FURTHER WORK ON THE USE OF K_o FACTORS DETERMINED BY THE CADMIUM SUBTRACTION METHOD AS A TOOL FOR A CRITICAL EVALUATION OF NUCLEAR DATA

T. Elnimr

Physics Department, Faculty of Science,
Tanta University, Tanta, Egypt

1. INTRODUCTION

Nuclear constants for use in reactor activation analysis and epicadmium neutron activation analysis, especially (n, γ) cross-sections and absolute gamma intensities, are known to show a rather large scatter in the literature [1]. This work is a continuation of that already published [2], in which shows how experimentally determined and accurate K_o-factors, used in a new comparator technique [5, 6], in some cases can be used to make a critical evaluation of the above mentioned constants. The method was applied to select preferred values for thermal cross-section (σ_o), resonance integral (I_o) and absolute gamma intensity.

Table 1. Different Reaction and Decay Types Together With Related Nuclear Parameters and Formulae When Using the K_o-Method

Reaction decay type	Reaction and decay schemes	K_o (definition)	Q_o analytical	A_{sp} (calculation)
(I)	$1 \xrightarrow[\sigma_o,\ I_o]{n,\ \nu} \underline{2} \xrightarrow{\lambda_2}$	$\frac{M^*\theta\ \sigma_o\ \nu_2}{M\ \theta^*\ \sigma_o^*\ \nu^*}$	$\frac{I_o}{\sigma_o}$	$\frac{N_{p,2}/t_m}{wS_2D_2C_2}$
(II)	$\begin{tikzcd} & 2 \arrow[dd] & \\ 1 \arrow[ur, "\sigma_o^m,\ I_o^m"] \arrow[dr, "\sigma_o^g,\ I_o^g"'] \arrow[r, phantom, "n,\ \nu"] & {} & \\ & \underline{3} \arrow[r, "F_2,\ \lambda_2", "\lambda_2"'] & {} \end{tikzcd}$	$\frac{M^*\theta\ \sigma_o^g\ \nu_3}{M\ \theta^*\ \sigma_o^*\ \nu^*}$	$\frac{I_o^g}{\sigma_o^g}$	$\frac{N_{p,3}/t_m}{w}\left[\frac{F_2\ \sigma_o^m}{\sigma_o^g}\times\frac{(F+Q_o^m)}{(F+Q_o^g)}\times\frac{\lambda_3S_2D_2C_2-\lambda_2S_3D_3C_3}{\lambda_3-\lambda_2}+S_3D_3C_3\right]^{-1}$ $=\frac{N_{p,3}/t_m}{w}\left[\frac{K_o^m}{K_o^g}\times\frac{(F+Q_o^m)}{(F+Q_o^g)}\times\frac{\lambda_3S_2D_2C_2-\lambda_2S_3D_3C_3}{\lambda_3-\lambda_2}+S_3D_3C_3\right]^{-1}$
(III)	Special case: $\lambda_2 \gg \lambda_3$ and $D_2 = 0$	$\frac{M^*\theta(F_2\ \sigma_o^m+\sigma_o^g)\ \nu_3}{M\ \theta^*\ \sigma_o^*\ \nu^*}$	$\frac{F_2\ I_o^m+I_o^g}{F_2\sigma_o^m+\sigma_o^g}$	$\frac{N_{p,3}/t_m}{wS_3D_3C_3}$

Table 2. Preferred Nuclear Data and Decay Parameters Concerning the (n,γ) Reaction

Target element	Atomic Weight	σ_0 (barn) [26]	I_0 (barn) [26]	Target Isotope	Abundance (%) [26]	Isotope (reaction decay type)	Half-life $T_{1/2}$	$\bar{E}_r$ (eV) [15]
Mg	24.30	0.063	0.038	^{26}Mg	11.01	^{27}Mg (I)	9.46 m	220 000
Al	26.98	0.233	0.17	^{27}Al	100	^{28}Al (I)	2.2405 m	8240
S	32.06	0.52	0.24	^{36}S	0.02	^{37}S (I)	5.06 m	
Ca	40.08	0.43	0.24	^{48}Ca	0.187	^{49}Ca (I)	8.72 m	
Sc	44.96	27	12	^{45}Sc	100	^{46}Sc (III)	83.8 d	4110
Fe	55.85	2.55	1.4	^{58}Fe	0.28	^{59}Fe (I)	44.50 d	325
Ga	69.72	2.9	22	^{71}Ga	39.9	^{72}Ga (III)	14.1 h	152
As	74.92	4.4	61	^{75}As	100	^{76}As (I)	26.3 h	102
Se	78.96	11.7	14	^{74}Se	0.9	^{75}Se (I)	119.8 d	29.5
Br	79.90	6.8	92	^{79}Br	50.69	^{80m}Br ^{80}Br (II)	4.42 h 17.6 m	51.4
Sr	87.62	1.2	10	^{86}Sr	9.86	^{87m}Sr (I)	2.806 h	672

F_{Cd} [5, 7, 8]	E_γ Main gamma (keV)	$Q_o(\alpha=0)$ recom. [32]	$(K_{o,Au})_{exp}$ (rel. err., %)L	$(K_{o,Au})_{theor}$	Evaluation value		
					σ_o (barn)	I_o (barn)	Absolute gamma Intensity (%)
1.00	170.5	0.69	3.00×10^{-6} (1.0)	3.09×10^{-6}	0.038	0.025	0.86
	843.8		2.52×10^{-4} (0.6)	2.51×10^{-4}			70.0
	1014.2		9.79×10^{-5} (0.6)	9.81×10^{-5}			27.3
1.00	2779.0	0.73	1.77×10^{-2} (0.9)	1.78×10^{-2}	0.230	0.17	100
	3103.8	1.12	1.94×10^{-6} (0.9)	1.95×10^{-6}	0.15	0.17	99.7
	3084.2	0.45	1.00×10^{-4} (1.2)	9.86×10^{-5}	1.1	0.50	92.1
	889.3	0.44	1.25 (0.8)	1.25	27	12	100
	1120.5		1.24 (0.4)	1.25			100
1.00	1099.2	0.96	7.84×10^{-5} (0.9)	7.86×10^{-5}	1.33	1.1	56.5
	1291.6		5.99×10^{-5} (0.9)	6.01×10^{-5}			43.2
1.00	629.9	6.63	1.48×10^{-2} (0.8)	1.46×10^{-2}	4.65	30.8	26.3
	834.1		5.27×10^{-2} (0.5)	5.31×10^{-2}			95.54
	894.2		5.49×10^{-3} (0.9)	5.47×10^{-3}			9.847
	1050.7		3.85×10^{-3} (1.1)	3.84×10^{-3}			6.921
	2201.6		1.44×10^{-2} (1.0)	1.45×10^{-2}			26.07
	2490.9		4.20×10^{-3} (1.5)	4.15×10^{-3}			7.476
	2501.6 ($E_{eff.}$)		1.15×10^{-2} (1.3)	1.14×10^{-2}			20.54
	2507.7 ($E_{eff.}$)		7.30×10^{-3} (1.0)	7.25×10^{-3}			13.06
1.00	559.2 ($E_{eff.}$)	14.0	4.99×10^{-2} (1.0)	5.03×10^{-2}	4.3	60	41.99
	657.0		6.65×10^{-3} (0.8)	6.82×10^{-3}			5.69
	1215.2 ($E_{eff.}$)		5.25×10^{-3} (1.2)	5.21×10^{-3}			4.35
0.94	121.1	10.9	1.98×10^{-3} (0.5)	1.99×10^{-3}	51.8	565	16.15
	136.0		6.88×10^{-3} (0.6)	6.90×10^{-3}			56.02
	264.7		7.23×10^{-3} (0.9)	7.22×10^{-3}			58.60
	279.5		3.06×10^{-3} (0.9)	3.07×10^{-3}			24.9
	400.6		1.43×10^{-3} (0.8)	1.45×10^{-3}			11.78
1.00							
1.00	616.9	11.4	6.68×10^{-3} (0.9)	7.01×10^{-3}	0.4	96	6.3
	666.3		1.18×10^{-3} (0.9)	1.17×10^{-3}			1.05
1.00	388.5	4.11	1.49×10^{-3} (0.7)	1.49×10^{-3}	0.369	3.16	82.5

2. EXPERIMENTAL DETAILS AND RESULTS

The experimental method has been described previously [2–4]; in the present work all K_0 factors were experimentally determined and calculated *versus* the 411.794 keV γ-line of ^{198}Au [5]. The nuclear data of interest, which are required for the calculations, are listed in Table 1 of Reference [2]. Counting was performed using a 104 cm^3 and 40 cm^3 single open-ended coaxial Ge(Li) detector with a source-to-detector separation of 15 cm. Appropriate formulae for specific count rate calculations (and K_0 and Q_0 definitions) for several complex decay schemes (mother–daughter decay, *etc.*) are given in Table 1. The listed K_0-factors are those recommended when obtained according to the experimental method that has been described previously [2] and when the standard deviation on the mean was less than 2%. It should be realized that the average usually results from five measurements on two irradiation channels. Results of K_0 determinations are shown in Table 2 for 12 isotopes, covering 29 γ-lines. In this evaluation several compilations were systematically surveyed [9–31] and other recent publications were consulted. The finally adopted values are based on the present evaluation result, and *t*-test can be performed for the comparison of the theoretical $(X)_{\text{theor}}$ and mean experimental value $(\bar{X})_{\text{exp}}$. If S_{exp} is the standard deviation on the mean for an average value $(\bar{X})_{\text{exp}}$, then

$$t = \frac{(\bar{X})_{\text{exp}} - X_{\text{theor}}}{S_{\text{exp}}} .$$

ACKNOWLEDGEMENTS

We are indebted to Professor Dr. A. M. Hassan, Dr. F. M. Ela-Assaly, and Dr. N. B. Rofail for their helpful discussions. We are also grateful to the staff of the Egyptian Reactor for their assistance with the irradiations.

REFERENCES

[1] V. Krivân, *Symposium on Applications of Nuclear Data in Science and Technology, Paris, March,* 1973.

[2] T. Elnimr, "A Critical Evaluation of Nuclear Data Using K_0-Factors Determined by the Cadmium Subtraction Method", *Arabian Journal for Science and Engineering,* **10(2)** (1985), p. 139.

[3] T. Elnimr and F. A. El-Hussiny, "Further Work on the Use of $K_{e,0}$ Factors as a Tool for a Critical Evaluation of Reactor Thermal and Epithermal (n, γ) Cross-Sections and of Absolute Gamma Intensities", *Journal of Physics D: Applied Physics,* **18** (1985), p. 1967.

[4] T. Elnimr and I. I. Bondouk, "The Use of $K_{e,0}$ Factors as a Tool for a Critical Evaluation of Reactor Thermal and Epithermal (n, γ) Cross-Sections and of Absolute Gamma-Intensities", *Journal of Physics D: Applied Physics,* **16** (1983), p. 1407.

[5] T. Elnimr, L. Moens, F. De Corte, A. Simonits, and J. Hoste, "Epicadmium Neutron Activation Analysis (ENAA) Based on the K_0-Comparator Method", *Journal of Radioanalytical Chemistry,* **67** (1981), p. 421.

[6] T. Elnimr, "Epicadmium Neutronenactiverings Analyses Met Behulp van De K_0-Standaardisatie Methode", *Doctoral Thesis, University of Ghent, Belgium,* 1981.

[7] T. Elnimr and F. M. El-Assaly, "Determination of the Attenuation of Epicadmium Neutrons Using the Method of Varying Cd-Thickness", *Journal of Radioanalytical and Nuclear Chemistry,* **109(1)** (1987), p. 3.

[8] T. Elnimr and F.M. El-Assaly, "The Cadmium Transmission Factor for Epithermal Neutrons Using the Method of Varying Cd-Thickness", *Proceedings of the Mathematical and Physical Society of Egypt,* **58** (1984), p. 93

[9] J. Legrand, J. P. Perolat, F. Lagoutine, and Y. Le Gallio, *Table des Radionuclides.* Paris: CEA/BNM/LMRL, 1975.

[10] M. J. Martin, "Nuclear Decay Data for Selected Radionuclides", *Report ORNL-5114,* 1976.

[11] D. C. Kocher, *Oak Ridge National Laboratory: Report ORNL/NUREGTM-102,* 1977.

[12] G. Erdtmann and W. Woyka, "Die γ-lines der Radionuklide", *Report: Jülich-1003 A.C., Zentralinstitut für Analytische Chemie,* 1974.

[13] O. T. Høgdahl, "Neutron Absorption in Pile Neutron Activation Analysis", *Report of the Michigan Memorial Phoenix Project: MMPP-226-1,* University of Michigan, December 1962.

[14] R. W. Stoughton and J. Halperin, "Effective Cutoff Energies for Boron, Cadmium, Gadolinium, and Samarium Filters", *Journal of Nuclear Science and Engineering,* **15** (1963), p. 314.

[15] L. Moens, F. De Corte, A. Simonits, A. De Wispelaere, and J. Hoste, "The Effective Resonance Energy $\bar{E}_r$, as a Parameter for the Correction of Resonance Integrals in $1/E^{1-\alpha}$ Epithermal Neutron Spectra Tabulation of $\bar{E}_r$-Values for 96 Isotopes", *Journal of Radioanalytical Chemistry,* **52** (1979), p. 379.

[16] N. E. Holden and F. W. Walker, *Chart of the Nuclides, Eleventh Edition.* Schenectady, NY: General Electric Co., 1972.

[17] S. F. Mughabghab and D. I. Garber, *Neutron Cross Sections, vol. 1, Resonance Parameters, Third Edition.* Upton, LI: Brookhaven National Laboratory, *Report: BNL-325, NTIS,* June 1973.

[18] J. I. Kim and H. J. Born, "Monostandard Activation Analysis and Its Applications to Analysis of Kale

Powder and NBS Standard Glass Samples", *Journal of Radioanalytical Chemistry,* **13** (1973), p. 427.

[19] E. Ricci, *Analytica Chemica Acta,* **79** (1975), p. 109.

[20] T. Bereznai and G. Keömley, "Effect of Error in Halfline Data on the Accuracy of Activation Analysis", Radiochemical Radioanalytical Letters, **17** (1974), p. 305.

[21] F. W. Walker, G. J. Kirouac, and F. M. Rourke, *Chart of the Nuclides, 12th Edn.* Schenectady, NY: General Electric Co., 1977.

[22] N. E. Holden, "IUPAC Commission on Atomic Weights and Isotopic Abundances", *Pure and Applied Chemistry,* **52** (1980), p. 2349.

[23] "Handbook of Nuclear Activation Cross-Sections", *International Atomic Energy Agency, Technical Reports Series, No. 156,* 1974.

[24] R. L. Heath, *Gamma-Ray Spectrum Catalogue, vol. 2, Third Edition.* Idaho: Aerojet Nuclear Company, ANCR-1000-2, 1974.

[25] T. B. Ryves, "A New Thermal Neutron Flux Convention", *Metrologia,* **5** (1969), p. 119.

[26] W. Garder, T. D. MacMahon, and A. Egan, "INDENT—a Radioisotope Identification Subroutine for Use with the Gamma-Ray Spectrum Analysis Program SAMPO", *Talanta,* **25** (1978), p. 21.

[27] P. F. Schmidt, J. E. Riley, Jr., and D. J. MacMillan, "Parametric Neutron Activation Analysis of Samples, Generating Complex Gamma-Ray Spectra", *Analytical Chemistry,* **51(2)** (1979), p. 189.

[28] W. W. Bowman and K. W. MacMurdo, *Atomic Data Nuclear Data Tables (ADNDT),* **13(2−3)** (February 1974).

[29] V. P. De Bievre, "Atomic Weight of the Elements", *Journal of Pure and Applied Chemistry,* **47** (1976), p. 75.

[30] *Nuclear Data Sheets (USA),* **7** (1972), pp. 33, 363, 419; **B7** (1972), p. 1; **B8(1)** (1972), p. 29; **9** (1973), p. 319; **10** (1973), pp. 1, 47, 241, 429, 991; **11** (1974), p. 121; **12** (1974), p. 477; **14** (1975), pp. 247, 347, 471, 559; **15** (1975), p. 315; **16** (1975), p. 383; **18** (1976), pp. 125, 331.

[31] I. M. H. Pagden, G. J. Pearson, and J. M. Bewers, *Journal of Radioanalytical Chemistry,* **8** (1971), pp. 129, 373; *Ibid* **9** (1971), p. 101.

[32] A. Simonits, F. De Corte, T. Elnimr, L. Moens, and J. Hoste, "Comparative Study of Measured and Critically Evaluated Resonance Integral to Thermal Cross-Section Ratio. Part II", *Journal of Radioanalytical and Nuclear Chemistry,* **81(2)** (1984), p. 397.

Paper Received 25 November 1986; Revised 13 May 1987.