8*)	1368.672	0.064 *6*	11.34 *4*	av Eβ=1865.5 *3*.

† Absolute intensity per 100 decays.

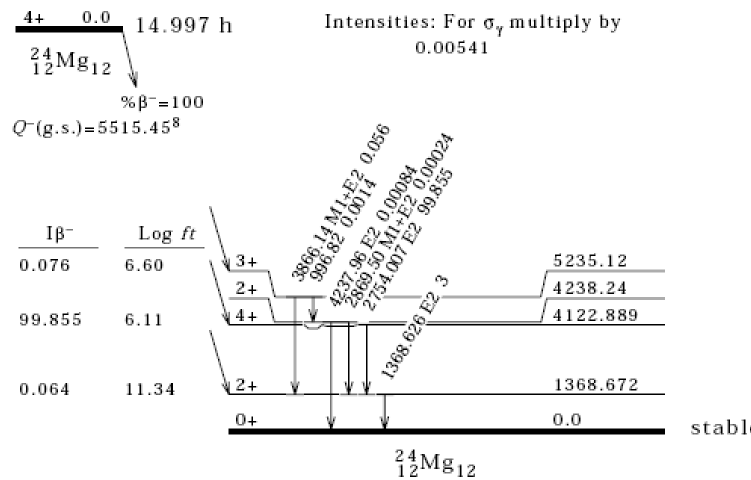
γ(^{24}Mg)

Eγ†	E(level)	P_γ†‡	Mult.	δ	α	I(γ+ce)‡	Comments
996.82 *9*	5235.12	0.0014 *2*					
1368.626 *5*	1368.672	99.9936 *15*	E2		1.3×10⁻⁵	3	k_0=0.0492 *4*. k_0=0.0468 3 (IUPAC, 2003De34). P_γ: σγ(Budapest)=0.5409 25 b.
2754.007 *11*	4122.889	99.855 *5*	E2				P_γ: σγ(Budapest)=0.5433 35 b. k_0=0.0491 *4*. k_0=0.0462 4 (IUPAC, 2003De34).
2869.50 *6*	4238.24	0.00024 *3*	M1+E2	−23 *9*			
3866.14 *10*	5235.12	0.056 *7*	M1+E2	−17 *4*			P_γ: σγ(Budapest)=0.00042 6 b.
4237.96 *6*	4238.24	0.00084 *10*	E2				

† From DDEP evaluation (2004BeZr).
‡ Absolute intensity per 100 decays.

^{24}Na β⁻ Decay (14.997 h) (continued)

Decay Scheme



P_γ on table, conversion factor to σ_γ on drawing

Other considerations

Theory

- DICEBOX level density and γ-ray strength function parameters
- Calculated continuum (Z>20)
- Calculation population below E_{crit}
- Nuclear model J^{π} calculations for RIPL

Experiment

- Average resonance data
- Surrogate reaction data
- Granddaughter decay data

Conclusions

- Publication of EGAF data in NDS is straightforward
- Data would be published by elemental sets
- EGAF evaluation in collaboration with LLNL, Budapest, Prague, and the IAEA will continue to be the major effort of the Isotopes Project in the future.
- Others are welcome to participate.