A CRITICAL EVALUATION OF NUCLEAR DATA USING K_0-FACTORS DETERMINED BY THE CADMIUM SUBTRACTION METHOD

T. Elnimr

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

الخلاصة :

بمقارنة معاملات K_0 المستنبطة بطريقة الطرح للكادميوم باستخدام اماكن تشعيع ذات اختلاف كبير في نسبة فيض النيوترونات الحرارية الى فوق الحرارية مع معاملات K_0 المحسوبة نظريا ، جعل من الممكن في بعض الحالات أختيار أفضل القيم للمقطع المستعرض التنشيطى وشدة جاما المطلقة من المراجع العلمية وذلك لتفاعل (نيوترون ، جاما) .

ABSTRACT

Experimental K_0-factors determined by the cadmium subtraction method in reactor positions with greatly different thermal-to-epithermal neutron flux ratios are compared with theoretically calculated K_0-factors, and by this means it is found to be possible in some cases to select the best values from the literature data for (n, γ) activation cross sections and for absolute gamma intensities. Twenty-four different isotopes are considered.

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INTRODUCTION

Nuclear constants for use in reactor activation analysis, especially (n, γ) cross sections and absolute gamma intensities, are known to show a rather large scatter in the literature [1, 2]. A critical evaluation of these data may lead to preferred values. The present work shows how experimentally determined and accurate K_0-factors, used in a new comparator technique [3], in some cases can be used to make a critical evaluation of the above-mentioned constants. The method outlined helps to select or predict best values from widely scattered literature data. The method is applied to select preferred values for thermal cross section, σ_0, resonance integral, I_0, and absolute gamma intensity.

THEORY OF THE K_0-METHOD

When co-irradiating a standard and a comparator element in a reactor channel, the K_{anal} ratio of specific count rates of the measured γ-lines can be written, after rearranging the well-known activation formula, as

$$K_{anal}=\frac{A_{sp}}{A^*_{sp}}=\underbrace{\frac{M^*\theta\gamma\sigma_0}{M\theta^*\gamma^*\sigma_0^*}}_{K_0}\left[\frac{\frac{\phi_s}{\phi_e}+\frac{I_0}{\sigma_0}}{\frac{\phi_s}{\phi_e}+\left(\frac{I_0}{\sigma_0}\right)^*}\right]\frac{\varepsilon_p}{\varepsilon_p^*} \qquad (1)$$

where the asterisk refers to the comparator and A_{sp} is the specific activity of the measured γ-peak.

$$A_{sp}=\frac{A_p}{SDCW}$$

where A_p is the measured average activity of the full-energy peak, and

$$A_p=\frac{N_p}{t_m}$$

with N_p being the measured number of net counts under the full-energy peak.

$$S=1-\exp(-\lambda t_{irr})$$

is the saturation factor; $\lambda=\ln 2/T_{1/2}$ is the decay constant; $T_{1/2}$ is the half-life; and t_{irr} is the irradiation period.

$$D=\exp(-\lambda t_d)$$

is the decay factor; t_d is the decay period.

$$C=\frac{1-\exp(-\lambda t_m)}{\lambda t_m}$$

is the measurement factor correcting for decay during the measured period, t_m. W is the weight of the irradiated element. M is the atomic weight of the irradiation element. θ is the isotopic abundance of the target nuclide. γ is the absolute intensity of the measured γ-ray. ε_p is the absolute full-energy peak efficiency of the detector for the measured γ-line.

$$\phi_s=v_0\int_0^{E_{Cd}} n(v)\mathrm{d}v$$

is the subcadmium neutron flux according to Høgdahl's convention [4] where the integral represents the neutron density up to the Cd-cut off. $v_0=2{,}200$ m/s. σ_0 is the thermal neutron cross section at neutron velocity v_0. This value multiplied by ϕ_s gives the subcadmium reaction rate per atom for isotopes having a $1/v$ cross-section function up to 1–2 eV (valid for most isotopes). ϕ_e is the epithermal or intermediate neutron flux per unit ln E neutron energy interval: ϕ_e is considered to be independent of neutron energy. The epithermal flux distribution is assumed to follow a $1/E$ shape, so $\phi(E)=\phi_e/E$.

$$I_0=\int_{E_{Cd}}^{\infty}\sigma(E)\mathrm{d}E/E$$

is the infinitely dilute resonance integral, with $E_{Cd}=0.55$ eV being the effective Cd-cut off energy for a $1/v$ isotope irradiated as a small sample positioned in a cylindrical Cd-box (height/dia. = 2) of 1 mm wall thickness [5]. The conditions under which Equation (1) is valid are as follows.

(1) The epithermal neutron density distribution follows a $1/E$ shape.
(2) Isotopes have $1/v$ cross sections up to 1–2 eV of the neutron energy.
(3) Neutron and γ-absorption as well as burn-up are negligible or corrected for.
(4) Random and true coincidence as well as system

dead-time and pile-up losses are negligible during spectra accumulation or are corrected for.

(5) Standards and comparators have point-source geometry.

It has also been shown [3, 6] that when the energy distribution of the neutron flux can be described by an expression of the form $1/E^{1+\alpha}$, rather than the simpler $1/E$ expression, the K_0-factor from Equation (1) becomes

$$(K_0)_{exp}=\frac{A_{sp}}{A^*_{sp}}\left[\frac{\frac{\phi_s}{\phi_e}+\frac{I_0(\alpha)}{\sigma_0}}{\frac{\phi_s}{\phi_e}+\left(\frac{I_0(\alpha)}{\sigma_0}\right)^*}\right]\frac{\varepsilon_p}{\varepsilon^*_p} \tag{2a}$$

or

$$(K_0)_{theor}=\frac{M^*}{M}\frac{\theta}{\theta^*}\frac{\gamma}{\gamma^*}\frac{\sigma_0}{\sigma^*_0}. \tag{2b}$$

If K_{anal} values are available for a number of isotopes in a given analytical setup, the ρ_i concentration (in ppm) for a given element can be calculated simply as

$$\rho_i=\frac{\left(\frac{A_{p,i}}{SDCw}\right)}{K_{anal}A^*_{sp}} \tag{3}$$

where w represents the sample weight in grams and A^*_{sp} is the specific count rate of the co-irradiated comparator (per μg). We introduce the following notation:

$$Q_0=\frac{I_0}{\sigma_0},\qquad Q_0(\alpha)=\frac{I_0(\alpha)}{\sigma_0},\qquad \text{and}\qquad f=\frac{\phi_s}{\phi_e}$$

where

$$Q_0(\alpha)=\frac{Q_0-0.429}{(\bar{E}_r)^\alpha}+\frac{0.429}{(2\alpha+1)(0.55)^\alpha}$$

and

$\bar{E}_r$ is the effective resonance energy [7];

α is the deviation parameter from the $1/E$ shape of the ϕ_e [8, 9].

When analytical work is considered, K_{anal} values can be derived from Equation (1) in the following conditions.

(1) The flux ratio f is known or can be determined during irradiation (instantaneous flux ratio monitoring).

(2) the relative efficiency curve is available at least in the energy range of 100–2000 keV.

(3) λ, Q_0, and K_0 values are available from the literature.

Flux ratios, f, can be determined relatively easily by Cd-ratio measurement.

Ge(Li) detector efficiency calibration can be accomplished with about 1% accuracy using calibrated single or multigamma sources. Half-lives (or λ) are considered to be the most accurate nuclear data at present. Q_0 values are usually available from the literature [10, 11].

Finally, let us examine the remaining nuclear data group denoted as a K_0-factor. It is seen from Equation (2b) that K_0 is independent of the reactor neutron spectrum and of the detector characteristics because it contains only well-defined invariable nuclear constants.

It would seem to be obvious, at first glance, that K_0-factors can be determined directly by calculation taking all the nuclear data in Equation (2b) from the literature. The introduction of absolute M, θ, and especially γ and σ_0 values, however, makes the method absolute and thus strongly dependent on the accuracy of the relevant nuclear data from the literature. Although some authors [12,13] believe that existing nuclear data are accurate enough to accomplish reliable absolute analysis for most elements, it seems that this is, in fact, not yet the case. Kriváň [1] has pointed out that the typical scatter range of decay scheme values such as γ–abundances is 2–15% (80% max.), whereas for thermal neutron cross sections this range is 5–40% (100% max.). Erdtmann [2] also states in his compilation for radionuclides that: 'There are only a few nuclides where the intensities of at least the most intense lines are certain to within less than 3%. Generally, uncertainties of ±10% for the most intense lines and of 30–50% for the weak lines must be considered'. This means that absolute reactor neutron activation analysis based on literature nuclear data is not accurate enough.

Nuclear constants such as σ_0, γ, etc., usually cannot be determined directly and simply by facilities available at activation laboratories. The K_0-factors as compound nuclear constants can, however, be determined easily and accurately by using Equation (2a) from bare irradiation in the whole reactor neutron spectrum, but this method requires the knowledge of f, Q_0, α, and $\bar{E}_r$, which is hidden in the $Q_0(\alpha)$ terms [8]. However, the K_0-factor can also be determined easily and accurately by using the cadmium subtraction method, requiring two irradiations, namely with and without Cd-cover

K_0 can then be calculated according to the expression

$$(K_0, \mathrm{st})_{\mathrm{exp}} = \frac{A_{\mathrm{sp}} - (A_{\mathrm{sp}})_{\mathrm{Cd}}/F_{\mathrm{Cd}}}{A^*_{\mathrm{sp}} - (A_{\mathrm{sp}})^*_{\mathrm{Cd}}/F^*_{\mathrm{Cd}}} \frac{\varepsilon^*_{\mathrm{p}}}{\varepsilon_{\mathrm{p}}} \quad (4)$$

where F_{Cd} is the cadmium epithermal neutron transmission factor (mostly ≤ 1).

This K_0 determination technique, which has been applied in this work for comparison with the K_0-factors from Equation (2a), obviously offers the advantage that the parameters f, Q_0, α, and $\bar{E}_r$ are no longer involved. On the other hand, the double irradiations and counting technique makes the determination more time-consuming.

EVALUATION PRINCIPLE

In the evaluation method, it was assumed that the accuracy of the nuclear constant for the comparator isotope was known with sufficient accuracy not to influence significantly the accuracy on the K_0-factors. Thus, the evaluation referred to merely concerns the nuclear data for the isotope to be investigated, denoted as standard. Furthermore, since the propagation factor for the error on the half-life was minimized by choosing appropriate irradiation, decay, and measuring periods, the effect of the inaccuracy of $T_{1/2}$ on $(K_0, \mathrm{st})_{\mathrm{exp}}$ can be considered to be negligible [14].

By comparison of the theoretical and experimental K_0-factors (Equations (2a) and (2b)), and using accurate values of I_0/σ_0, inaccuracies of the data used in the calculations according to Equation (2b) become detectable. If it is assumed that the values for the atomic mass, M, and for the isotopic abundance, θ, are known accurately (which is generally the case) the accuracy of $(K_0, \mathrm{st})_{\mathrm{theor}}$ will then be determined by the data for σ_0 and γ. This dependence on two parameters makes it at first sight impossible to select preferred values. However, it may be possible in the following cases.

(a) If σ_0 has been evaluated by comparison of $(K_0, \mathrm{st})_{\mathrm{exp}}$ values for different $\phi_{\mathrm{s}}/\phi_{\mathrm{e}}$ ratios, evaluation of γ-data becomes possible.
(b) If there is little doubt about the accuracy of σ_0 (i.e. the literature data is consistent), γ-data can be evaluated.
(c) If there is little doubt about the accuracy of the γ value (i.e. the literature data is consistent), σ_0 data can be evaluated.
(d) If there is a large scatter in both the σ_0 and γ-literature data, one consistent pair of values might be selected.

The serious error reduction introduced when determining experimental K_0 values can be considered as an advantage when selecting σ_0 and γ values. A t-test can be performed for comparison of the theoretical, $(X)_{\mathrm{theor}}$, and mean experimental, $(\bar{X})_{\mathrm{exp}}$, values. If $(S)_{\mathrm{exp}}$ is the standard deviation of the mean for an average value, $(\bar{X})_{\mathrm{exp}}$, then

$$t = \frac{(\bar{X})_{\mathrm{exp}} - (X)_{\mathrm{theor}}}{(S)_{\mathrm{exp}}}.$$

EXPERIMENTAL METHOD AND RESULTS

In order to enable the determination of accurate K_0-factors and to eliminate the risk of systematic errors, we performed this work at two different irradiation sites, and in each channel in triplicate. Suitable target material was packed together with a 0.503% Au–Al wire (dia. 1 mm) in a standard Cd-box. In a number of cases where no suitable wires or foils were available, use was made of small cylindrical Whatman 41 paper pellets, which contained the investigated element.

In the present work, γ-counting was performed on two single open-ended coaxial Ge(Li) detectors, coupled to a 4096 channel multichannel analyzer. The most important characteristics of the measuring chains and counting equipment are given in [6].

Measured spectra were transferred on-line to a PDP–09 or a PDP–11/45 computer and peak areas were then calculated with the aid of suitable programs [15].

Calculations were done so as to take into account the effects resulting from the following.

(1) The deviation from the $1/E$ shape of the epithermal neutron flux [8,9].
(2) The error which arises from the fact that in practice it might happen that a bulky source is measured at a small source–detector distance [6].

All K_0 values are given versus the 411.8 keV γ-line of ^{198}Au as a comparator. The nuclear data of interest, which are required for the calculations according to Equations (2) and (3), are listed in Table 1.

Table 1. Nuclear Activation Data and Decay Parameters Concerning the Reaction $^{197}Au(n, \gamma)^{198}Au$

Target isotope	M	θ (%)	σ_0 (barn)	Isotope formed	$T_{\frac{1}{2}}$ (day)	E_γ (keV)	γ (%)	E_r (eV)	F_{Cd}	I_0 (barn)
^{197}Au	196.97 [16]	100 [17]	98.8 [12]	^{198}Au	2.696 [2]	411.8 [19]	95.53 [2]	5.47 [20]	0.99 [3]	1550 [18]

Table 2. Experimental Determination of $K_{0,Au}$-Factors

Target element	Sample form, weight, dilution, backing, etc.	Isotope	θ (%) [10]	Q_0 recom. [27]	Half-life, $T_{1/2}$	E_γ (keV)	$(K_{0,Au})_{exp}$ (rel. err., %)*	
Na	Na_2CO_3, 10 mg on W41, pellet 7 mm dia. × 3 mm height	^{25}Na	100	0.59	14.96 h	1368.6	4.74×10^{-2}	(0.7)
						2753.8	4.71×10^{-2}	(1.3)
Cl	NaCl, 1.0 mg on W41, pellet 7 mm × 3 mm (in H_2O)	^{38}Cl	24.23	0.72	37.3 min	1642.7	1.97×10^{-2}	(0.9)
						2167.5	2.56×10^{-2}	(1.1)
K	$KHC_8O_4H_4$, 6 mg on W 41, pellet 7 mm × 3 mm	^{42}K	6.73	0.97	12.36 h	1524.7	9.20×10^{-4}	(3.1)
Ti	Ti-wire, 0.127 mm dia.	^{51}Ti	5.2	0.67	5.80 min	230.1	3.76×10^{-4}	(2.8)
						928.6	2.57×10^{-5}	(3.6)
V	~1.0 mg of pure vanadium	^{52}V	99.75	0.55	3.76 min	1434.0	1.95×10^{-1}	(4.0)
Cr	Al–0.99% Cr wire, 0.5 mm dia.	^{51}Cr	4.35	0.53	27.70 day	320.1	2.65×10^{-3}	(2.7)
Mn	Al–1% Mn wire, 0.2 mm dia.	^{56}Mn	100	1.07	2.576 h	846.8	5.02×10^{-1}	(1.0)
						1810.7	1.34×10^{-1}	(1.2)
						2113.0	6.90×10^{-2}	(1.3)
Co	Al–2% Cu wire, 1 mm dia.	^{60}Co	100	2.03	5.272 year	1173.3	1.31	(1.0)
						1332.5	1.32	(1.1)
Ni	Ni wire, 0.25 mm dia.	^{65}Ni	0.91	0.67	2.520 h	366.2	2.48×10^{-5}	(3.7)
						1115.5	8.21×10^{-5}	(0.8)
						1481.8	1.28×10^{-4}	(4.2)
Cu	Cu foil, 0.0256 mm thickness	^{64}Cu	69.17	1.14	12.70 h	511.0 (β^+ annih.)	3.45×10^{-2}	(5.2)
		^{65}Cu	30.83	1.06	5.10 min	1039.2	1.81×10^{-3}	(1.9)
Zn	10 mg on W41, pellet 7 mm × 3 mm	^{65}Zn	48.6	1.96	243.8 day	1115.5	5.60×10^{-3}	(2.1)
		^{69m}Zn	18.8	3.52	13.76 h	438.6	3.68×10^{-4}	(2.3)
Br	KBr (in H_2O) on W41, 4 mg, pellet 7 mm × 3 mm	^{82m}Br	49.31	19.3	6.1 min			
		I.T. / $F_2=0.976$						
		^{82}Br			35.34 h	554.3	2.45×10^{-2}	(1.9)
						619.1	1.50×10^{-2}	(2.0)
						698.4	9.52×10^{-3}	(2.1)
						776.5	2.86×10^{-2}	(1.8)
						827.8	8.15×10^{-3}	(2.2)
						1044.0	9.36×10^{-3}	(1.4)
						1317.4	9.16×10^{-3}	(1.0)
Rb	15 mg RbCl (in H_2O) on W41, pellet 7 mm × 3 mm	^{86}Rb	72.17	14.8	18.65 day	1076.8	7.21×10^{-4}	(1.0)
Rb	6 mg RbCl (in H_2O) on W41, pellet 7 mm × 3 mm	^{88}Rb	27.83	23.3	17.8 min	898.0	9.87×10^{-5}	(2.8)
						1836.0	1.55×10^{-4}	(2.6)

*Error relative to the mean value.

Table 2. *(continued)*

Target element	Sample form, weight, dilution, backing, etc.	Isotope	θ (%) [10]	Q_0 recom. [27]	Half-life, $T_{1/2}$	E_γ (keV)	$(K_{0,Au})_{exp}$ (rel. err., %)*
Y	10 mg Y_2O_3 (in HCl) on W41, pellet 7 mm × 3 mm	^{90m}Y	100	5.93	3.19 h	202.5	2.33×10^{-5} (1.0)
						479.4	2.15×10^{-3} (3.2)
Zr	Zr-foil, 0.127 mm thickness	^{95}Zr	17.25	5.82	64.03 day	724.2	9.14×10^{-5} (2.2)
						756.7	1.11×10^{-4} (3.5)
		^{97}Zr	2.76	282	16.75 h		
		$\frac{F_{24}=0.03}{\frac{I.T.}{F_3=1}\ ^{97m}Nb}\ \frac{F_2=0.97}{\beta^-}$			1.0 min	743.4	1.20×10^{-5} (1.95)
		^{97}Nb			72.1 min	658.2	1.21×10^{-5} (1.6)
Mo	Mo-foil, 0.025 mm thickness	^{99}Mo	24.23	53.1	65.95 h	181.1	4.14×10^{-5} (0.3)
						739.5	8.59×10^{-5} (1.7)
		$\frac{\beta^- 5.07\%}{\frac{I.T.}{98.9\%}\ ^{99m}Tc}\ \frac{\beta^-}{F_2=0.874}$			6.01 h	140.5	5.40×10^{-4} (0.7)
		140.5 keV					
		^{101}Mo	9.6	19.3	14.62 min	505.8 (E_{eff})	4.80×10^{-5} (4.7)
		$\frac{\beta^-}{F_2=1}$				590.9 (E_{eff})	8.09×10^{-5} (3.0)
						695.9	2.72×10^{-5} (3.1)
						1012.5 (E_{eff})	6.00×10^{-5} (3.3)
		^{101}Tc			14.2 min	306.8	3.68×10^{-4} (4.3)
						545.1	2.39×10^{-5} (4.2)
Ag	Ag-foil	^{108}Ag	51.83	2.34	2.418 min	133.9	1.57×10^{-3} (0.9)
						633.0	5.80×10^{-3} (0.7)

*Error relative to the mean value.

Table 2 gives the results of the present work for a first series of 24 isotopes covering 48 γ-lines, which show an accuracy with an average of about 2.2%. Additionally, for comparison, Figure 1 shows the ratio of the mean experimental values of K(Cd-subtr) to the recommended values reported formerly of (K_0, st).

It is clear that the deviations, which are not systematic, amount to an average of only 3.2% and that the K_0 values reported in this work are of relatively high accuracy.

To prove that recent nuclear data bases could also contain numerous unreliable data, we constructed an additional comparative figure using a recently compiled nuclear data library [21, 22] for activation analysis. It can be seen from Figure 2 that, unfortunately, the nuclear data are not accurate enough for reliable absolute activation analysis.

If we compare the experimental K_0- factors with those calculated theoretically, the critical evaluation of σ_0, γ, and the best value of I_0 become possible. In this

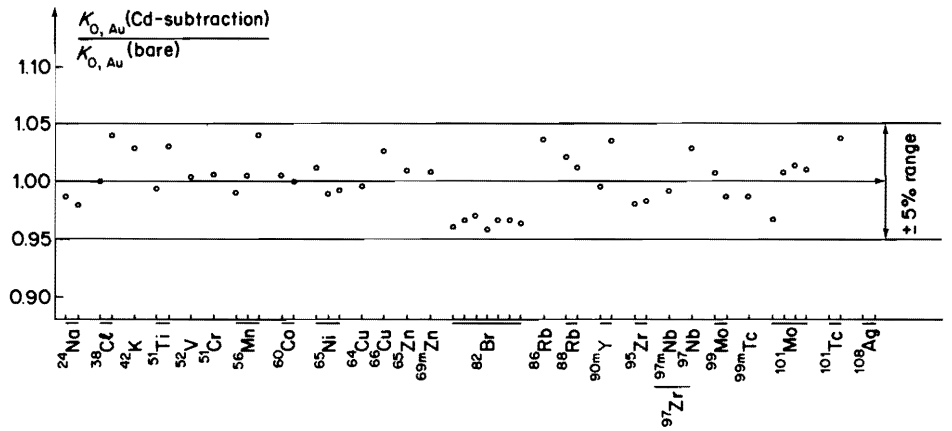

Figure 1. Comparison of Experimentally Determined and Recommended K_0*-factors*

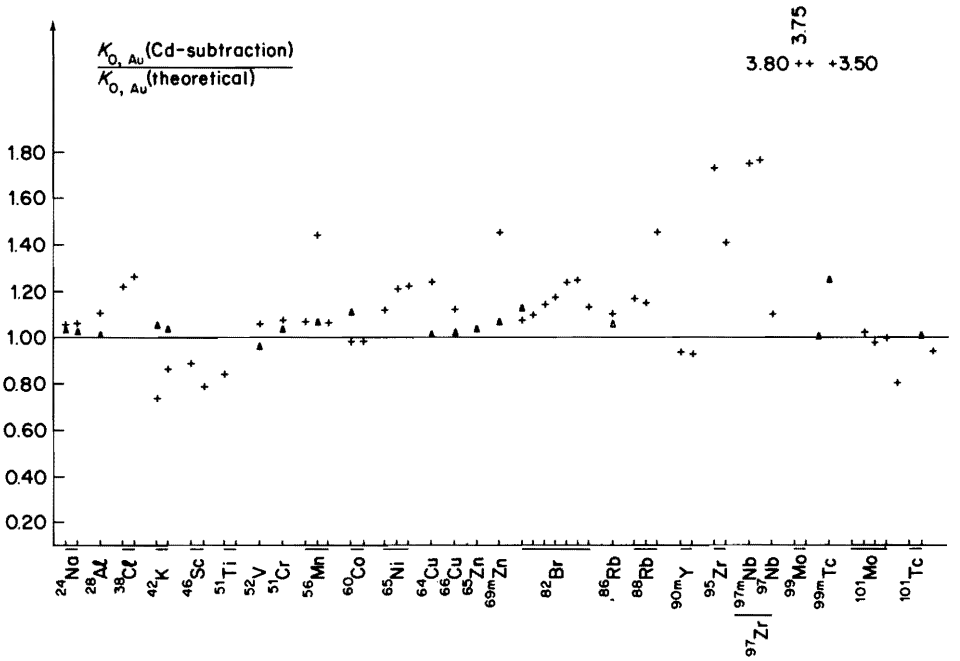

Figure 2. Values of $(K_0)_{exp}/(K_0)_{theor}$ *Using a Recently Compiled Nuclear Data Library for Activation Analysis*

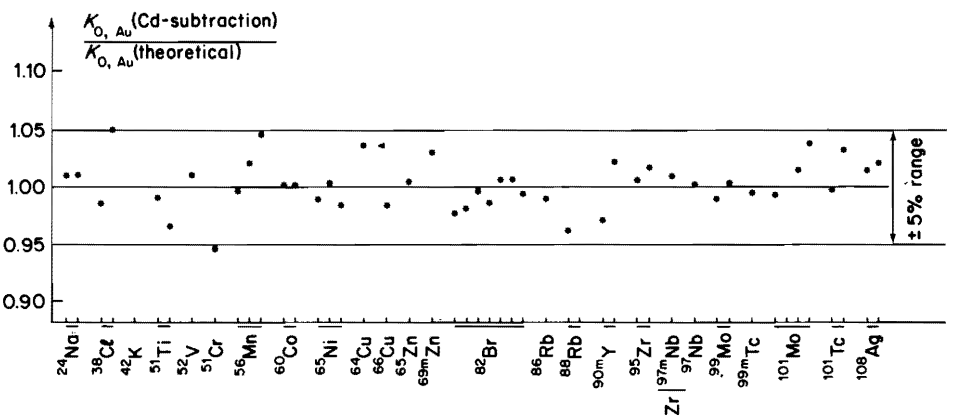

Figure 3. Values of $(K_0)_{exp}/(K_0)_{theor}$ *for Some Isotopes (*^{97m}Nb, ^{99m}Tc, *and* ^{101}Tc *are daughter isotopes)*

Table 3. Preferred Nuclear Data and Decay Parameters Concerning the (n, γ) Reaction

Target element	Atomic weight	σ_0 (barn) [21]	I_0 (barn) [21]	Target isotope	Abundance (%) [21]	Isotope	Half-life, $T_{1/2}$	$\bar{E}_r$ (eV) [10]	F_{Cd} [2]
Na	22.99	0.530	0.32	^{23}Na	100	^{24}Na	14.96 h	3,130	1.00
Cl	35.45	33	12	^{37}Cl	24.23	^{38}Cl	37.3 min	30,600	1.00
K	39.10	2.1	1.0	^{41}K	6.730	^{42}K	12.36 h	9,040	1.00
Ti	47.88	6.1	2.9	^{50}Ti	5.2	^{51}Ti	5.80 min	—	1.00
V	50.94	5.06	2.7	^{51}V	99.75	^{52}V	3.76 min	5,960	1.00
Cr	52.00	3.1	1.6	^{50}Cr	4.35	^{51}Cr	27.70 day	5,940	1.00
Mn	54.94	13.3	14.2	^{55}Mn	100	^{56}Mn	2.576 h	412	1.00
Co	58.93	37.2	75	^{59}Co	100	^{60}Co	5.272 year	133	1.00
Ni	58.69	4.4	2.2	^{64}Ni	0.91	^{65}Ni	2.520 h	14,300	1.00
Cu	63.55	3.77	4.1	^{63}Cu	69.17	^{64}Cu	12.70 h	742	1.00
				^{65}Cu	30.83	^{66}Cu	5.1 min	452	1.034
Zn	65.38	1.1	2.3	^{64}Zn	48.6	^{65}Zn	243.8 day	853	1.00
				^{68}Zn	18.8	^{69m}Zn	13.76 h	515	1.00
Br	79.90	6.8	92	^{81}Br	49.31	^{82}Br	35.34 h	114	0.95
Rb	85.47	0.36	5.0	^{85}Rb	72.17	^{86}Rb	18.65 day	694	1.00
				^{87}Rb	27.83	^{88}Rb	17.8 min	376	1.00
Y	88.91	1.28	1.0	^{89}Y	100	^{90m}Y	3.19 h	3440	1.00
Zr	91.22	0.184	1.0	^{94}Zr	17.25	^{95}Zr	64.03 day	4520	1.00
				^{96}Zr	2.76	^{97}Zr	16.75 h	340	1.00
						^{97m}Nb	1.0 min		
						^{97}Nb	72.1 min		
Mo	95.94	2.66	25	^{98}Mo	24.23	^{99}Mo	65.95 h	221	1.00
						^{99m}Tc	6.01 h		
				^{100}Mo	9.63	^{101}Mo	14.62 min	513	1.00
						^{101}Tc	14.2 min		
Ag	107.87	63.6	750	^{107}Ag	51.83	^{108}Ag	2.418 min	31.4	1.00

E_γ Main gamma (keV)	$Q_0(\alpha=0)$ recom. [27]	$(K_{0,Au})_{exp}$ (rel. err., %)L	$(K_{0,Au})_{theor}$	Evaluation value		
				σ_0 (barn)	I_0 (barn)	Absolute gamma intensity (%)
1,368.6	0.59	4.74×10^{-2}(0.7)	4.79×10^{-2}	0.528	0.31	99.99
2,753.8		4.71×10^{-2}(1.3)	4.78×10^{-2}			99.85
1,642.7	0.72	1.97×10^{-2}(0.9)	1.94×10^{-2}	0.43	0.31	31.0
2,167.5		2.56×10^{-3}(1.1)	2.70×10^{-3}			42.0
312.7	0.97	9.20×10^{-4}(3.1)	9.39×10^{-4}	1.46	1.42	17.9
320.1	0.67	3.76×10^{-4}(2.8)	3.72×10^{-4}	0.179	0.124	90
928.6		2.57×10^{-5}(3.6)	2.48×10^{-5}			6
1,434.0	0.55	1.95×10^{-1}(4.0)	1.97×10^{-1}	4.88	2.7	99
320.1	0.53	2.65×10^{-3}(2.7)	2.70×10^{-3}	16	8.5	9.8
846.8	1.07	5.02×10^{-1}(1.0)	5.0×10^{-1}	13.3	14.2	99.9
1,810.7		1.34×10^{-1}(1.2)	1.37×10^{-1}			27.19
2,113.0		6.90×10^{-2}(1.3)	7.22×10^{-2}			14.3
1,173.2	2.03	1.31 (1.0)	1.31	37.2	75.1	99.9
1,332.5		1.32 (1.1)	1.32			100
366.2	0.67	2.48×10^{-5}(3.7)	2.45×10^{-5}	1.58	1.04	4.8
1,115.5		8.21×10^{-5}(0.8)	8.23×10^{-5}			16.1
1,481.8		1.28×10^{-4}(4.2)	1.26×10^{-4}			24.6
511.0 (annih.)	1.14	3.45×10^{-2}(5.0)	3.58×10^{-2}	4.4	5.0	35.76
1,039.2	1.06	1.81×10^{-3}(1.9)	1.78×10^{-3}	2.2	2.33	8.0
1,115.5	1.96	5.60×10^{-3}(2.1)	5.61×10^{-3}	0.715	1.41	50.6
438.6	3.52	3.68×10^{-4}(2.3)	3.98×10^{-4}	0.07	0.245	94.8
554.3	19.3	2.45×10^{-2}(1.9)	2.39×10^{-2}	2.63	47.1	70.47
619.1		1.50×10^{-2}(2.0)	1.47×10^{-2}			43.32
698.4		9.52×10^{-3}(2.1)	9.48×10^{-3}			28.0
776.5		2.86×10^{-2}(2.0)	2.82×10^{-2}			83.2
827.8		8.15×10^{-3}(1.7)	8.20×10^{-3}			24.2
1,044.0		9.36×10^{-3}(1.7)	9.42×10^{-3}			27.82
1,317.4		9.16×10^{-3}(1.0)	9.10×10^{-3}			26.9
1,076.8	14.8	7.21×10^{-4}(1.0)	7.13×10^{-4}	0.46	6.81	8.8
898.0	23.3	9.87×10^{-5}(2.8)	9.46×10^{-5}	0.12	2.7	11.6
1,836.0		1.55×10^{-4}(2.6)	1.75×10^{-4}			21.4
202.2	5.93	2.33×10^{-5}(1.0)	2.30×10^{-5}	0.001	4.86×10^{-3}	97.6
479.4		2.15×10^{-5}(3.2)	2.20×10^{-5}			92.8
724.2	5.88	9.14×10^{-5}(2.2)	9.20×10^{-5}	0.052	0.309	44.2
756.3		1.11×10^{-4}(3.5)	1.13×10^{-4}			54.44
	282					
743.4		1.20×10^{-5}(1.95)	1.21×10^{-5}	0.02	5.54	97.9
658.2		1.21×10^{-5}(1.6)	1.21×10^{-5}			98.2
181.1	53.1	4.14×10^{-5}(0.3)	4.09×10^{-5}	0.13	7.23	6.0
739.5		8.59×10^{-5}(1.7)	8.59×10^{-5}			12.6
140.5		5.40×10^{-4}(0.7)	5.37×10^{-4}			90.0
505.8 (E_{eff})	19.3	4.80×10^{-5}(4.7)	4.76×10^{-5}	0.2	3.86	11.4
590.7 (E_{eff})		8.09×10^{-5}(3.0)	8.10×10^{-5}			19.4
695.9		2.72×10^{-5}(3.0)	2.76×10^{-5}			6.60
1,012.3 (E_{eff})		6.00×10^{-5}(3.3)	6.21×10^{-5}			14.87
306.8		3.68×10^{-4}(4.3)	3.67×10^{-4}			88.0
545.1		2.39×10^{-5}(4.2)	2.46×10^{-5}			5.90
433.9	2.34	1.59×10^{-3}(0.9)	1.59×10^{-3}	35.3	80.8	0.45
633.0		5.80×10^{-3}(0.7)	5.91×10^{-3}			1.67

evaluation, several compilations were systematically surveyed [2,10,11,18, 19,21,23–26]. The finally adopted values based on the results of the present evaluation and on *t*-tests are given in Table 3.

For easy and quick comparison of the K_0 results, the ratio $(K_0)_{exp}/(K_0)_{theor}$ are plotted in Figure 3. It can be seen that the deviations are not larger than 5%.

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