INDC(NED)-013
Distr. G,NM,PH

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PRESENT STATUS OF EXPERIMENTAL GAMMA-RAY STRENGTH FUNCTIONS DERIVED FROM NEUTRON CAPTURE

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September 2016

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Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria

Printed by the IAEA in Austria
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ABSTRACT

An earlier compilation of photon strength functions (f(L)), based on experimental data from resonance or thermal capture has been reviewed and updated, using the recent values of the s-wave spacing D_o. The derived atomic mass A dependence of f(E1) and f(M1) is discussed as a possible tool to test different strength function models used in Hauser-Feshbach statistical calculations of σ_γ and further to validate new f(L) measurements using other experimental techniques, in particular ARC data. The previous compilation from 1994 has been used in all RIPL documentations as the average f(E1) and f(M1) database. The future comprehensive use of ARC data is documented and discussed.

September 2016

Contents

1. Introduction

The compound nucleus mechanism for neutron capture is a dominant process up to several MeV of incident neutron energy. Therefore, the statistical model is generally used to describe and calculate the capture cross section and spectra for these energies. An exception to this can occur in thermal or resonance capture in certain mass regions, where non-statistical processes may become important.

The γ-ray transmission coefficient T_{XL} (used in model calculations) is related to the γ-ray strength functions f_{XL} as

$$T_{XL} = 2\pi E_{\gamma}^{2L+1}\, f_{XL}(E_{\gamma}) \,, \qquad (1)$$

where E_{γ} is the γ-ray energy and L is the multipolarity of the radiation. Therefore, both theoretical and experimental knowledge of f_{XL} are very important for the calculation of photon data in all reaction channels.

The derived $f_{XL}(E_{\gamma})$ data are based on experimental determination of the partial radiative width $\Gamma_{\gamma i}$ from measured absolute gamma ray intensities. Three types of experiments are usually used, capture in isolated resonances using TOF spectrometry, the average resonance capture (ARC) with filtered beams and finally the thermal neutron-capture data. The last method is preferably used for nuclei with the thermal capture dominated by a single strong s-wave resonance. Common to these experiments is the necessity to average over Porter-Thomas fluctuations which govern the distribution of partial radiative width.

The differential strength function, determined for a number of primary transitions with known multipolarity, is defined as

$$f_L\, (E_{\gamma i}) = \; <\Gamma_{\gamma i} \,/\, E^3_{\gamma i}> \; . \; 1/D_0 \,, \qquad (2)$$

where $\Gamma_{\gamma i}$ is the partial radiative width and D_0 is the s-wave resonance spacing.

In order to increase the statistical accuracy, the averaged quasi-mono energetic strength function was introduced, and used in all previous compilations [1-3]. The average is applied over a selected number of primary transitions in the narrow energy region, neglecting the additional energy dependence above the phase factor. For a region of width about 1 MeV broad this is an acceptable assumption. The mean energy of the considered data is usually between 6 – 7 MeV.

$$<f_L\, (E_{\gamma i})> \; = \; << \Gamma_{\gamma i} \,/\, E^3_{\gamma i} >>. \; 1/D_0 \;, \qquad (3)$$

where $< \Gamma_{\gamma i} \,/\, E^3_{\gamma i} >$ is a weighted mean over the used primary transitions. Two common presentations of f(L) data are shown in Fig. 1, the single energy (quasi-monoenergetic) point and differential data.

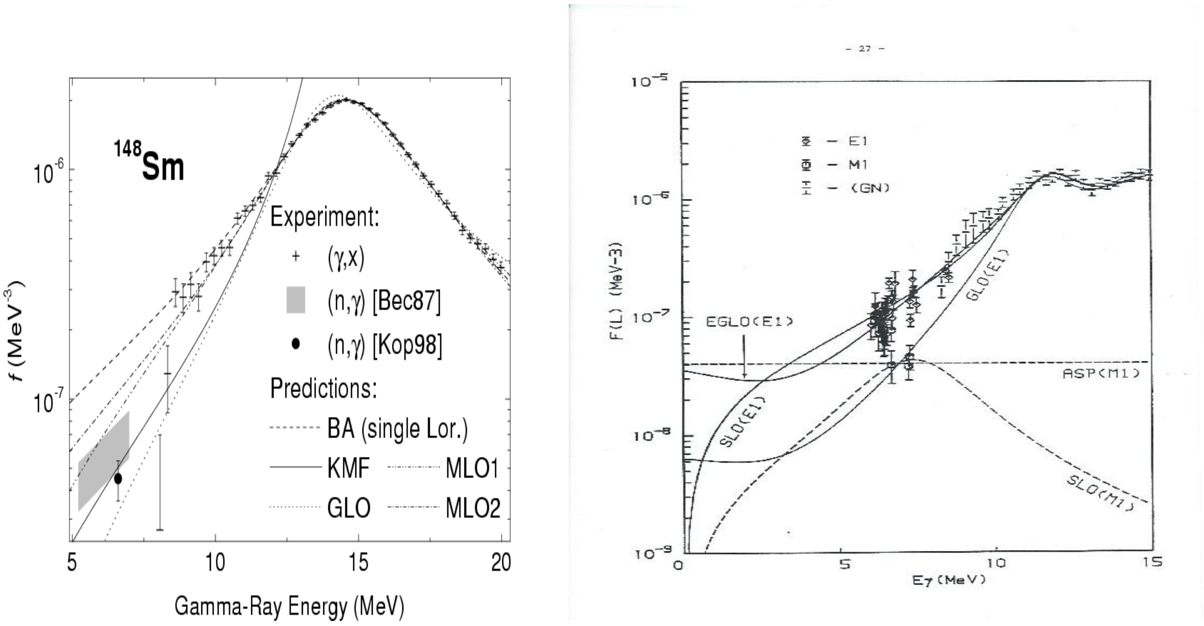

FIG. 1. *a: ^{148}Sm (γ,x) data [4] and (n,γ) <$f_L(E_{\gamma i})$> point at 7 MeV from previous compilation [3]*
b: ^{156}Gd data (γ,x) data and (n,γ) ARC differential data from [5].

The advantage of the quasi mono-energetic approach is clearly evident from the first plot of Fig.1. The different theoretical formulations of f(E1) have a large spread of predicted curves at low energies < 10 MeV and the <f (E1)> data point y can serve as an important check of the applied model.

2. Update, accuracy and revision of data

In this study we concentrate on the latest update of the compilation of gamma-ray strength functions by Kopecky and Uhl [6] finalized in Ref. [3]. This compilation was included in all RIPL documentations and remained unchanged trough all releases up to 2009. It was based on the work of McCullagh et al. [1,2] from 1981, extended by measurements between 1981 and 1994.

The advantage of a one-step reaction, such as neutron capture, compared to two-step reactions (e.g. (n,$\alpha\gamma$), is that the level density parameter enters only as D_0, which is a well documented experimental value. However, the absolute values of D_0, used in the original compilations [1] and [3], have been several times updated and have therefore been the primary focus of the present recalculation. The two latest D_0 compilations have been considered, namely in the BNL cross section book [7] from 2006 and RIPL-3 [8]. No new data have been added (except ^{138}Ba) and only minor corrections have been carried out to the experimental <$\Gamma_{\gamma i}/E_\gamma 3$>, used in [3]. The data used in Ref. [3] were revised by removing the photonuclear data and introducing the two latest D_0 evaluations as mentioned above. The new data evaluation is listed in the Appendix.

Given errors include

1. **Statistical errors** of γ-ray partial intensities $dI_{\gamma i}$ taken from original data sources.
2. N**ormalization uncertainties** are assumed to be 20% (which include the absolute calibration of Γ_γ) and
3. **Porter-Thomas uncertainties** based on the reduction factor of partial γ-widths by $\sqrt{(2/\upsilon)}$. The degrees of freedom υ for an isolated resonance capture is given by the number of resonances [9].

The number of resonances and gamma-rays used in the evaluation are quoted in Table (Appendix) to indicate the quality of averaging. The mean energy of the adopted data is between 6 - 7 MeV. The additional uncertainties not included in the quoted errors 1-3, are discussed in detail:

4. **D_0 parameter** - This quantity is deduced from measured resonances and may seriously influence f(E1) and f(M1) values. Results of older evaluations at ENEA Bologna, Obninsk, CNDS and BNL were critically reviewed in Ref. [3] and several significant disagreements were spotted, despite the fact that a similar methodology (corrections for missed or wrongly assigned resonances) was applied. The two new D_0 evaluations, recently published at BNL [7] and RIPL-3 [8], superseding the earlier evaluations, were now considered (see Table 1). The evaluated D_0 data can be categorized into two groups, those with and without significant differences in D_0 values and consequently the first group gives an additional uncertainty to the evaluated strength functions. For these nuclides the "D_0 uncertain" warning is given in the Appendix.

5. **E_γ dependence -** Another assessment concerns the mean energy $<E_{\gamma i}>$ from which the strength function value is derived. Following Eq. (3) only the phase factor reduction has been applied and no additional energy dependency was assumed. This is reasonably true if the energy region is narrow and therefore the additional energy dependence coming from the extrapolation of the giant resonance is negligible. The quoted f(E1) and f(M1) values, averaged over partial entries, correspond approximately to the mean value of the $<E_\gamma>$ region used. An inspection of these data shows that the majority of f(E1) and f(M1) values do not significantly deviate from the 6 – 7 MeV region. Data outside this region are ^{20}F and actinides for E1, while more nuclides deviate from this rule for M1, which may be the reason for the larger observed scatter of f(M1). The energy correction due to the additional energy dependence (e.g $(E_\gamma/<E_\gamma>)^2$) may then need to be considered.

6. **Thermal capture data -** The capture state is formed by tails of, often a limited number, resonances and the estimate of their contribution is complicated. Bollinger [10] has shown that the distribution of γ-ray intensities following a thermal capture follows only approximately the Porter-Thomas distribution, if both spins contribute in the thermal region, between one or two degrees of freedom. Therefore, the only application for f(L) determination is the quasi mono-energetic single $<E_\gamma>$ value based on averaging over a number of primary transitions. For the conversion of γ-ray intensities in partial $\Gamma_{\gamma\iota}$ the total radiative width Γγ is used. Only measurements (published before 1990) with directly derived <f(E1)> and <f(M1)> values were included in this compilation.

3. Discussion of results

All surveyed data with their revised values are displayed in Fig. 2 and 3 together with the LSQ fit of a power dependence on mass number A. The derived mass dependence of the strength functions are

$$<f(E1)> = 2.1E^{-03}A^{1.63} \text{ and } <f(M1)> = 3.6E^{-02}A^{0.76} \qquad (4)$$

where $R^2 = 0.66$ and $R^2 = 0.18$. R^2 is a measure of the goodness of the fit of the trend line to the data.

3.1. E1 radiation

The evaluated data reasonably follow the expected smooth trend (see Fig. 2) with two exceptions, the mass regions with $A < 40$ and $170 < A < 190$. Reasons for the larger scattering of low mass data can be probably attributed to insufficient averaging of the small number of isolated resonances. For major outliers (^{25}Mg, ^{29}Si, ^{33}S and ^{36}Cl) only one or two resonances were considered. Furthermore, the single-particle character of some primary transitions may be present. If these nuclides are removed from the LSQ fit, the R^2 value increases from 0.66 to 0.82.

The scatter in the $170 < A < 190$ region is more complex and is greatly influenced by an enhancement by 5 major outliers, ^{168}Er, ^{174}Yb, ^{178}Hf, ^{184}W and ^{199}Hg measurement. All these data belong to the 1994 update of experimental $<\Gamma_{\gamma i}>/E_\gamma^3$ values, taken from original references and double-checked here for correctness. One explanationmay be that they belong to deformed nuclides ($160 < A < 190$) with the increased gamma strength, as shown by Uhl and Kopecky [3,11]. The GLO model underestimates f(E1) in this mass region and an empirical enhancement factor has therefore been introduced in the EGLO model. The explanation of this enhancement is discussed in detail in Ref. [3] (see Fig 8 therein) in connection with the possible influence of the Γ_γ distribution. Furthermore, two strong primary transitions have been detected in ^{199}Hg, which are partially responsible for the large <f(E1)> value.

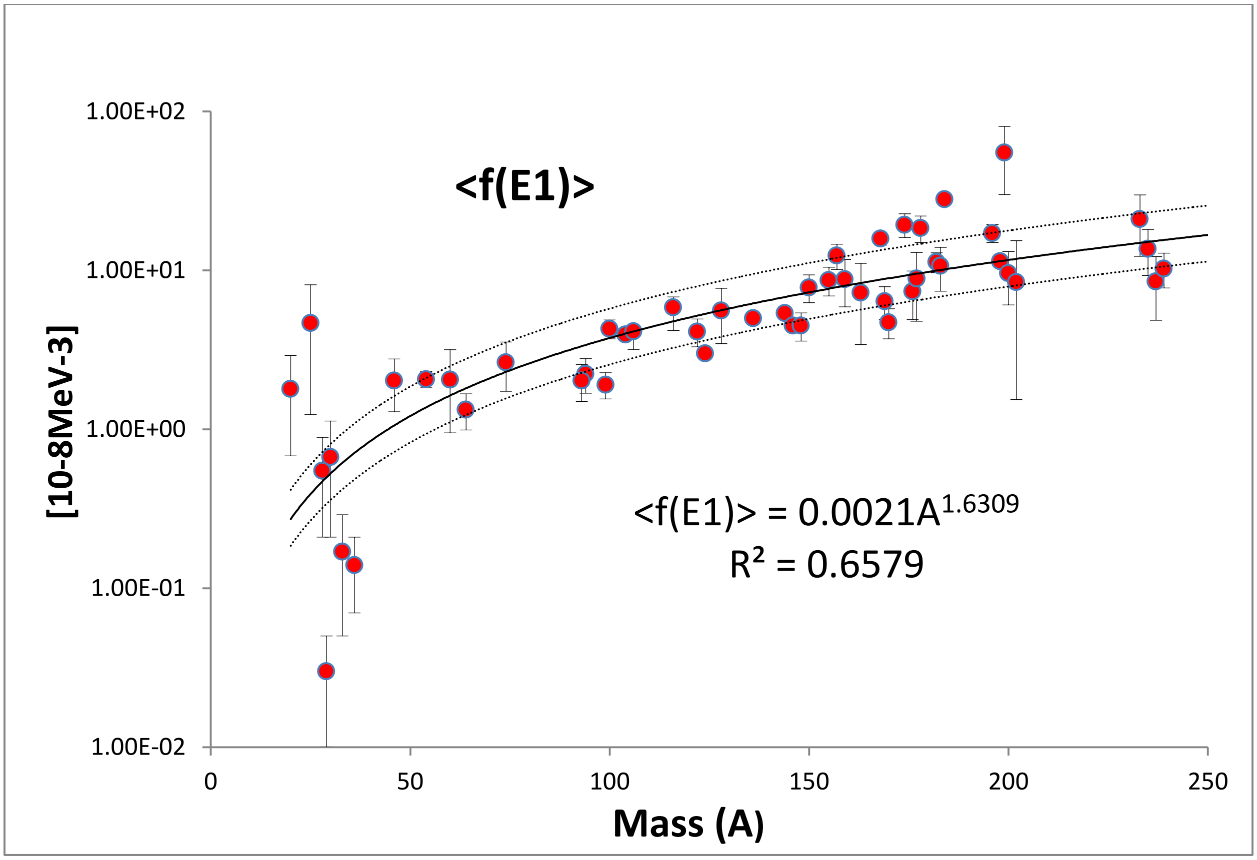

FIG. 2. *Plot of <f(E1)> values. The full curve represents the LSQ fit to recent data with the R^2 value. The uncertainty band of A/f and A.f with f=1.5 is plotted.*

A comment on the accuracy of these measurements: an example of a conflict between two independent measurements of the same nuclide is present for ^{128}I. The <f(E1)> results, based on isolated resonance averaging and thermal data significantly differ, see Appendix. The difference for E1 is especially large.

3.2. M1 radiation

For M1 radiation, the situation is complicated for several reasons. The systematic trend of the M1 strength function (see Fig. 3) shows a similar mass dependence as the E1 vase. However, the scattering of data is broader, which may point to larger inaccuracies of M1 compared to E1 data.

The reasons may be, less statistical accuracy, inadequate averaging, etc. The most probable theoretical model for M1 is a standard Lorentzian based on the spin-flip resonance and the Brink hypothesis. In such a case the presented data are close to the resonance maximum. Some of the enhanced data between A = 150 – 200 seem to cluster again in an enhanced structure.

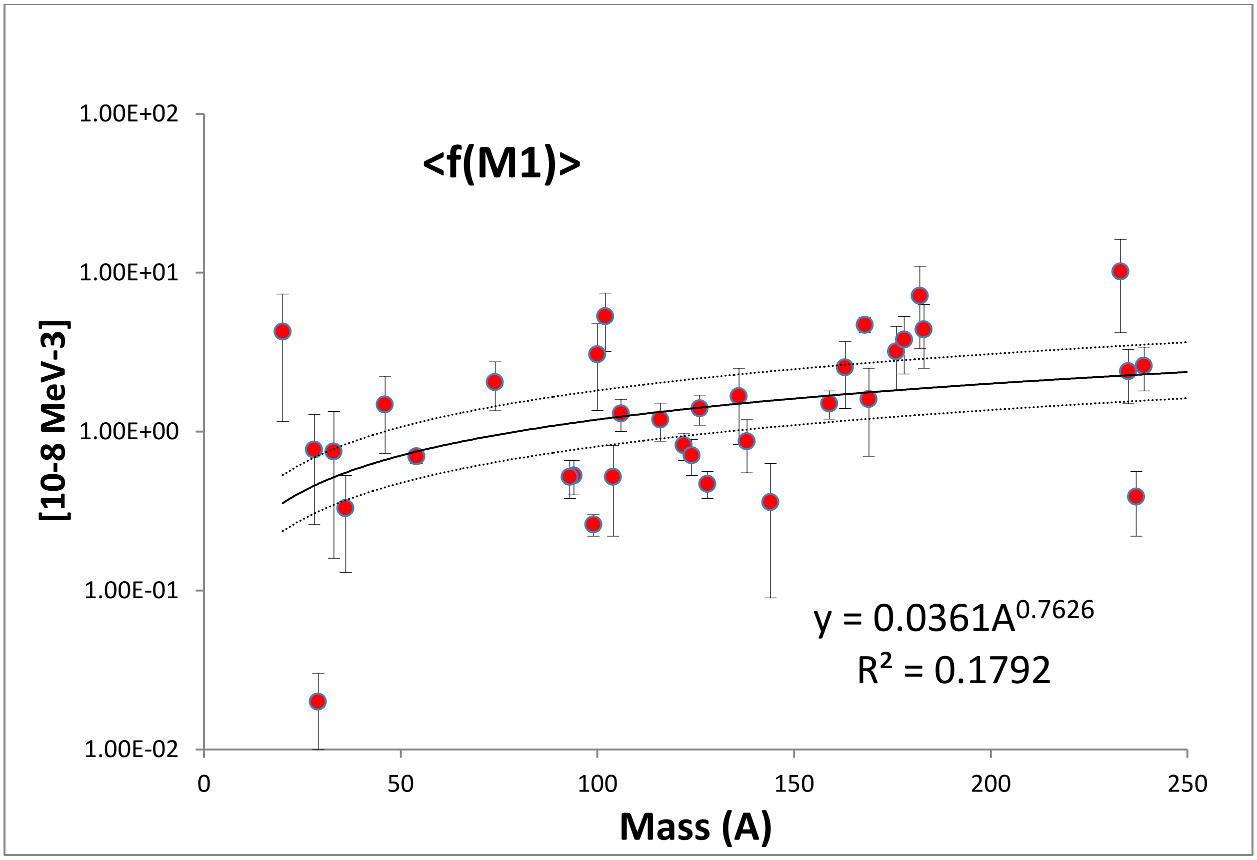

FIG. 3. *Plot of <f(M1)> values. The full curve represents the LSQ fit to recent data with* R^2 *value. The uncertainty band of A/f and fA with f=1.5 is plotted.*

3.3. E1/M1 ratio

The ratio of E1 to M1 strength with energies between 6 and 7 MeV is shown in Fig. 4. In the left hand part both E1 and M1 data are plotted together, while the next plot shows their ratio calculated from the two trend equations presented above.

Contrary to the older observation of Bollinger [9], that the E1/M1 strength ratio is in the vicinity of the neutron separation energy about 7, we have shown that at $<E_\gamma>$ = 6-7 MeV the ratio increases with the mass A from about unity for low mass nuclides up to 6-7 for heavy nuclides with A > 200.

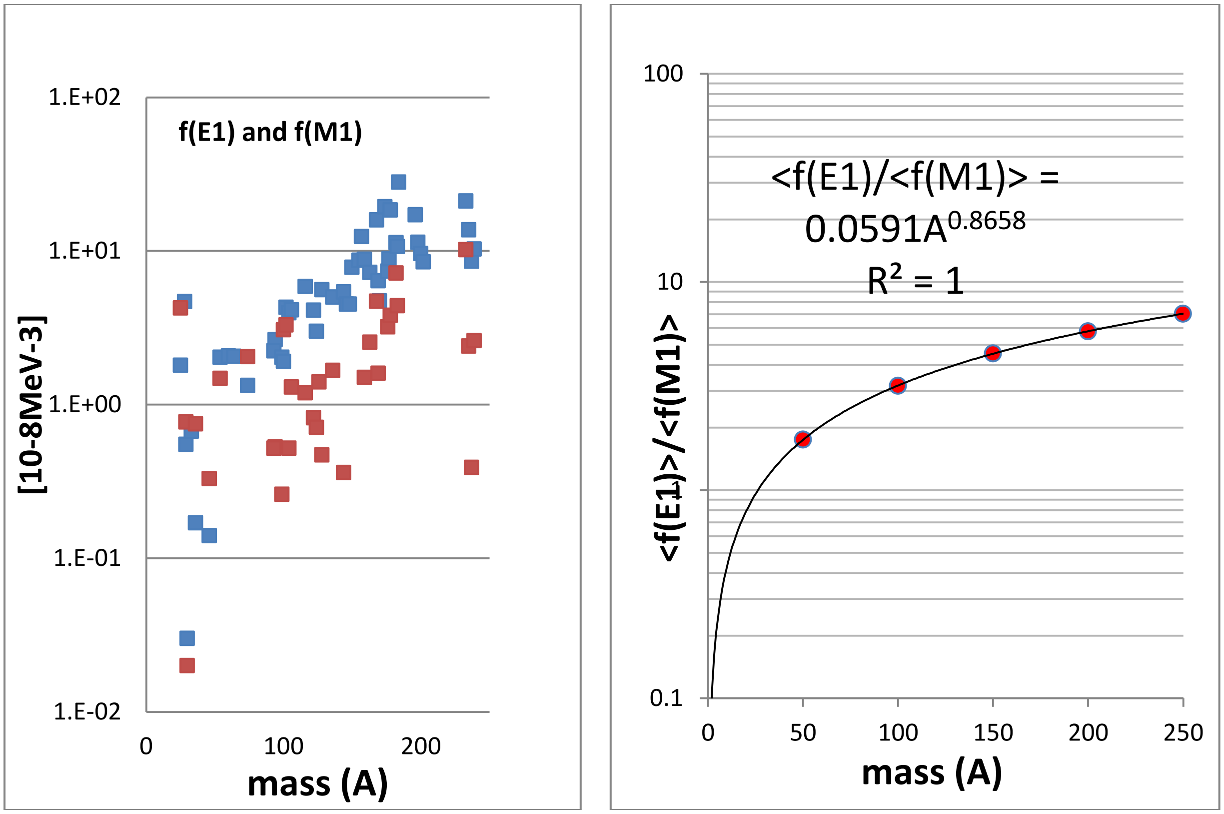

FIG. 4. *Plot of <f(E1)> /red points/ and<f(M1)> /green points/ values together and their ratio as a function of A.*

3.4. Comparison with earlier trend equation

For an indication of how the present data revision has influenced the general trend of <f(E1)> data, fitted curves from the previous 1994 [3] and present evaluations are plotted in Fig. 5. The present revision consists primarily of the most recent D_0 values. The reduced partial $\Gamma_{\gamma i}$ values were adopted from Ref. [3] without changes. The present revision has no significant influence on the global behavior of <f(E1)> values, especially for targets with A > 100, as can be seen in Fig.5. The trend line for targets with A < 50 is decreased by about a factor of two.

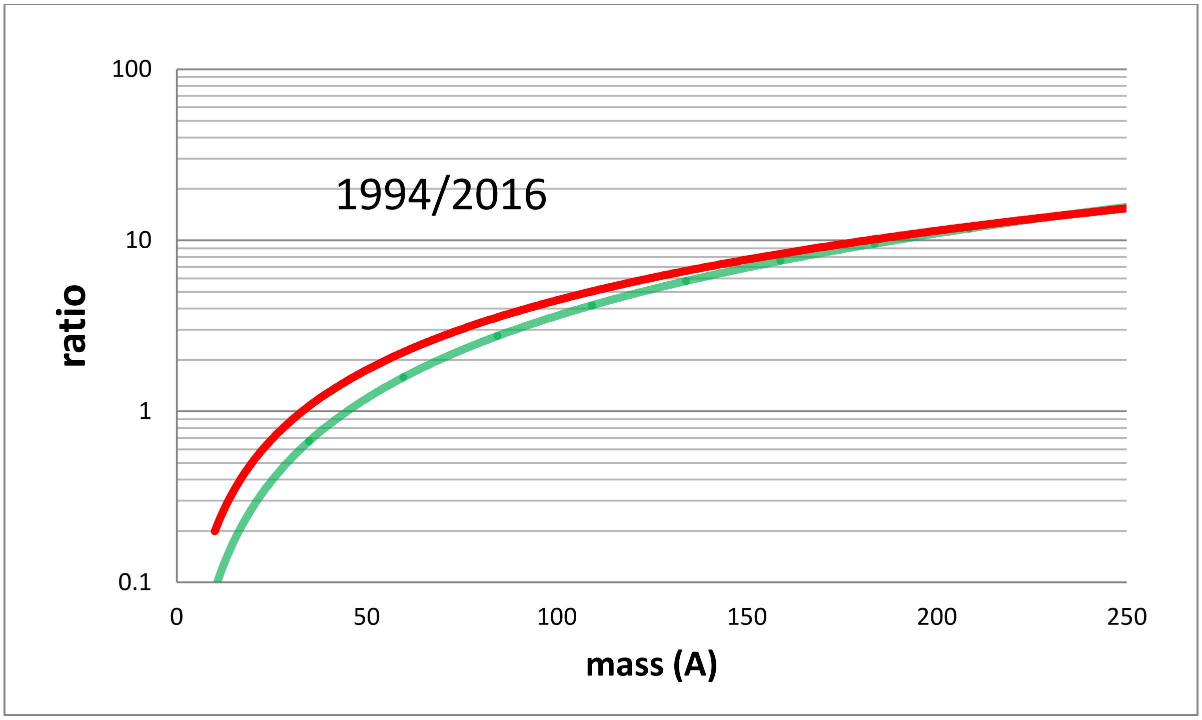

FIG. 5. *Plot of <f(E1)> trend from Ref. [3] <f(E1)> = 9.24E^{-03} A$^{1.34}$ (red curve) and from the present work <f(E1)> = 2.4E^{-03}A$^{1.64}$ (green curve).*

4. Comments on resonance capture data

The resonance capture is actually the only direct experimental way to determine the partial radiative width in a single-channel reaction process and to convert it into a strength function. Experimentally, either capture, in isolated resonances (using the TOF spectrometry) or in large number of resonances simultaneously (using filtered neutron beams (ARC measurements) can be used. For neutron filter materials, boron [12], scandium and iron [13] have been used, at ANL, NEL Idaho and BNL laboratories respectively. Boron selectively removes the low energy neutrons, while the remaining 1/E spectrum reduces the high energy neutrons. The remaining neutron window is broad enough to ensure averaging over many resonances. The more accurate method (in terms of the spectrum definition and number of involved resonances) uses scandium and iron filtered beams with mean neutron energies of 2 and 24 keV.

The *isolated resonance γ-ray spectrum measurements* are the most frequent experiment in the resonance region. From the measured gamma-ray spectra the reduced partial intensities $I_{\gamma i}/E_{\gamma}^{3}$ of primary transitions are deduced and further converted in partial widths through the equation $\Gamma_{\gamma I} = (I_{\gamma i}/E_{\gamma}^{3})\ \Gamma_{\gamma}(\mathrm{res})$. A complete collection of these measurements has been included in previous compilations and documented in Refs. [1-3]. The complete list is added in the Appendix as a reference. However, only in a limited number of publications have these data been documented as partial f_i (E1) or f_i (M1) (see e.g. Ref. [14]). An important task for the next future is to complete this approach for all available data sources.

The *filtered beam ARC measurements* have not been considered for inclusion the Appendix table because of their differential character. However, it is certainly desirable to include them in a future compilation, which should include both f(L) data sources, single energy as well as differential data. The list of documented measurements within the BNL/Petten collaborations is included in Table 1 below.

The ARC technique was developed to overcome the statistical distribution of the primary intensities from thermal or isolated resonance capture. It was realized that by simultaneous averaging over many resonances the Porter-Thomas fluctuations can be reduced and the primary transitions to the states of given J^π have approximately the same intensity. The majority of ARC measurements with Sc/Fe filters were used in nuclear spectroscopy studies, assigning primary and secondary transitions, their multipolarity and constructing the decay schemes, especially of deformed nuclides in the frame of the IBA model. Corresponding references in Table 1 are in italics and ARC data are documented as $I_{\gamma i}/E_{\gamma i}^3$ or $I_{\gamma i}/E_{\gamma i}^5$. No conversion to the strength function scale has been performed. Only small number of publications from BNL/ECN/IRK collaboration (Chrien, Kopecky and Uhl) studied the strength function values and their comparison with theoretical model predictions.

Contrary to isolated resonance capture, in which the Γ_γ width of the resonance is used to convert the reduced $I_{\gamma i}$ to $\Gamma_{\gamma i}$, the filtered beam experiments involve simultaneously a large number of resonances. Different normalization procedures have been used in published papers, usually using the information from the isolated resonance capture experiments. However, one previously unused approach can be mentioned here. This is the use of the empirical <f(E1)> and<f(M1)> systematic calculated in the current work, which may be important if no isolated resonance data are available or can be used as a double check of any calibration.

TABLE 1. LIST OF DIFFERENTIAL F(E1) AND F(M1) MEASUREMENTS BASED ON AVERAGE RESONANCE TECHNIQUE WITH FILTERED BEAMS; B (ANL), SC (IDAHO, BNL) AND FE (BNL) STANDS FOR FILTERED BEAM MATERIALS BORON, SCANDIUM AND IRON, RESPECTIVELY.

Product nuclide	**B**	**Sc**	**Fe**	**Publication**	**$\langle I\gamma\rangle_i/E_i^3$ or $\langle\Gamma\gamma\rangle_i/E_i^3$ data source**
Mo-96		x	x		BNL/ECN database
Ru-102		x	x		BNL/ECN database
Pd-106	x	 x	 x	*Phys.Rev. C2(1970) 1951* **Nucl.Phys. A468 (1987) 285**	idem BNL/ECN database
Ag-108		x	x	*J.Phys. G11 (1985) 1231*	idem
Cd-114		x	x		BNL/ECN database
Te-124		x	x	*Phys.Rev. C44 (1991) 523*	idem
Nd-146	x			*Phys.Rev. C2(1970) 1951*	BNL/ECN database
Sm-155		x	x		BNL/ECN database
Gd-156	x	 x		*Phys.Rev. C2(1970) 1951* *Nucl.Phys.A380(1982) 189* **ECN-RX—92-011**	idem idem BNL/ECN database
Gd-157		x	x	**Phys.Rev. C47(1993) 312**	BNL/ECN database
Gd-158	 x	x x	x	**ECN-RX—92-011** *Phys.Rev. C2(1970) 1951* *Nucl.Phys. A304 (1978) 327*	BNL/ECN database idem idem (Idaho)
Gd-159		x	x	Nucl.Phys. A279 (2003) 679	idem
Dy-162		x	x		BNL/ECN database
Dy-163		x	x	*Nucl.Phys. A504 (1989) 1*	idem
Dy-164		x	x		BNL/ECN database
Ho-166	x			*Phys.Rev. C2(1970) 1951*	BNL/ECN database
Er-168	x	 x	 x	*Phys.Rev. C2(1970) 1951* *J.Phys. G7 (1981) 455*	idem BNL/ECN database
Lu-176		x	x	*Nucl.Phys. A437 (1985) 285*	BNL/ECN database
Yb-172		x x	x	 *Nucl.Phys. A252(1975) 260*	BNL/ECN database
Yb-174		x x	x	Nucl.Phys. A757(2005) 287 *Phys.Rev. C23(1981) 153*	BNL/ECN database idem(Idaho)
Hf-178		x	x	*Nucl.Phys. A455 (1986) 231*	idem
W-184		x		*Nucl.Phys. A223 (1974) 66*	idem (Idaho)
Os-193		x	x	*Nucl.Phys. A316 (1979) 13*	idem
Pt-195		x	x	*Phys.Rev. C26 (1982) 1921*	BNL/ECN database
Au-198		x	x	*Nucl.Phys. A492(1989) 1* **Phys.Rev.C41(1990)1941**	idem
Th-233		x	x		BNL/ECN database
U-239	x	 x	 x	*Phys.Rev. C6(1972) 1322*	 BNL/ECN database
Pu-240		x	x	**Nucl.Phys. A436 (1985) 205**	

Data measured at 2 keV beam facility at Idaho laboratory are denoted separately. The content of this table was documented at the end of BNL/ECN/IRK collaboration. References in bold resulted from this collaboration. The completeness of existing ARC data is not granted.

The BNL/ECN/IRK collaboration was ended in 1994 due to several reasons (the shut-down of HFBR at BNL, personal issues etc.). Not all data, measured at BNL Sc/Fe filtered beam facility, have been published; the source of the measured partial intensities or widths is summarized in the last column of Table 1. The unpublished data from the BNL/ECN database are in a tabular format available at JUKO Research (J. Kopecky), originating from BNL measurements during late eighties.

5. Conclusions

1) The single energy (quasi mono-energetic) approach to strength functions is a practical tool for a global representation of averaged f(E1) and f(M1) values. It can be used as a first direct test for the calculated data with different f(L) models (see Fig.1 and Fig. 6). This is probably the most valuable feature.

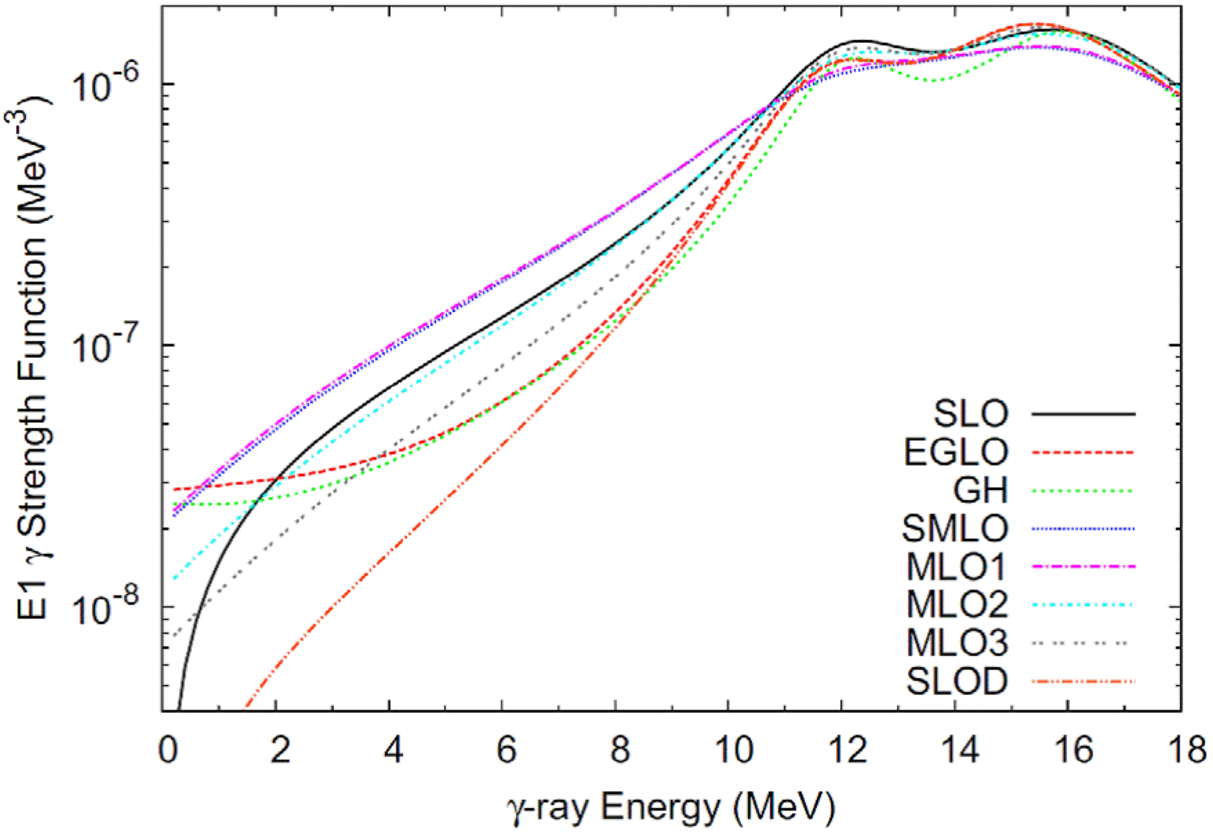

FIG. 6. *Plot of f(E1) for Gd-161 calculated with different strength function models taken from Ref. [15].*

2) Another application of the averaged single energy strength function is its use for absolute calibration of ARC experiments, because the absolute calibration using Γ_γ is not possible due to the large number of resonances in the neutron spectrum.

3) The original data for E1 and M1 gamma-ray strength functions [3] has been reviewed and

the most recent D_0 values applied. The data were restricted only to neutron capture in order to consider the same reaction mode. From the smooth increasing dependence of <f(L)> on mass A, the single-particle model can be disregarded for both multipolarities.

4) Data fluctuations around the fitted systematic are dominated by the combined effect of experimental uncertainties (including the averaging properties) and D_0 uncertainties and are discussed in detail in the text. The global trend seems to be well represented as a semi-empirical quantity.

5) The C/E ratio of Γ_γ is a frequently used tool for verification or normalization in statistical model calculations. The <f(E1)> and <f(M1)> trend equations presented here can, however, be used as a reasonable approximation if experimental Γ_γ values are not available.

6) Differential f(E1) and f(M1) data from isolated resonance or ARC measurements are a clean direct information on the strength function behavior between about 5 MeV and neutron binding energy and thus to test strength function models for E1 (GR) or M1 (spin-flip). A comprehensive compilation of differential strength function data looks to be the next step.

Acknowledgment

The author wishes cordially to thank Dr. F. Becvar for many helpful discussions and for giving access to a large number of old references.

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Appendix

Recommended experimental data base of f_{E1} and f_{M1} in a tabular form.

Nucleus [Ref]	Reac	#Res/E1/M1 D_0[eV] adopted	<$E\gamma_{E1}/E\gamma_{M1}$>	D_0[eV] from [1,2], $f_{E1}(df_{E1})$ [10^{-8} MeV^{-3}]	Δ $f_{M1}(df_{M1})$ [10^{-8} MeV^{-3}]
		Comment	Revised values		
F -20	[1] rr	2/5/3	<4.4/4.4>	60000(D1),*	
		33200 [3]		1.80(112)	4.26(310)
Mg-25	[2] rr	1/4/*	<6.0/*>	158000(D1),160000	0.99
		158000		4.68(344)	
Al-28	[3] rr	2/5/2	<6.6/6.9>	53700, 55000	0.98
		53700		0.55(34)	0.77(51)
Si-29	[4] rr	2/5/2	<6.0/5.4>	332000, 332000	1.0
		332000		0.03(2)	0.02(1)
Si-30	[4] rr	1/2/*	<6.9/*>	52400(D1),85400	0.61
		52400		1.09(75)	
		85400		0.67(46)	
		D_0 uncertain			
S -33	[1] rr	1/4/3	<7.5/7.5>	179000,190000	0.94
		179000		0.17(12)	0.75(59)
Cl-36	[3] rr	1/9/5	<7.2/5.4>	22300,23000	0.97
		22300		0.14(7)	0.33(20)
Sc-46	[6] rr	2/13/9	<7.0/7.2>	1030,1300	0.79
		1030		2.03(74)	1.48(75)
Cr-54	[7] rr	23/33/31	<6.7/6.7>	5960,6700	0.89
		5960		2.07(24)	0.70(7)
Co-60	[8] rr	1/8/*	<7.0/*>	1390,1450	0.96
		1390		2.06(111)	
Cu-64	[9] rr	3/9/-	<7.5/*>	722,700	1.03
		722		1.33(34)	
Ge-74	[10] rr	5/7/7	<7.1/7.9>	99,62	1.60
		99		2.64(90)	2.05(70)
		62		4.22(145)	3.27(112)
		D_0 uncertain			
Nb-94	[11] rr	7/15/16	<6.5/6.5>	84.8,94	0.90
		84.8		2.24(55)	0.53(13)

```
---------------------------------------------------------------------
Mo-93   [12] rr     8/10/9       <6.6/6.2>    2800,2700         1.04
                    2800                      2.03(53)      0.52(14)
---------------------------------------------------------------------
Mo-99   [13] rr     17/7/8       <5.5/5.5>    970,1000          0.97
                    970                       1.91(36)      0.26(4)
---------------------------------------------------------------------
Ru-100  [14] rr     4/5/10       <6.9/7.4>    21.7,25           0.87
                    21.7                      4.30(59)      3.07(171)
---------------------------------------------------------------------
Ru-102  [14] rr     6/*/5        <*/7.8>      18.5,18           1.03
                    18.5                                    5.32(213)
---------------------------------------------------------------------
Rh-104  [15] rr     6/4/2        <6.9/6.9>    24.2,32           0.76
                    24.2                      3.96(32)      0.52(30)
---------------------------------------------------------------------
Pd-106   [3] rr     8/10/12      <7.9/7.9>    10.9,10.3         1.06
                    10.9                      4.14(95)      1.30(30)
---------------------------------------------------------------------
In-116  [16] rr     31/12/12     <5.9/6.1>    9.0,9.5           0.95
                    9.0                       5.87(168)     1.19(32)
---------------------------------------------------------------------
Sb-122  [17] rr     12/9/9       <6.1/5.9>    10,13             0.77
                    10.0                      4.12(82)      0.82(16)
---------------------------------------------------------------------
Sb-124  [17] rr     4/11/13      <5.6/5.8>    24,24             1.00
                    24.0                      3.0(17)       0.71(18)
---------------------------------------------------------------------
Te-126   [3] rr     6/10/*       <7.7/*>      42.7,43           0.99
                    42.7                                    1.4(3)
---------------------------------------------------------------------
I -128   [3] rr     8/7/12       <6.5/6.5>    9.7,15            0.65
                    9.7                       1.9(5)        0.31(5)
                    15                        1.23(33)      0.20(3)
        [18] th     0/11/20      <6.5/6.5>
                    9.7                       0.34(13)       0.73(13)
                    15                        0.51(19)       1.13(200)
                    D0 uncertain
                    err/th in disagreement
---------------------------------------------------------------------
Ba-136   [3] rr     6/1/4        <6.6/7.9>    40,40             1.00
                    40                        5.0(30)       1.67(84)
        [19] th     0/4/16     <6.5/6.5>
                    40                        5.2(7)        2.02(52)
---------------------------------------------------------------------
Ba-138  [19] th     0/*/16       <6.5/6.5>    290,350          0.83
                    40                                      0.87(32)
---------------------------------------------------------------------
Nd-144   [3] rr     10/3/1       <6.6/6.3>    37.6,38           0.99
                    37.6                      5.4(22)       0.36(27)
---------------------------------------------------------------------
```

Nd-146	[20] rr	10/2/* 17.8	<6.7/*>	17.8,17 4.5(18)	1.05
Sm-148	[21] rr	12/16/* 5.7	<6.6/*>	5.7,5.7 4.5(9)	1.00
Sm-150	[22] rr	3/31/* 2.2	<6.3/*>	2.2,2.4 4.5(11)	0.94
	[23] rr	7/13/* 2.2	<6.5/*>	2.2,2.4 7.83(157)	0.92
Gd-155	[24] rr	15/8/* 13.8	<5.9/*>	13.8,14.5 8.7(18)	0.95
Gd-157	[23] rr	NA/5/* 30.5	<6.0/*>	30.5,30 12.4(223)	1.02
Gd-159	[23] rr	12/8/9 87.0	<5.3/5.1>	87.0,82 8.8(29)	1.06 1.5(30)
Dy-163	[25] th	0/9/7 62.9	<5.7/5.3>	62.9,62 7.26(385)	1.01 2.54(114)
Er-168	[26] rr	45/6/4 4.0	<6.4/6.4>	4.0,4.2 15.9(148)	0.95 4.7(5)
Er-169	[27] rr	7/26/9 94	<4.9/5.2>	94,100 6.4(15)	0.94 1.6(9)
Tm-170	[28] rr	9/16/* 7.28	<5.9/*>	7.28,8.5 4.72(101)	0.86
Lu-176	[3] rr	11/8/2 3.45	<5.8/5.8>	3.45,* 7.4(25)	 3.2(14)
Lu-177	[23] rr	6/15/* 1.61 D_0 uncertain	<5.9/*>	1.61,2.4 8.9(41)	0.68
Yb-174	[12] rr	22/5/5 8.06	<6.3/*>	8.06,7.5 19.4(32)	1.07
Hf-178	[29] rr	37/18/3 2.4	<6.5/6.2>	2.4,2.4 18.5(35)	1.00 3.8(15)
Ta-182	[3] rr	19/66/1 4.17	<5.2/4.3>	4.17,4.2 11.3(16)	0.99 7.17(384)
W -183	[3] rr	7/15/5 66	<5.2/4.7>	63.4,60 10.7(33)	1.06 4.4(19)

W -184	**[3]**	**rr**	**6/13/***	**<6.3/*>**	**12,12**	**1.00**
			12		**28.1(97)**	
Pt-196	**[3]**	**rr**	**22/9/***	**<7.0/*>**	**19.2,18**	**1.07**
			16.3		**17.2(22)**	
Au-198	**[30]**	**rr**	**4/5/***	**<6.4/*>**	**15.7,1.5**	**1.05**
			15.7		**11.4(53)**	
Hg-199	**[31]**	**rr**	**2/4/***	**<6.5/*>**	**69,105**	**0.65**
			105		**55.3(253)**	
			D0 uncertain 2 strong trans.			
Hg-200	**[31]**	**rr**	**3/9/***	**<7.2/*>**	**100,80**	**1.25**
			100		**9.62(356)**	
Hg-202	**[31]**	**rr**	**3/3/***	**<7.2/*>**	**98,90**	**1.09**
			100.5		**8.47(693)**	
Th-233	**[32]**	**rr**	**5/3/1**	**<4.2/4.5>**	**15.8,16.5**	**0.96**
			18.2		**21.1(88)**	**10.2(60)**
U -235	**[33]**	**rr**	**4/53/19**	**<3.9/4.4>**	**10.9,11.2**	**0.97**
			12.3		**13.7(44)**	**2.4(9)**
U -237	**[3]**	**rr**	**7/2/3**	**<4.6/4.8>**	**14.7,14**	**1.05**
			14.7		**8.55(369)**	**0.39(17)**
U- 239	**[34]**	**rr**	**23/9/5**	**<3.8/4.4>**	**20.3,20.3**	**1.00**
			16.4		**10.29(254)**	**2.6(8)**

* no data of this type

Notation in the 1-st line:

Nucleus	final nucleus for which the entry is given (e.g. Nb-94)
[Ref]	reference to the source of $<\Gamma_{\gamma i}/E_\gamma^3>$
[Ref]	added in [3]
Reac	(rr) - <discrete resonance capture> (th) - thermal neutron capture
#Res/E1/M1	number of considered resonances/number of E1 transitions/ number of M1 transitions
$<E_\gamma$E1/E_γM1>	mean energy of E1 transitions/mean energy of M1 transitions
$<E_\gamma$E1/E_γM1>	Underlined E_γ is < 5 MeV
D_0	resonance spacing values from 2 major sources: BNL Brookhaven 2006 [1], RIPL-3 2009 [2]

Δ=[1]/[2]

Notation in the 2-nd line:

D0	actually adopted resonance spacing value
fE1(a)	gamma-ray strength function f(E1): in 10^{-8} MeV^{-3} units based on s-(p-) wave neutron capture with df_{E1} being in quadrature added statistical, normalizations (20%) and Porter-Thomas uncertainty
fM1(a)	gamma-ray strength function f(M1), otherwise see above

Data errors are given in parentheses in units of the last given decimal place (e.g. 10.47(157) means 10.47±1.57).

In the third line of data sections a comment is given on the quality of data treatment in original references (if doubts exist). If a revision is executed (based on strong arguments), the correction factor and the revised f(E1) and f(M1) values are presented, respectively.

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