ORNL/TM-2000/314

SUGGEL: A PROGRAM SUGGESTING THE ORBITAL ANGULAR MOMENTUM OF A NEUTRON RESONANCE FROM THE MAGNITUDE OF ITS NEUTRON WIDTH

February 2001

Prepared by
S.Y. Oh. and L. C. Leal

ORNL/TM-2000/314

Computational Physics and Engineering Division

SUGGEL: A Program Suggesting the Orbital Angular Momentum of a Neutron Resonance from the Magnitude of its Neutron Width

Soo-Youl Oh* **and Luiz C. Leal**

February 2001

* **Nuclear Data Evaluation Lab., Korea Atomic Energy Research Institute**

Prepared by
OAK RIDGE NATIONAL LABORATORY
P.O. Box 2008
Oak Ridge, Tennessee 37831-6285
managed by
UT-Battelle, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

ABSTRACT

The SUGGEL computer code has been developed to suggest a value for the orbital angular momentum of a neutron resonance that is consistent with the magnitude of its neutron width. The suggestion is based on the probability that a resonance having a certain value of $g\Gamma_n$ is an l-wave resonance. The probability is calculated by using Bayes' theorem on the conditional probability. The probability density functions (pdf's) of $g\Gamma_n$ for up to d-wave (l=2) have been derived from the χ^2 distribution of Porter and Thomas. The pdf's take two possible channel spins into account.

This code is a tool which evaluators will use to construct resonance parameters and help to assign resonance spin. The use of this tool is expected to reduce time and effort in the evaluation procedure, since the number of repeated runs of the fitting code (*e.g.*, SAMMY) may be reduced.

Table of Contents

List of Tables

List of Figures

1. Introduction

In most neutron cross section measurements in the resolved-resonance region, the quantity obtained after preliminary processing will be, for example, the total cross section as a function of energy. Then the experimenter or evaluator deduces individual resonance parameters for every resonance; these parameters include the channel radius, the resonance energy, the partial reaction widths (Γ_n, Γ_γ, Γ_f, and competition reaction width if any), and the angular momentum quantum numbers (orbital l and total J) for each resonance.[1] These quantities compose a complete set of resonance parameters that should be provided to the evaluated library, specifically File 2 in the ENDF format. Any of several methodologies may be applicable to obtaining the resonance parameters from the measurements [for instance, Ha70, Mu80]; nevertheless it is still not a simple task to deduce values for all relevant parameters if a complete set of measurements is not available.[2] This is the major reason why we often find $g\Gamma_n$ or reaction areas instead of individual values of g (equivalent to J), Γ_n and Γ_γ in the literature.

Let us assume a situation in which an evaluator is deducing a complete set of resonance parameters for every resonance in a particular nuclide, starting from a known set of energy-dependent cross sections. The computer code SAMMY [La00], which is one of the most comprehensive and widely used tools in obtaining resonance parameters from measured data, could be used for this purpose. The evaluator must specify the values of l and J before the code[3] is run, because these values cannot be automatically adjusted (fitted) within the code. The current practice is as follows: The evaluator assigns values as a part of input at his/her discretion, runs the code, investigates whether the fitted widths are satisfactory, then modifies the assignments of the quantum numbers for some resonances, and reruns the code, and so on. This trial-and-error method, in addition to consuming time and effort, requires the evaluator to make "judgment calls" based on his experience alone.

In this report we describe a method, and its implementation, for suggesting appropriate values for the quantum numbers for each resonance from the resonance's known $g\Gamma_n$ in a rather automatic way.

---

[1] The ENDF-6 format for the Reich-Moore formula has been recently revised [La99] to identify the channel spin (s). So the channel spin is an additional quantity to be identified in case of adopting the Reich-Moore formalism.

[2] For instance, the quantity obtained from the transmission measurement is $g\Gamma_n$ (thin sample) or $g\Gamma_n\,\Gamma$ (thick sample), while the parameters to be provided in an evaluated library are l, J (from which g may be derived), Γ_n, Γ_γ, etc. If a measurement of scattering area (which is proportional to $g\Gamma_n^2/\Gamma$) or capture area (proportional to $g\Gamma_n\Gamma_\gamma/\Gamma$) is available as a supplement to the thin and thick sample transmission measurements, one can deduce values for each of g, Γ_n, and Γ_γ for a non-fissile nuclide.

[3] Actually, each resonance is identified by the spin group in SAMMY. The spin group is defined by l, s (channel spin), and J.

The resulting values could be a good initial assignment, thus saving time and effort for the evaluator. Chapter 2 describes the method. Chapter 3 describes the computer program SUGGEL; a description of the input is provided, along with some of the models used for calculating basic parameters such as the spin dispersion parameter. Also presented are examples using resonances of ^{109}Ag, ^{27}Al and ^{235}U. A conclusion and a discussion of future works are found in the final chapter. The derivation of the probability density functions is found in Appendix A. The program source list of SUGGEL is provided in Appendix B, and a brief description for the program LADDER in Appendix C.

2. Bayesian Approach for the Identification of *l* and *J*

2.1. Formula of Conditional Probability

The Bayesian approach can be used to calculate a probability that a resonance with a known neutron width is an *l*-wave resonance. In spite of a potential danger of incorrect assignment of *l* [Mu80, Ga82], this approach has been used quite frequently. Bollinger and Thomas introduced this method in distinguishing *p*-wave resonances from *s*-wave resonances for ^{238}U [Bo68]. Mizumoto *et al*. used the same concept in distinguishing *d*-wave from *p*-wave resonances for ^{206}Pb [Mi79]. There are other cases such as the analyses for ^{113}Cd of Frankle *et al*. [Fr94] and for ^{107}Ag and ^{109}Ag of Lowie *et al*. [Lo97] A recent evaluation of fission products also adopted the method with refined formulae [Oh00].

The problem being addressed is the determination of *l* of a resonance at energy E_n from its known $g\Gamma_n$ value. The neutron width multiplied by the statistical factor *g* ($g\Gamma_n$) is called the neutron width hereafter for convenience. The formula for determination of *J* is easily derived and will be presented later. According to Bayes' theorem of conditional probability [Sm91], the probability that this resonance is an *l*-wave resonance is given by

$$P\left(\, l \,\middle|\, g\Gamma_n \right) = \frac{P\left(g\Gamma_n \middle| l\right) P_l}{\sum_{l'} P\left(g\Gamma_n \middle| l'\right) P_{l'}},$$

where P_l is the *a priori* probability that the resonance is an *l*-wave resonance. $P(g\Gamma_n | l)$ is the probability that an *l*-wave resonance has the neutron width of $g\Gamma_n$. If the analysis is restricted to values of $l \le 2$ (*d*-wave), the above equation reduces to

$$P\left(l \middle| g\Gamma_n\right) = \frac{P\left(g\Gamma_n \middle| l\right) P_l}{\sum_{l'=0}^{2} P\left(g\Gamma_n \middle| l'\right) P_{l'}} = \frac{P\left(g\Gamma_n \middle| l\right)}{\sum_{l'=0}^{2} P\left(g\Gamma_n \middle| l'\right) \frac{P_{l'}}{P_l}}. \qquad (1)$$

Implicit in these equations is the assumption that the contribution of higher *l* values to the width Γ_n of a low-*l* resonance is negligible. For instance, $g\Gamma_n$ of a resonance identified as an *s*-wave may, in fact, include the *d*-wave contribution; however, the contribution is neglected by considering the small penetrability of high-*l* neutrons especially in a low energy region. As a result, each resonance is assumed to be characterized by a single *l* value.

2.2. *A Priori* Probability

The *a priori* probability is assumed to be proportional to the level density, so that the ratio is given by

$$P_{l'} \Big/ P_l = \left\langle D_l \right\rangle \Big/ \left\langle D_{l'} \right\rangle ,$$

where $<D_l>$ is the average level spacing of *l*-wave resonances. The level spacing is calculated from the Bethe formula for the level density [Be36], with an assumption that the level spacing is independent of the incident neutron energy in the energy range of interest.[4] Hence the level spacing is given by the formula

$$\frac{1}{\left\langle D_l \right\rangle} = C \cdot \sum_j \left(2J_{lj}+1\right) exp\left\{-\left(J_{lj}+1/2\right)^2 \Big/ 2\sigma^2\right\}, \tag{2}$$

where *j* is the index for possible *J* values of given *l*-wave resonance and σ^2 is the spin cutoff parameter. Generally, it is not necessary to know the proportionality constant *C* because only the ratio of level spacing is required in Eq. (1). When a value for the proportional constant is needed, it can be calculated from the *s*-wave average level spacing that is well known for most nuclides. A description of the calculation of the spin cutoff parameter and the proportionality constant *C* is in Chapter 3.

Due to the finite resolution of measurements, many weak (especially higher than *s*-wave) resonances may not be detected. Thus, for resonances readily detected, it is reasonable to adopt the *a priori* probability from the 'measurable' number of resonances, not from 'theoretically expected' numbers. In fact, this consideration is a formality only, because the effect of the *a priori* probability on the Bayesian *a posteriori* probability is much smaller than those of penetrability, which depends on the resonance energy, and the magnitude of $g\Gamma_n$ itself. Moreover, in practice, the parameter values for the level density formula are obtained from measured resonance data. However, even if it is not important from the practical point of view, an option is provided in the program SUGGEL to modify the code-calculating *a priori* probabilities based on Eq. (2).

[4] It is assumed that the energy of resolved resonance region is much lower than the magnitude (several MeV) of the neutron separation energy of a compound nucleus.

2.3. The Probability Density Functions

The probability density functions (pdf), $P(g\Gamma_n|l)$, l = 0, 1, and 2, have been derived from the χ^2 distribution proposed by Porter and Thomas [Po56]. The derivation, as well as assumptions incorporated in the derivation, is presented in the Appendix A. The results are:

for *s*-wave,

$$P\left(g\Gamma_n\middle|l=0\right)=\sum_{j=1,2} w_{0j}^{3/2}\frac{exp\left(-\dfrac{w_{0j}}{2g_{0j}S_0\left\langle D_0\right\rangle}\dfrac{g\Gamma_n}{\sqrt{E}V_0}\right)}{\sqrt{2\pi\, g_{0j}\, S_0\left\langle D_0\right\rangle\sqrt{E}V_0\, g\Gamma_n}}, \tag{3}$$

for *p*-wave,

$$P\left(g\Gamma_n\middle|l=1\right)=\sum_{j=1,4} w_{1j}^{3/2}\frac{exp\left(-\dfrac{w_{1j}}{2g_{1j}S_1\left\langle D_1\right\rangle}\dfrac{g\Gamma_n}{\sqrt{E}V_1}\right)}{\sqrt{2\pi\, g_{1j}\, S_1\left\langle D_1\right\rangle\sqrt{E}V_1\, g\Gamma_n}}+\sum_{j=2,3} w_{1j}^{2}\frac{exp\left(-\dfrac{w_{1j}}{2g_{1j}S_1\left\langle D_1\right\rangle}\dfrac{g\Gamma_n}{\sqrt{E}V_1}\right)}{2\, g_{1j}\, S_1\left\langle D_1\right\rangle\sqrt{E}V_1}, \tag{4}$$

and for *d*-wave,

$$P\left(g\Gamma_n\middle|l=2\right)=\sum_{j=1,6} w_{2j}^{3/2}\frac{exp\left(-\dfrac{w_{2j}}{2g_{2j}S_2\left\langle D_2\right\rangle}\dfrac{g\Gamma_n}{\sqrt{E}V_2}\right)}{\sqrt{2\pi\, g_{2j}\, S_2\left\langle D_2\right\rangle\sqrt{E}V_2\, g\Gamma_n}}+\sum_{j=2}^{5} w_{2j}^{2}\frac{exp\left(-\dfrac{w_{2j}}{2g_{2j}S_2\left\langle D_2\right\rangle}\dfrac{g\Gamma_n}{\sqrt{E}V_2}\right)}{2\, g_{2j}\, S_2\left\langle D_2\right\rangle\sqrt{E}V_2}. \tag{5}$$

The index j again identifies distinct J values. The weight w_{lj} is defined as the ratio of the number of l-wave resonances for which the total spin is J_{lj} to the total number of l-wave resonances; thus it represents the *a priori* probability that the total spin of an l-wave resonance is J_{lj}. Other quantities appearing in the above equations are defined in Appendix A.

The first terms on the right-hand side of Eqs. (4) and (5) are those for the J-values for which the multiplicity is 1, and represent the Porter-Thomas distribution, *i.e.*, the χ^2 distribution with the degree-of-freedom of 1. The second terms are for J's with the multiplicity of 2. The above formulae all include the possibility of two channel spins for one J value. Depending on the value of target spin, some weights w_{lj} may take the value of zero. For I = 0 nuclides, for instance, weights for j = 1 or 2 (but not both) of l = 0, for j = 2 and 3 of l = 1, and for j = 2 to5 of l = 2 become zero, in which case the pdf's reduce to forms rather similar to the traditional Porter-Thomas distribution.

2.4. Interpretation of Calculated Probability

The Bayesian approach is a statistical method. Hence, there is a potential area of concern: a resonance could, in fact, have orbital angular momentum *l'* regardless of how large is the probability that the orbital angular momentum is *l*. Nevertheless, if there is no indication other than the calculated probability, the value suggested by the statistical model is an appropriate choice.

There is a question regarding how large the calculated probability should be for a suggested *l* value. For instance, in distinguishing *p*-wave from *d*-wave resonances of ^{206}Pb, Mizumoto *et al*. [Mi79] regarded a resonance as a 'certain' *p*-wave if the probability to be *p*-wave is greater than 0.99, and as 'uncertain but probably' *p*-wave if the probability is between 0.33 and 0.99. Frankle *et al*. [Fr94], in distinguishing *s*-wave from *p*-wave resonances of ^{113}Cd, suggested *p*-wave if the probability is greater than 0.69.[5] In spite of the ambiguity, it seems reasonable to suggest the *l* value showing greatest *a posteriori* probability.

The program SUGGEL suggests the *l* value with the maximum probability among the three probabilities (for *s*-, *p*-, and *d*-waves). However, as described in the next chapter, a user can specify a minimum probability for *l*-value alteration via an input variable 'pcut'; if the maximum probability is less than this value, the original *l* value is maintained.

2.5. Further Consideration

In addition to the intrinsic limitation originating from the statistical approach, a second type of limitation exists. This is best described by an example. Consider a simplified problem of distinguishing *s*- and *p*-wave resonances for zero-spin target nuclides. According to the $(2J+1)$ law for the level density, the probability for a resonance to be a *p*-wave is as follows:

$$P(l=1|\, g\Gamma_n) = \left[1 + \frac{1}{3}\sqrt{\frac{S_1 V_1}{S_0 V_0}}\, exp\left\{\frac{g\Gamma_n}{2\langle D_0\rangle\sqrt{E}}\left(\frac{1}{S_1 V_1} - \frac{1}{S_0 V_0}\right)\right\}\right]^{-1}.$$

See Eq. (A10) of Appendix A. This formula was used by Bollinger and Thomas.[Bo68]

Consider an extreme case in which the equality $S_1V_1 = S_0V_0$ holds. Here, regardless of the magnitude of $g\Gamma_n$, the probability $P(l=1|\, g\Gamma_n)$ becomes 0.75, which is equal to the *a priori* probability. This suggests that, in a situation for which S_1V_1 is approximately equal to S_0V_0, the Bayesian approach

may lose its ability to distinguish between different *l*-waves. In general, the strength functions of *s*-, *p*-, and *d*-wave are within an order of magnitude. In addition, because the penetrabilities of *p*- and *d*-wave neutrons increase to unity as the neutron energy increases,[6] it is expected that the applicability of the Bayesian approach should diminish in the high-energy region.[7]

The following example shows the limitation of the Bayesian approach for resonances in higher energy region from the other point of view. Figs. 1 and 2 show the magnitude of $g\Gamma_n$'s of resonances of ^{27}Al and ^{109}Ag, respectively. Those resonances were adopted from a recent compilation of Sukhoruchkin *et al*. [Su98] (See sample cases 1 and 3 in Section 3.3). In Fig. 1, for which the energy range is below 800 keV, $g\Gamma_n$'s of each *l*-value are intermixed, so that it would be impossible to say which one belongs to which *l*-value if there were no legend. This is in contrast to Fig. 2, for which the energy range is below 1.5 keV. Note that the $g\Gamma_n$'s are well separated for each wave. The difference between Figs. 1 and 2, *i.e*. the degree of separation, is due to the variation of the penetrability with the incident neutron energy. As presented in Section 3.3, the Bayesian approach for resonances correctly predicted *l* values for 67 of 70 resonances for ^{109}Ag, but only 32 of 46 resonances for ^{27}Al. In conclusion, the magnitude of $g\Gamma_n$ should be distinguishable wave by wave for the Bayesian approach to work. However, that is not the case in a high energy region, say above several hundred keV, so the approach might be applicable only to low energy resonances.

---

[5] Frankle, et al. wrote that the *a priori* probabilities for *s*- and *p*-wave were assumed equal. However, their probability calculation formula readily includes adequate *a priori* probabilities, 4/9 and 5/9. The same problem is found in the work of Lowie *et al*.[Lo97]

[6] For example, the p-wave penetrability, with a scattering radius of 5 fm, is about 0.5 at 1 MeV, 0.18 at 100 keV, and 0.001 at 1 keV.

[7] Thus the approach should have its limitation for the resonances of light nuclides.

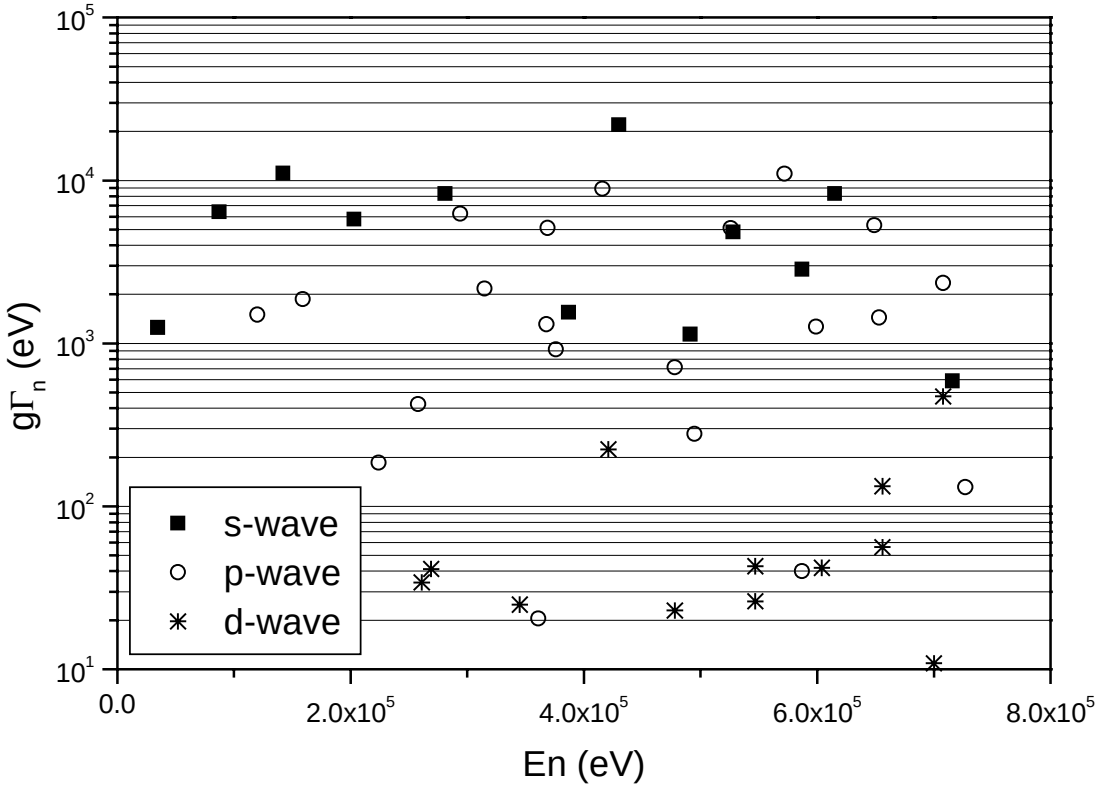

Fig. 1. $g\Gamma_n$ Values of ^{27}Al Resonances

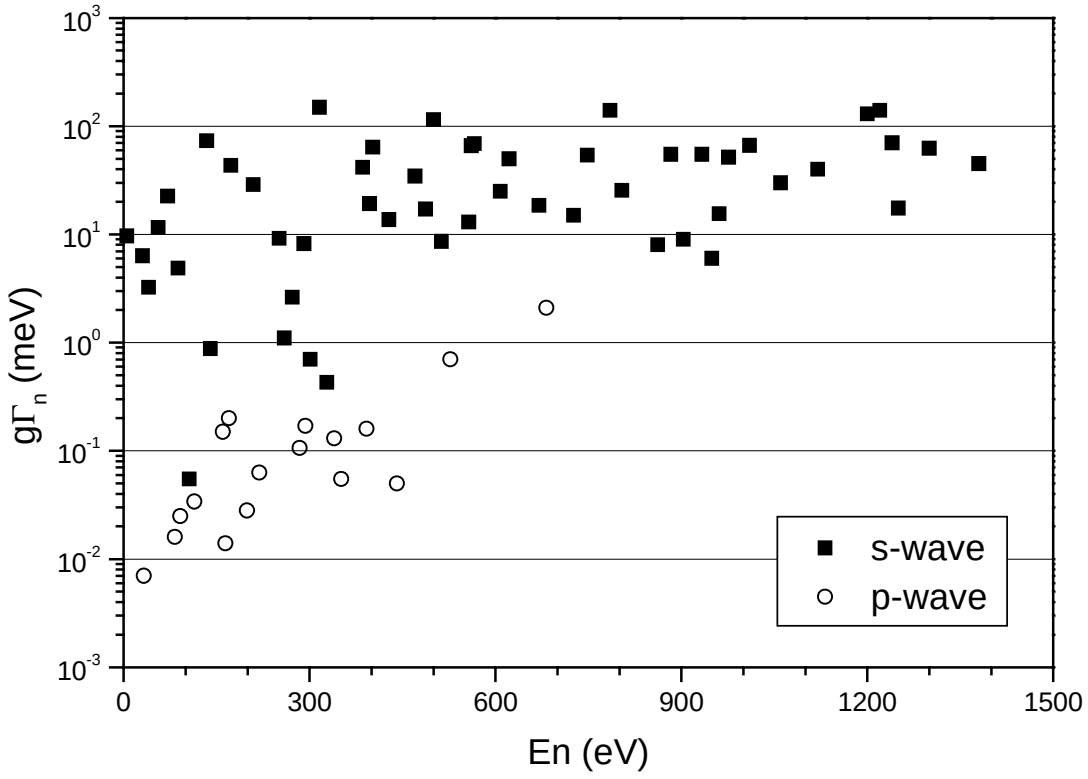

Fig. 2. $g\Gamma_n$ Values of ^{109}Ag Resonances

2.6. Identification of *J*

After the decision of *l*, the resonance spin (*J*) is determined using a similar method. Below is an example for an *s*-wave resonance in a non-zero target spin nuclide. Applying each term in Eq. (3) to the Bayesian theorem, the *a posteriori* probability that *J* is to be ($I-1/2$) is written as

$$P(J = I - \frac{1}{2} \mid g\Gamma_n) = \left[1 + \frac{1-w}{w} \sqrt{\frac{1-w}{w} \frac{I}{I+1}} exp\left\{ \frac{(2I+1) g\Gamma_n}{2 S_0 \langle D_0 \rangle \sqrt{E}} \left(\frac{w}{I} - \frac{1-w}{I+1} \right) \right\} \right]^{-1},$$

where *w* is *a priori* probability that $J = I - 1/2$.

Here is a deficiency similar to that presented in the previous section. With the ($2J$+1) law, $w = I/(2I+1)$, thus the *a posteriori* probability becomes *w*, exactly same as the *a priori* probability. Because *w* is less than 0.5 for any *I*, the resulting *J* must be I+1/2 always. This implies that the calculation is useless in distinguishing $J = I$–1/2 from $J = I$+1/2 from the magnitude of $g\Gamma_n$. Since the difference between *a posteriori* probability using ($2J$+1) law and the probability taking into account the exponential term in Eq. (2) is negligible in most cases,[8] the deficiency seldom is removed. The same situation occurs for *p*- or *d*-wave resonances.

The program SUGGEL provides two options on the *J* assignment. One is a deterministic method for which the most probable *J*-value, *i.e*. the value of *J* having the maximum probability from the Bayesian calculation. The other is a random assignment method for which the cumulative distribution function is obtained from the *a priori* probabilities [Oh00]. Users are advised to use the former method.

[8] Especially for nuclides with a large spin cutoff parameter and/or with a large spin.

3. Program SUGGEL

3.1. General Description

The program SUGGEL is written in FORTRAN 77. This program produces a "suggested value" for the orbital angular momentum (l) of a resonance from the magnitude of its $g\Gamma_n$. SUGGEL also either suggests the most probable resonance spin (J), or assigns the spin value randomly, according to user preference. The suggested value is based on the probability calculated by using the Bayesian approach as described in the previous chapter. The source listing for SUGGEL is found in Appendix B.

The physics models and assumptions are summarized as follows.

– Each resonance is identified by l and J.[9]

– The distribution of reduced neutron widths, $g\Gamma_n^l$, follows the χ^2 distribution as described in Appendix A. For an l >0 resonance of a non-zero spin nuclide, the pdf contains two terms, one with the degree-of-freedom (dof) equal to two and the other with dof equal to one. With this pdf, two channel spins, $s = I \pm 1/2$, are allowed for a resonance.

– The neutron strength function of (l, J) resonances is assumed to be $S_{l,J} = \mu_{lJ} \cdot S_l$, where $\mu_{l,J}$ is the degree-of-freedom for resonances with quantum numbers (l, J).

– The level density is assumed to be constant over the energy range under consideration, and is given by Eq. (2).

The program requires two input files and generates two output files. The basic data, as well as some control options, for the calculation are included in a file named in "suggel.inp", while sets of resonance energy and neutron widths are provided in the other input file. One of the output files shows calculation results; the other output file contains resonance parameters in SAMMY.PAR format [La00].

3.2. Input Description

The file "suggel.inp" is prepared in the name-list format. This file consists of:

The first card (or "record" or "line"): "&indata" from column 2 to 8,

The second to the last-but-one cards: data section with the name-list keywords (each card shall have the first column blank), and

[9] In SAMMY, a resonance is usually identified with l, J, and s (the channel spin) for dealing with the Reich-Moore formula.

The last card: "&end" from column 2 to 5. Notes can be added after this card for the user's convenience.

Table 1 Variables Appearing in the "suggel.inp" File

Keyword	Unit	Description
parin		Input resonance parameter data file name. In the file, the resonance energy is given in eV and Γ_n (or $g\Gamma_n$) in meV.
partyp		Type of neutron width in 'parin' file. If partyp=0, the parin file is in SAMMY.PAR file format and Γ_n's are given; otherwise, the file is in rsap.gamma format and $g\Gamma_n$'s are given. Concerning the rsap.gamma file, see the text following this table.
fout		Output list file name.
parout		File name of the output resonance parameter file, which is in SAMMY.PAR format.
awri		Atomic mass of target nuclide.
spin		Spin of the target nuclide (I).
scattr	fm	Scattering radius (R'). If scattr=0., the program calculates it as R' = 0.123 $(awri)^{1/3}$ +0.08 [10^{-12} cm]
disp		Square root of spin cutoff parameter (spin dispersion parameter, σ). If disp=0., the program calculates the value. A very large value for 'disp' (e.g. 999) indicates that the $(2J+1)$ law is to be used, for which the level density is proportional to $2J+1$.
sigcon		Constant for the calculation of spin cutoff parameter. See further discussion for 'disp' and 'sigcon' in the text following this table.
bn	MeV	Neutron separation energy of (A+1) nuclide
pair	MeV	Pairing energy
denpar	MeV^{-1}	Level density parameter
eini	eV	Lower energy boundary under the analysis
efin	eV	Upper energy boundary under the analysis

Table 1 Variables Appearing in the "suggel.inp" File

Keyword	Unit	Description
pcut		Probability cutoff. The suggested orbital angular momentum is adopted for a resonance for which the probability is higher than this value. When the probability is lower than this value, the value for *l* is not altered from its original assignment as given in 'parin' file. When the rsap.gamma file is used for input, the suggested orbital angular momentum value is always adopted.
optj		Method of *J* assignment. If optj=0, the most probable *J* value is adopted; otherwise, the *J* value is assigned randomly. However, if the original *l* value is retained due to the probability cutoff, then the *J* value is also not altered. See Section 2.6.
stn(i), i=1,2,3	10^{-4}	Neutron strength functions for *s*-, *p*-, and *d*-wave, respectively
dzero	eV	Average level spacing of *s*-wave resonance. Level spacings of *p*- and *d*-wave are calculated in the program.
frac(i), i=1,2,3		*A priori* probability correction factors for *s*-, *p*-, and *d*-wave, respectively. See Section 2.2.
lsam(i), i=1~max.18		*l* value of spin group *i* in 'parin' file. This definition shall be kept in subsequent SAMMY run. The number of spin groups can be more than 18 in a SAMMY run (as is often the case when more than one nuclide is included), but is limited to 18 in SUGGEL.
ajsam(i), i=1~max.18		*J* value of spin group *i* in 'parin' file. This definition shall be kept in subsequent SAMMY run.

One of the features of the program RSAP [Sa00] is the ability to do a "peak search" from the measured total cross section in the resonance region. The results of this peak search, the resonance energy and $g\Gamma_n$, are listed in a file 'rsap.gamma'. This search can be the initial step in a resonance parameter evaluation; the resulting energies and widths could be compiled into the *a priori* parameter file as one of SAMMY input files.

The spin cutoff parameter, σ^2, is calculated in the program (if disp=0) as

$$\sigma^2 = C \cdot \sqrt{aU}\, A^{2/3},$$

where a is the level density parameter, U the effective excitation energy, and A is compound nucleus mass. The program calculates U as $U = B_n + (eini+efin)/2 - E_{pair}$, where all four parameters are input quantities. The theoretical value of C ('sigcon' in the input file) has been known as $6/\pi^2 \times 0.24 = 0.146$ [Fa68], however, a value of 0.0888 is also used traditionally. In addition, there is the other possibility; Mughabghab obtained a value of 0.0494 via fittings [Mu98]. One has to pay attention to the choice of C value, because the values of level density parameter and pairing energy are strongly connected to C. For instance, when a user wants to adopt the pairing energy and level density parameter from [Mu98], the value of C must be 0.0494.

It should be noted that the value of $g\Gamma_n$, rather than the value of Γ_n, is conserved in 'parin' and 'parout' file. If the newly assigned J value differs from the original value, Γ_n in 'parout' must be different from that in 'parin' in order to conserve the reaction area.

3.3. Sample Cases

Case 1: ^{109}Ag resonances

An attempt was made to assign l and J values for ^{109}Ag resonances. The resonance energies, l and J, and $g\Gamma_n$ values for 70 resonances up to 1.383 keV were adopted from the recent compilation of Sukhoruchkin *et al*.[Su98] The resonance parameters in the compilation, except those for only one resonance at 5.145 eV, came from the measurements of Corvi *et al*.[Co97], in which they determined quantum numbers from the analysis of capture gamma-ray spectra. Lowie *et al*.[Lo97] also reported the measurement with l and J assignment using the Bayesian approach, and their $g\Gamma_n$ values are almost identical to those in the compilation of Sukhoruchkin.

Table 2 shows the input file, 'suggel.inp'. The sources of values are summarized at the end of input file. (It is not a part of input.) J values will be assigned per the calculated probabilities. Table 3 lists the standard output. The calculated *a priori* probabilities (0.157 for *s*, 0.334 for *p*, and 0.509 for *d*-wave) differ from those assuming the $(2J+1)$ law (0.143, 0.321, and 0.536 for *s*-, *p*-, and *d*-wave, respectively).

The code failed in the assignment of l for only 3 resonances at 106.2, 327.8, and 681.5 eV among 70 resonances.[10] It seems that the mis-assignment for the first two resonances cannot be avoided because their probabilities to be *p*-wave are so large. This shows the potential danger of the Bayesian approach. The resonance at 681.5 eV, however, needs careful investigation because its *s*-wave probability is rather far from both ends, zero and unity. A user may pay attention to the resonances at 169.8 and 300.9 eV as well.

Concerning the *J* assignment, the results reveal the deficiency described in section 2.6: The code assigned *J* = 1.0 to all *s*-wave and most *p*-wave resonances. These suggested *J* values are dubious as a whole, and might be used just as the starting guess of spin groups for a detailed analysis with SAMMY.

The information below the "`New assignment`" section in the output is based on the missing level estimation (MLE) [Mo78, Ga82] for each wave. In integrating theoretical quantities for the MLE, the pdf's derived in this work have been used. For the *s*-wave MLE, the range of integration is 0.25 to infinity in units of $g\Gamma_n^0 / \langle g\Gamma_n^0 \rangle$. The range is set to 0.25 to 5.0 for *p*- and *d*-wave MLEs, respectively. By using a finite upper limit, the possible contamination of lower *l*-wave resonances is presumably removed. The relative inherent uncertainty in $\langle D_l \rangle$ is given as of $\sqrt{0.52^2/N}$, where *N* is the number of resonances, from the Wigner's surmise [Wi57] and that in $\langle g\Gamma_n^l \rangle$ is $\sqrt{2/N}$ from the Porter-Thomas distribution [Po56]. The relative uncertainty of strength function is calculated as $\sqrt{0.52^2/N_D + 2/N_W}$, in which the number of resonances for calculating average reduced width, N_W, could be different from that for calculating average level spacing. For the ^{109}Ag case, the *s*-wave MLE resulted in the strength function of (0.67±0.14)×10^{-4} and $\langle D_0 \rangle$ of 17.4±1.0 eV, which are consistent with S_0 = (0.75±0.08)×10^{-4} and $\langle D_0 \rangle$ = 15.1±1.4 eV recommended in the RIPL [Re98] within their associated uncertainties.[11]

The MLE for each wave could provide information to help a user determine whether the input values are reasonable or not. Unfortunately in a real situation, however, it may not provide good values for high *l* resonances due to insufficient number of measured resonances. If the input strength functions and *s*-wave level spacing are quite different from those from the MLE, iteration with the new values is recommended. Actually values of S_0 and D_0 in the input for ^{109}Ag (Table 2) came from the *s*-wave MLE in the initial run with S_0 =1.0 and D_0 =15.1 eV. Note that the input S_0 and that from the MLE are same in Table 3.

---

[10] Lowie's calculation using the Bayesian approach [Lo97] showed very similar results. Of course, the *a posteriori* probabilities of Lowie are different, even if it is not significant, from those in Table 3.

[11] However, the *s*-wave strength function is much lower than 1.0×10^{-4} of Lowie.

Table 2. Input for Sample Case 1

```
 &indata
 parin="ag109.par", partyp=0, fout="ag109.out", parout="ag109new.par",
 awri=108.905, spin=0.5, scattr=0.00,
 disp=0., sigcon=0.0888, bn=6.809,  pair=-0.1, denpar=16.95,
 eini=0., efin=1400., pcut=0., optj=0,
 stn(1)=0.674, 3.900, 1.000, dzero=17.4,
 frac(1)=1.000, 1.000, 1.000,
 lsam(1)=0, 0, 1, 1, 1, 2, 2, 2,
 ajsam(1)=0., 1., 0., 1., 2., 1., 2., 3.
 &end

 NOTES
 level density parameter= 16.95 (calc. from Su Zongdi 85)
 pairing energy = -0.44+0.34 (from Su Zongdi 85)
 S2=S0 assumed (not affect anyhow)
 resonance parameters from Sukhoruchkin 98 compilation
 S0=1.00, S1=3.9 from Lowie 97
 D0=17.5 from RIPL Ch.3
 S0 and D0 adopted from the s-wave MLE
```

Table 3. Output of Sample Case 1

```
------------------------------
***  PROGRAM SUGGEL v.1.0  ***
------------------------------

* Input (En, Gn) data file name = ag109.par

* Input Variables:
    Energy range under consideration [eV] =   0.0000E+00 to 1.4000E+03
    n. strength function (s,p,d) [1E-04]  =   0.674  3.900  1.000
    s-wave avg level spacing [eV]         =   1.7400E+01
    target spin                           =   0.500
    atomic weight (AWRI)                  = 107.969
    probability cutoff for renewal of L   =   0.000
    J assignment                          =   most probable

* Calculated Quantities from the input:
    scattering radius (AP) [fm]           =   6.657
    spin dispersion parameter (sigma)     =   4.682
    A priori probabilities, s, p, and d   =   0.157  0.334  0.509
    p & d level spacing, relative to s    =   0.470  0.308

---- ---------- ---------- -----------------  -------    -------
nres     En     Reduced Gn     Probability        L          J
        (eV)       (eV)       s     p     d    old new    old new
---- ---------- ---------- ----- ----- -----  --- ---    --- ---
  1  5.1450E+00 5.6726E-03  1.000 0.000 0.000   0   0     1.0 1.0
  2  3.0600E+01 1.5257E-03  1.000 0.000 0.000   0   0     1.0 1.0
  3  3.2700E+01 2.3776E-02  0.024 0.976 0.000   1   1     1.0 1.0
  4  4.0300E+01 6.8050E-04  1.000 0.000 0.000   0   0     1.0 1.0
  5  5.5800E+01 2.0741E-03  1.000 0.000 0.000   0   0     0.0 1.0
  6  7.1000E+01 3.5683E-03  1.000 0.000 0.000   0   0     1.0 1.0
  7  8.2500E+01 8.1377E-03  0.026 0.974 0.000   1   1     2.0 2.0
  8  8.7700E+01 6.9337E-04  1.000 0.000 0.000   0   0     1.0 1.0
  9  9.1500E+01 1.8144E-02  0.032 0.968 0.000   1   1     2.0 1.0
 10  1.0630E+02 3.1878E-02  0.060 0.940 0.000   0   1 *   0.0 1.0
 11  1.1350E+02 1.7862E-02  0.035 0.965 0.000   1   1     2.0 1.0
```

12	1.3390E+02	8.4576E-03	1.000	0.000	0.000	0	0		1.0	1.0
13	1.3960E+02	9.9304E-05	1.000	0.000	0.000	0	0		1.0	1.0
14	1.6030E+02	4.6954E-02	0.135	0.865	0.000	1	1		1.0	1.0
15	1.6430E+02	2.5340E-03	0.028	0.972	0.000	1	1		2.0	2.0
16	1.6980E+02	5.7427E-02	0.208	0.792	0.000	1	1		0.0	1.0
17	1.7310E+02	4.3881E-03	1.000	0.000	0.000	0	0		1.0	1.0
18	1.9900E+02	3.8023E-03	0.032	0.968	0.000	1	1		1.0	2.0
19	2.0920E+02	2.6595E-03	1.000	0.000	0.000	0	0		1.0	1.0
20	2.1920E+02	7.4006E-03	0.039	0.961	0.000	1	1		2.0	2.0
21	2.5120E+02	7.7398E-04	1.000	0.000	0.000	0	0		1.0	1.0
22	2.5900E+02	9.1134E-05	0.988	0.012	0.000	0	0		0.0	1.0
23	2.7240E+02	2.1247E-04	1.000	0.000	0.000	0	0		1.0	1.0
24	2.8400E+02	8.4445E-03	0.047	0.953	0.000	1	1		2.0	2.0
25	2.9060E+02	6.4217E-04	1.000	0.000	0.000	0	0		1.0	1.0
26	2.9330E+02	2.1508E-02	0.063	0.937	0.000	1	1		1.0	1.0
27	3.0090E+02	5.3805E-05	0.574	0.426	0.000	0	0		0.0	1.0
28	3.1620E+02	1.1210E-02	1.000	0.000	0.000	0	0		1.0	1.0
29	3.2780E+02	4.6046E-02	0.175	0.825	0.000	0	1	*	1.0	1.0
30	3.4020E+02	7.9002E-03	0.050	0.950	0.000	1	1		2.0	2.0
31	3.5140E+02	3.1840E-03	0.041	0.959	0.000	1	1		2.0	2.0
32	3.8620E+02	2.8150E-03	1.000	0.000	0.000	0	0		1.0	1.0
33	3.9160E+02	7.8740E-03	0.053	0.947	0.000	1	1		1.0	2.0
34	3.9730E+02	1.2823E-03	1.000	0.000	0.000	0	0		1.0	1.0
35	4.0170E+02	4.2510E-03	1.000	0.000	0.000	0	0		0.0	1.0
36	4.2790E+02	8.8626E-04	1.000	0.000	0.000	0	0		1.0	1.0
37	4.4100E+02	2.0592E-03	0.044	0.956	0.000	1	1		1.0	2.0
38	4.6970E+02	2.1225E-03	1.000	0.000	0.000	0	0		0.0	1.0
39	4.8700E+02	1.0338E-03	1.000	0.000	0.000	0	0		1.0	1.0
40	4.9980E+02	6.8406E-03	1.000	0.000	0.000	0	0		1.0	1.0
41	5.1260E+02	5.0646E-04	1.000	0.000	0.000	0	0		0.0	1.0
42	5.2670E+02	3.6819E-02	0.149	0.851	0.000	1	1		1.0	1.0
43	5.5720E+02	7.3429E-04	1.000	0.000	0.000	0	0		1.0	1.0
44	5.6070E+02	3.7164E-03	1.000	0.000	0.000	0	0		0.0	1.0
45	5.6550E+02	3.8688E-03	1.000	0.000	0.000	0	0		1.0	1.0
46	6.0810E+02	1.3517E-03	1.000	0.000	0.000	0	0		1.0	1.0
47	6.2240E+02	2.6722E-03	1.000	0.000	0.000	0	0		1.0	1.0
48	6.6950E+02	9.5333E-04	1.000	0.000	0.000	0	0		1.0	1.0
49	6.8150E+02	1.0726E-04	0.547	0.453	0.000	1	0	*	2.0	1.0
50	7.2610E+02	7.4222E-04	1.000	0.000	0.000	0	0		1.0	1.0
51	7.4760E+02	2.6333E-03	1.000	0.000	0.000	0	0		1.0	1.0
52	7.8470E+02	6.6638E-03	1.000	0.000	0.000	0	0		1.0	1.0
53	8.0380E+02	1.1992E-03	1.000	0.000	0.000	0	0		1.0	1.0
54	8.6180E+02	3.6336E-04	0.999	0.001	0.000	0	0		1.0	1.0
55	8.8300E+02	2.4679E-03	1.000	0.000	0.000	0	0		1.0	1.0
56	9.0280E+02	3.9938E-04	0.999	0.001	0.000	0	0		1.0	1.0
57	9.3300E+02	2.4008E-03	1.000	0.000	0.000	0	0		1.0	1.0
58	9.4930E+02	2.5965E-04	0.956	0.044	0.000	0	0		1.0	1.0
59	9.6100E+02	6.6667E-04	1.000	0.000	0.000	0	0		0.0	1.0
60	9.7600E+02	2.1980E-03	1.000	0.000	0.000	0	0		1.0	1.0
61	1.0090E+03	2.7914E-03	1.000	0.000	0.000	0	0		0.0	1.0
62	1.0570E+03	1.2303E-03	1.000	0.000	0.000	0	0		1.0	1.0
63	1.0620E+03	1.2274E-03	1.000	0.000	0.000	0	0		0.0	1.0
64	1.1160E+03	1.5965E-03	1.000	0.000	0.000	0	0		1.0	1.0
65	1.2040E+03	4.9953E-03	1.000	0.000	0.000	0	0		1.0	1.0
66	1.2190E+03	5.3465E-03	1.000	0.000	0.000	0	0		1.0	1.0
67	1.2360E+03	2.6548E-03	1.000	0.000	0.000	0	0		1.0	1.0
68	1.2540E+03	6.5890E-04	1.000	0.000	0.000	0	0		1.0	1.0
69	1.3000E+03	2.3112E-03	1.000	0.000	0.000	0	0		1.0	1.0
70	1.3830E+03	1.6134E-03	1.000	0.000	0.000	0	0		0.0	1.0

* : L has been altered from the original assignment.
? : L should be altered, but the probability is too low.

Energy range has been adjusted to 3.7801E+00 ~ 1.3844E+03 eV.

```
                                          s          p          d
                                  ---------- ---------- ----------
Original assignment:
  Number of resonances          =         53         17          0
  Strength function [1E-04]     =      0.654      0.694      0.000

New assignment:
  Number of resonances          =         52         18          0
  Strength function [1E-04]     =      0.654      0.699      0.000

From the Missing Level Estim.,
  Avg. g*red.width [eV]         =  1.171E-03  1.099E-03  0.000E+00?
  Expected no. of resonances    =         79         39          1?

Based on the "s"-wave MLE:
  Number of resonances          =         79        169        258
  Strength function [1E-04]     =      0.673      0.449      1.000
  Measurement efficiency        =      0.655      0.107      0.000
  Avg. level spacing [eV]       =  1.738E+01  8.170E+00  5.355E+00

Recommended frac (as the input) =      1.000      0.163      0.000
```

Case 2: ^{235}U pseudo-resonances

A pseudo-resonance parameter file for ^{235}U was generated using the program LADDER (see Appendix C). The input strength functions for this LADDER run were 1.0, 1.2, and 0.5×10^{-4} for *s*-, *p*-, *d*-wave, respectively; nevertheless, those of the actually-generated resonances are 0.99, 1.03, and 0.51×10^{-4}. (These slight differences indicate the statistical accuracy of the method.) In the energy range from 100 to 200 eV, the number of resonances generated by LADDER is 197 for *s*-waves, 380 for *p*-waves, and 577 for *d*-waves. However, weak resonances were eliminated from the LADDER output, so the file 'case1r.par' contains 193 *s*-wave, 108 *p*-wave, and 0 *d*-wave resonances in 100~200 eV energy region.

Table 4 shows the input file and Table 5 gives the output from the SUGGEL run (omitting the 6th through the 296th resonance). Because there are large differences between the values of $g\Gamma_n$'s for *s*- and *p*-wave resonances in this example, SUGGEL has correctly suggested the *l* values of 293 resonances among the total of 301. Meanwhile, the s-wave strength function and level spacing generated using the MLE agree well with values provided to the original LADDER run which generated these resonances. Similarly, the number of p-wave resonances estimated using the MLE agrees well with the actual number, while the expected strength function (0.83×10^{-4}) is rather small comparing with 1.2×10^{-4} for the LADDER run.

Table 4. Input for Sample Case 2

```
 &indata
 parin="case1r.par", partyp=0, fout="case1r.out", parout="sug1r.par",
 awri=233.03, spin=3.5, scattr=0.,
 disp=999., sigcon=0.0888, bn=0., pair=0., denpar=0.,
 eini=100.,efin=200., pcut=0., optj=1,
 stn(1)=1.00,1.20,0.50, dzero=0.50, frac=1.00,0.35,0.00,
 lsam(1)=2*0,4*1,6*2,
 ajsam(1)=3.,4., 2.,3.,4.,5., 1.,2.,3.,4.,5.,6.
 &end
  Test with pseudo par file generated by using ladder
    Set as S0=1.0, S1=1.2, S2=0.5, D0=0.5 eV
  Small resonances were removed from case1.par
```

Table 5. Output of Sample Case 2

```
------------------------------
***  PROGRAM SUGGEL v.1.0  ***
------------------------------

* Input (En, Gn) data file name = case1r.par

* Input Variables:
    Energy range under consideration [eV] =   1.0000E+02 to 2.0000E+02
    n. strength function (s,p,d) [1E-04]  =   1.000  1.200  0.500
    s-wave avg level spacing [eV]         =   5.0000E-01
    target spin                           =   3.500
    atomic weight (AWRI)                  = 233.030
    probability cutoff for renewal of L   =   0.000
    J assignment                          =   random
    spin dispersion parameter (sigma)     = 999.000

* Calculated Quantities from the input:
    scattering radius (AP) [fm]           =   8.369
    A priori probabilities, s, p, and d   =   0.588  0.412  0.000
    p & d level spacing, relative to s    =   1.429 99.000

---- ---------- ---------- -----------------  -------    -------
nres     En     Reduced Gn     Probability        L          J
        (eV)       (eV)       s     p     d    old new    old new
---- ---------- ---------- ----- ----- -----   --- ---    --- ---
  1  1.0052E+02 4.4001E-04  1.000 0.000 0.000   0   0     3.0 4.0
  2  1.0112E+02 5.2106E-05  1.000 0.000 0.000   0   0     4.0 3.0
  3  1.0174E+02 3.2304E-05  1.000 0.000 0.000   0   0     4.0 3.0
  4  1.0189E+02 1.5629E-06  1.000 0.000 0.000   0   0     3.0 4.0
  5  1.0202E+02 1.4167E-04  1.000 0.000 0.000   0   0     4.0 4.0
 ...
297  1.9793E+02 3.8945E-04  0.099 0.901 0.000   1   1     4.0 3.0
298  1.9839E+02 1.5046E-05  1.000 0.000 0.000   0   0     3.0 3.0
299  1.9890E+02 3.0790E-04  0.068 0.932 0.000   1   1     3.0 2.0
300  1.9903E+02 1.2077E-04  1.000 0.000 0.000   0   0     3.0 3.0
301  1.9963E+02 4.3334E-04  0.083 0.917 0.000   1   1     2.0 2.0

* : L has been altered from the original assignment.
? : L should be altered, but the probability is too low.

 Energy range has been adjusted to 1.0047E+02 ~ 1.9968E+02 eV.

                                          s          p          d
                                   ---------- ---------- ----------
```

```
Original assignment:
  Number of resonances           =         193        108          0
  Strength function [1E-04]      =       0.995      0.699      0.000

New assignment:
  Number of resonances           =         189        112          0
  Strength function [1E-04]      =       0.995      0.706      0.000

From the Missing Level Estim.,
  Avg. g*red.width [eV]          =   5.229E-05  6.436E-05  0.000E+00?
  Expected no. of resonances     =         187        383          1?

Based on the "p"-wave MLE:
  Number of resonances           =         202        383        527
  Strength function [1E-04]      =       1.065      0.829      0.500
  Measurement efficiency         =       0.936      0.292      0.000
  Avg. level spacing [eV]        =   4.913E-01  2.588E-01  1.884E-01

Recommended frac (as the input)  =       1.000      0.312      0.000
```

Case 3: ^{27}Al resonances

For ^{27}Al resonances, the resonance energies, l and J, and $g\Gamma_n$ values for 46 resonances were adopted from the recent compilation of Sukhoruchkin *et al.*[Su98] The number of resonances are: 12 (*s*-wave), 22 (*p*), and 12 (*d*), respectively, in an energy range 0 to 726.8 keV. Table 6 shows the input file and the sources of values are summarized at the end of input file. Due to insufficient number of measured resonances, $<D_0>$ and strength functions have very large uncertainties. An arbitrary value of 0.5 was adopted for 'pcut'.

Table 7 shows the output list. The l values for about 2/3 of resonances were assigned correctly. However, such assignments are more or less dubious because the calculated probabilities are scattered among the various values of l. For instance, the *p*-wave probabilities for resonances at 478.29 (Γ_n = 1.22 keV) and 490.82 keV (Γ_n = 1.95 keV) are around 0.55, which are not significantly large, and the suggested l values are 1 for both resonances. Note that the correct l values are 1 and 0, respectively. More ambiguous example is the resonance at 495.18 keV; the probabilities are around 1/3 for each wave, so one could not rely on the calculated probabilities in determining l value at all.

The above deficiency stems from large penetrabilities of high l wave neutrons in the high energy region. The Bayesian approach may lose its capability of distinguishing l values for resonances at high energy region, especially for the resonances of light nuclides. Even so, from the viewpoint that SUGGEL is a pre-analysis tool, the suggested assignment could be a good initial guess of the spin group for a detailed analysis using SAMMY.

Table 6. Input for Sample Case 3

```
&indata
parin="al27.par", partyp=0, fout="al27.out", parout="al27new.par",
awri=26.982, spin=2.5, scattr=0.00,
disp=0.0 ,sigcon=0.0888, bn=7.725,  pair=0.0, denpar=4.102,
eini=0., efin=730000., pcut=0.5, optj=0,
stn(1)=0.500, 2.600, 0.500, dzero=45000.,
frac(1)=1.000, 1.000, 1.000,
lsam(1)=2*0, 4*1, 6*2,
ajsam(1)=2.,3., 1.,2.,3.,4., 0.,1.,2.,3.,4.,5.
&end

NOTES
level density parameter= 4.102 (calc. from Su Zongdi 85)
pairing energy = 0.0 (from Su Zongdi 85, odd-odd)
resonance parameters from Sukhoruchkin 98 compilation
S0=0.5 read from Mughabghab 81, Fig.2
S1=2.6+-1.0 from Mughabghab 81
S2=S0 assumed
D0=45+-15 keV from RIPL Ch.3
```

Table 7. Output of Sample Case 3

```
------------------------------
***  PROGRAM SUGGEL v.1.0  ***
------------------------------

* Input (En, Gn) data file name = al27.par

* Input Variables:
    Energy range under consideration [eV] =   0.0000E+00 to 7.3000E+05
    n. strength function (s,p,d) [1E-04]  =   0.500  2.600  0.500
    s-wave avg level spacing [eV]         =   4.5000E+04
    target spin                           =   2.500
    atomic weight (AWRI)                  =  26.750
    probability cutoff for renewal of L   =   0.500
    J assignment                          =   most probable

* Calculated Quantities from the input:
    scattering radius (AP) [fm]           =   4.479
    spin dispersion parameter (sigma)     =   2.165
    A priori probabilities, s, p, and d   =   0.207  0.364  0.429
    p & d level spacing, relative to s    =   0.568  0.481

---- ---------- ---------- ----------------  -------    -------
nres     En     Reduced Gn     Probability        L          J
        (eV)       (eV)       s     p     d    old new    old new
---- ---------- ---------- ----- ----- -----  --- ---    --- ---
  1  5.9050E+03 2.4386E+01  0.125 0.875 0.000   1   1     1.0 2.0
  2  3.4750E+04 1.1495E+01  0.906 0.094 0.000   0   0     2.0 3.0
  3  8.7300E+04 3.7229E+01  0.729 0.271 0.000   0   0     3.0 3.0
  4  1.1975E+05 7.6422E+01  0.381 0.619 0.000   1   1     2.0 3.0
  5  1.4210E+05 3.4593E+02  0.342 0.658 0.000   0   1 *   3.0 4.0
  6  1.5860E+05 6.4364E+01  0.341 0.659 0.000   1   1     3.0 3.0
  7  2.0335E+05 1.4240E+02  0.271 0.729 0.000   0   1 *   2.0 3.0
  8  2.2419E+05 9.3136E+00  0.392 0.579 0.029   1   1     2.0 1.0
  9  2.5762E+05 1.7815E+01  0.385 0.610 0.005   1   1     3.0 1.0
 10  2.6094E+05 2.0246E+01  0.159 0.174 0.667   2   2     4.0 3.0
 11  2.6870E+05 2.2851E+01  0.182 0.199 0.619   2   2     4.0 3.0
```

12	2.8073E+05	1.3341E+02	0.178	0.822	0.000	0	1	*	3.0	3.0
13	2.9360E+05	9.4653E+01	0.207	0.793	0.000	1	1		2.0	3.0
14	3.1510E+05	4.1966E+01	0.307	0.693	0.000	1	1		1.0	2.0
15	3.4543E+05	1.0613E+01	0.083	0.077	0.840	2	2		5.0	2.0
16	3.6069E+05	7.8355E+00	0.073	0.065	0.862	1	2	*	1.0	2.0
17	3.6771E+05	2.0835E+01	0.357	0.642	0.002	1	1		2.0	2.0
18	3.6866E+05	8.1074E+01	0.220	0.780	0.000	1	1		4.0	2.0
19	3.7647E+05	1.4175E+01	0.383	0.609	0.007	1	1		2.0	2.0
20	3.8677E+05	2.3201E+01	0.348	0.651	0.001	0	1	*	3.0	2.0
21	4.1643E+05	8.6523E+01	0.144	0.856	0.000	1	1		2.0	3.0
22	4.2073E+05	3.3087E+01	0.338	0.369	0.292	2	2	?	4.0	4.0
23	4.2953E+05	2.0689E+02	0.032	0.968	0.000	0	1	*	2.0	3.0
24	4.7783E+05	7.5472E+00	0.077	0.062	0.861	2	2		1.0	1.0
25	4.7829E+05	1.3707E+01	0.405	0.533	0.063	1	1		3.0	1.0
26	4.9082E+05	1.2724E+01	0.391	0.587	0.022	0	1	*	3.0	2.0
27	4.9518E+05	5.1191E+00	0.328	0.342	0.330	1	1		1.0	1.0
28	5.2607E+05	5.2584E+01	0.229	0.771	0.000	1	1		3.0	2.0
29	5.2822E+05	4.9581E+01	0.237	0.763	0.000	0	1	*	3.0	2.0
30	5.4672E+05	6.1716E+00	0.092	0.072	0.835	2	2		1.0	2.0
31	5.4711E+05	6.2656E+00	0.084	0.064	0.852	2	2		4.0	1.0
32	5.7203E+05	7.3092E+01	0.114	0.886	0.000	1	1		3.0	3.0
33	5.8709E+05	2.5855E+01	0.319	0.676	0.005	0	1	*	3.0	2.0
34	5.8717E+05	8.1430E+00	0.092	0.070	0.838	1	2	*	4.0	1.0
35	5.9935E+05	1.8697E+01	0.393	0.557	0.050	1	1		4.0	1.0
36	6.0390E+05	8.0051E+00	0.094	0.071	0.836	2	2		4.0	1.0
37	6.1533E+05	7.1486E+01	0.159	0.841	0.000	0	1	*	3.0	2.0
38	6.4932E+05	4.2929E+01	0.236	0.763	0.001	1	1		3.0	2.0
39	6.5346E+05	1.9271E+01	0.388	0.555	0.057	1	1		2.0	1.0
40	6.5578E+05	5.3218E+00	0.101	0.076	0.823	2	2		5.0	2.0
41	6.5627E+05	1.2551E+01	0.147	0.120	0.734	2	2		4.0	2.0
42	7.0023E+05	1.4836E+00	0.117	0.077	0.806	2	2		5.0	1.0
43	7.0770E+05	2.0957E+01	0.313	0.307	0.380	2	2		4.0	4.0
44	7.0825E+05	1.7237E+01	0.356	0.616	0.027	1	1		2.0	2.0
45	7.1649E+05	1.6658E+00	0.340	0.348	0.312	0	0	?	2.0	2.0
46	7.2682E+05	9.8464E+00	0.136	0.106	0.758	1	2	*	2.0	2.0

* : L has been altered from the original assignment.
? : L should be altered, but the probability is too low.

Energy range has been adjusted to 1.2552E+03 ~ 7.3147E+05 eV.

		s	p	d
Original assignment:				
Number of resonances	=	12	22	12
Strength function [1E-04]	=	1.997	1.712	0.235
New assignment:				
Number of resonances	=	3	28	15
Strength function [1E-04]	=	0.399	4.527	0.261
From the Missing Level Estim.,				
Avg. g*red.width [eV]	=	6.062E+00	2.943E+01	3.792E+00
Expected no. of resonances	=	5	31	21
Based on the "p"-wave MLE:				
Number of resonances	=	17	31	36
Strength function [1E-04]	=	1.440	4.104	0.374
Measurement efficiency	=	0.173	0.916	0.416
Avg. level spacing [eV]	=	4.210E+04	2.390E+04	2.026E+04
Recommended frac (as the input)	=	1.000	1.000	0.454

4. Concluding Remarks

The SUGGEL computer code has been developed and tested on both resonance parameters taken from actual evaluations and on artificially-generated parameters. Test results show that SUGGEL is capable of providing a reasonable first estimate for the orbital angular momentum quantum numbers for many resonances. By using SUGGEL as a pre-analysis tool before running SAMMY, the analyst can expect a reduction in the time and effort required for proper spin group assignments.

This Bayesian approach is unfortunately not appropriate for some resonances at high energy region, higher than ~hundred keV, where the magnitudes of $g\Gamma_n$'s of *s*-wave and higher *l*-waves are comparable. This was anticipated initially, and is observed in a test for ^{27}Al with SUGGEL. There is another kind of deficiency: The Bayesian approach fails in distinguishing the total angular momentum. However, in spite of deficiencies in the *l* assignment for higher energy resonances as well as in the *J* assignment, SUGGEL is still effective in providing a good initial guess of spin group for a detailed analysis.

The method (as well as the calculation of the probability density functions) could be incorporated into the SAMMY code. An effective alternate procedure would be to run the three codes RSAP, SUGGEL, and then SAMMY. In this procedure, the RSAP peak search of the measured total or scattering cross sections will first provide approximate resonance energy and $g\Gamma_n$ values; then SUGGEL will generate a priori parameter file with suggested spin group identification. Finally, SAMMY will be used to perform the detailed analysis.

References

[Be36] Bethe, H.A., "An Attempt to Calculate the Number of Energy Levels of a Heavy Nucleus," *Phys. Rev*. **50**, 332 (1936).

[Bo68] Bollinger, L.M. and Thomas G.E., "p-Wave Resonances of U^{238}," *Phys. Rev*. **171**, 1293 (1968).

[Co97] Corvi, F. *et al*., "Parity Dependence of Low Level Populations in the ^{107}Ag(n,γ) and ^{109}Ag(n,γ) Resonance Reactions," *Proc. of Int. Conf. on Nucl. Data for Sci. and Technol*., p.731, Trieste, 19-24 May (1997).

[Fa68] Facchini, U., "Level density parameter values from neutron and proton resonances," *Energia Nucleare* **15**, 54 (1968). See also Fu, C.Y., *Nucl. Sci. Eng*. **135**, 246 (2000).

[Fr94] Frankle, C.M. *et al*., "Neutron resonance spectroscopy on ^{113}Cd to E_n = 15 keV," *Phys. Rev. C* **50**, 2774 (1994).

[Ga82] Garg, J.B. *et al*., "Neutron resonance parameters of ^{68}Zn+n and statistical distributions of level spacings and widths," *Phys. Rev. C* **25**, 1808 (1982).

[Ha70] Harvey, J.A., Ed., *Experimental Neutron Resonance Spectroscopy*, Academic Press (1970).

[La99] Larson, N.M., Leal, L.C., and Wright, R.Q., "Modification of ENDF Reich-Moore Format," *Proc. CSEWG mtg.*, Nov. 1999, Long Island, NY (2000).

[La00] Larson, N.M., *Updated Users' Guide for SAMMY: Multilevel R-Matrix Fits to Neutron Data Using Bayes' Equation*, ORNL/TM-9179/R5, Oak Ridge National Laboratory (2000).

[Le90] Leal, L.C., de Saussure, G., and Perez, R.B., *URR Computer Code: A Code to Calculate Resonance Neutron Cross-Section Probability Tables, Bondarenko Self-Shielding Factors, and Self-Indication Ratios for Fissile and Fertile Nuclides*, ORNL/TM-11297/R1, Oak Ridge National Laboratory (1990).

[Lo97] Lowie, L.Y. *et al.*, "Neutron resonance spectroscopy of ^{107}Ag and ^{109}Ag," *Phys. Rev. C* **56**, 90 (1997).

[Mi79] Mizumoto, M. *et al*., "Low-energy neutron resonances in ^{206}Pb," *Phys. Rev. C* **19**, 335 (1979).

[Mo78] Moore, M.S. *et al*., "Spin determination of resonance structure in ^{235}U+n below 25 keV," *Phys. Rev. C* **18**, 1328 (1978).

[Mu80] Mughabghab, S.F. *et al*., *Neutron Cross Sections*, Vol.1, Part A, Academic Press (1980).

[Mu98] Mughabghab, S.F. and Dunford, C.L., "New Approach for the Determination of the Nuclear Level Density Parameters," *Proc. Int. Conf. on Phys. of Nucl. Sci. and Technol*., p.784, Long Island, Oct. 5-8 (1998).

[Oh00] Oh, S.Y., Chang, J., and Mughabghab, S.F., *Neutron Cross Section Evaluations of Fission Products Below the Fast Energy Region*, BNL-NCS-67469 (KAERI/TR-1511/2000), Brookhaven National Lab. (2000).

[Po56] Porter, C.E. and Thomas, R.G., "Fluctuation of nuclear reaction widths," *Phys. Rev.* **104**, 483 (1956).

[Re98] Reffo, G., "Average Neutron Resonance Parameters," in *Reference Input Parameter Library*, IAEA-TECDOC-1034, p.25, IAEA (1998).

[Sa00] Sayer, R.O., *RSAP – A Code for Display of Neutron Cross Section Data and SAMMY Fit Results*, ORNL/TM-2001/15 (2001).

[Su98] Sukhoruchkin, S.I., Soroko, Z.N., and Deriglazov, V.V., *Low Energy Neutron Physics, Subvolume B- Tables of Neutron Resonance Parameters*, Spinger-Verlag (1998).

[Sm91] Smith, D.L., *Probability, Statistics, and Data Uncertainties in Nuclear Science and Technology*, OECD NEA, Published by American Nuclear Society (1991).

[Wi57] Wigner, E.P., *Conf. on Neutron Physics by Time of Flight*, p.59, Gatlinburg, 1956, ORNL-2309 (1957)

Appendix A. Probability Density Function of Neutron Width

A.1. Derivation of the Probability Density Functions

According to Porter and Thomas [Po56], the reduced neutron widths (represented as $x = \Gamma_n^l \Big/ \left\langle \Gamma_n^l \right\rangle$) obey the following distribution:

$$p(x)dx = \frac{1}{\sqrt{2\pi x}} e^{-x/2}\, dx \quad \text{for } \nu = 1, \text{ and} \tag{A1}$$

$$p(x)dx = e^{-x}\, dx \quad \text{for } \nu = 2. \tag{A2}$$

Here ν, the degree of freedom (dof), is the number of exit channels and is equal to the multiplicity of *J*. The neutron reduced width, Γ_n^l, is defined herein as

$$\Gamma_n^l = \sqrt{\frac{1\,\text{eV}}{E}}\,\frac{\Gamma_n}{V_l}, \tag{A3}$$

where *E* is the resonance energy and the penetrability V_l is given by

$$V_0 = 1,$$

$$V_1 = \frac{(kR)^2}{1+(kR)^2}, \text{ and}$$

$$V_2 = \frac{(kR)^4}{9+3(kR)^2+(kR)^4}$$

for l = 0, 1, and 2 (*s*, *p*, and *d*-waves) respectively. Here k and R are the neutron wave number and scattering radius, respectively.

If one then makes the change of variable from $x = \Gamma_n^l \Big/ \left\langle \Gamma_n^l \right\rangle$ in Eqs. (A1) and (A2) to $y = g\Gamma_n^l \Big/ \left\langle g\Gamma_n^l \right\rangle$, applies $p(x)dx = p(y)dy$, and re-arranges so that the integration variable is $g\Gamma_n$, then the equations take the form

$$p_{lj}(g\Gamma_n)\,d(g\Gamma_n) = \frac{exp\left(-\dfrac{g\Gamma_n^l}{2g_j\left\langle\Gamma_{nj}^l\right\rangle}\right)}{\sqrt{\dfrac{2\pi\, g\Gamma_n^l}{g_j\left\langle\Gamma_{nj}^l\right\rangle}}}\, d\left(\frac{g\Gamma_n^l}{g_j\left\langle\Gamma_{nj}^l\right\rangle}\right) = \frac{exp\left(-\dfrac{g\Gamma_n}{2g_j\left\langle\Gamma_{nj}^l\right\rangle\sqrt{E}V_l}\right)}{\sqrt{2\pi\, g\Gamma_n g_j\left\langle\Gamma_{nj}^l\right\rangle\sqrt{E}V_l}}\, d(g\Gamma_n), \quad \text{(A1')}$$

$$p_{lj}(g\Gamma_n)\,d(g\Gamma_n) = exp\left(-\frac{g\Gamma_n^l}{g_j\left\langle\Gamma_{nj}^l\right\rangle}\right) d\left(\frac{g\Gamma_n^l}{g_j\left\langle\Gamma_{nj}^l\right\rangle}\right)$$

$$= exp\left(-\frac{g\Gamma_n}{g_j\left\langle\Gamma_{nj}^l\right\rangle\sqrt{E}V_l}\right)\frac{d(g\Gamma_n)}{g_j\left\langle\Gamma_{nj}^l\right\rangle\sqrt{E}V_l}, \quad \text{(A2')}$$

in which the subscript j is an index representing the resonance spin J_j , and g_j is the statistical factor. Note that $g\Gamma_n$ is treated here as a single quantity. Also recall that above equations are for resonances of the same J_j.

Consider now the quantity $\left\langle\Gamma_{nj}^l\right\rangle$. This term, unlike $\left\langle g\Gamma_n^l\right\rangle$, is generally not known from measurements because statistical factors for all resonances are not determined experimentally.[12] From the definition of the neutron strength function,

$$S_{lj} = \frac{\left\langle\Gamma_{nj}^l\right\rangle}{\left\langle D_{lj}\right\rangle} \text{ and } S_l = \frac{\left\langle g\Gamma_n^l\right\rangle}{(2l+1)\left\langle D_l\right\rangle},$$

and an assumption [A1] that

$$S_{lj} = \mu_{lj} S_l,$$

where μ_{lj} is the multiplicity of J_j, $\left\langle\Gamma_{nj}^l\right\rangle$ is found to have the form

$$\left\langle\Gamma_{nj}^l\right\rangle = \left\langle D_l\right\rangle\frac{\left\langle D_{lj}\right\rangle}{\left\langle D_l\right\rangle}\mu_{lj}S_l = \frac{\left\langle D_l\right\rangle}{w_{lj}}\mu_{lj}S_l. \quad \text{(A4)}$$

[12] Actually, this is the reason to deal with $g\Gamma_n$, instead of Γ_n, as a single quantity.

The average level spacing can be calculated from a theoretical model with empirical model parameters such as the level density parameter. The model is described in Section 2.2 in the text. The determination of w_{lj} is described below; see Eq. (A6).

The pdf for *l*-wave resonances, in which all possible *J* values for the specific *l*-wave are taken into account, is derived as follows by weighting pdf's for each J_j given by Eq. (A1') or (A2'). The probability that the magnitude of neutron width of an *l*-wave resonance lies in between $g\Gamma_n$ and $g\Gamma_n + d(g\Gamma_n)$ is obtained as

$$P(g\Gamma_n \,|\, l)d(g\Gamma_n) = \sum_j w_{lj}\; p_{lj}(g\Gamma_n)d(g\Gamma_n), \tag{A5}$$

where the weight w_{lj} is the probability that the total spin of a certain *l*-wave resonance is J_j. The weight is calculated as the ratio of number of *l*-wave resonances of which resonance spin is J_j to the total number of *l*-wave resonances;

$$w_{lj} \equiv \frac{N_{lj}}{N_l} = \frac{\langle D_l \rangle}{\langle D_{lj} \rangle}. \tag{A6}$$

The sum over *j* in Eq. (A5) is the sum for all distinct J_j's only once, regardless of its multiplicity.

The following paragraphs indicate the derivation of the detailed form of the pdf for *p*-wave resonances. Pdf's for *s*- and *d*-wave can be derived in analogous fashion; results are given in the text in Eqs. (3) and (5).

For the *p*-wave, at most four different *J* values are permitted. For convenience, we consider *J* values sorted in ascending order. Table A1 shows this convention and the multiplicity.

Table A 1. Target Spin Dependent Multiplicity of J for p-wave Resonances

Target Spin	Channel Spin	Possible *J*				Multiplicity				Note
		j = 1	j = 2	j = 3	j = 4	j = 1	j = 2	j = 3	j = 4	
0	1/2	1/2			3/2	1	0	0	1	$w_{12} = w_{13} = 0$
1/2	0 1	0	1 1		2	1	2	0	1	$w_{13} = 0$
1	1/2 3/2		1/2 1/2	3/2 3/2	5/2	0	2	2	1	$w_{11} = 0$
≥ 3/2	I–1/2 I+1/2	I–3/2	I–1/2 I–1/2	I+1/2 I+1/2	I+3/2	1	2	2	1	

By applying Eq. (A1') for j = 1 and 4 and (A2') for j = 2 and 3, and using Eq. (A4) through Eq. (A5), we find that the pdf for p-waves takes the form

$$P\left(g\Gamma_n \middle| l=1\right) = w_{11}\frac{exp\left(-\frac{w_{11}}{2g_{11}S_1\langle D_1\rangle}\frac{g\Gamma_n}{\sqrt{E}V_1}\right)}{\sqrt{2\pi\, g_{11}\frac{S_1\langle D_1\rangle}{w_{11}}\sqrt{E}V_1 g\Gamma_n}} + w_{12}\frac{exp\left(-\frac{w_{12}}{g_{12}2S_1\langle D_1\rangle}\frac{g\Gamma_n}{\sqrt{E}V_1}\right)}{g_{12}\frac{2S_1\langle D_1\rangle}{w_{12}}\sqrt{E}V_1}$$

$$+ w_{13}\frac{exp\left(-\frac{w_{13}}{g_{13}2S_1\langle D_1\rangle}\frac{g\Gamma_n}{\sqrt{E}V_1}\right)}{g_{13}\frac{2S_1\langle D_1\rangle}{w_{13}}\sqrt{E}V_1} + w_{14}\frac{exp\left(-\frac{w_{11}}{2g_{14}S_1\langle D_1\rangle}\frac{g\Gamma_n}{\sqrt{E}V_1}\right)}{\sqrt{2\pi\, g_{14}\frac{S_1\langle D_1\rangle}{w_{14}}\sqrt{E}V_1 g\Gamma_n}}.$$

A.2. Approximation

If the (2J+1) law of the level density such that

$$\frac{1}{\langle D(J)\rangle} \propto (2J+1)$$

is assumed, the weight of Eq. (A6) becomes

$$w_{lj} = \frac{\langle D_l\rangle}{\langle D_{lj}\rangle} = \frac{(2J_{lj}+1)}{\sum_{j'}(2J_{lj'}+1)} = \frac{g_{lj}}{G_l},\ G_l \equiv \sum_j g_{lj}\ . \qquad \text{(A6')}$$

From the same concept, the l-wave average level spacing is calculated as $\langle D_l\rangle = \langle D_{l'}\rangle \cdot G_{l'}/G_l$, and especially, $\langle D_l\rangle = \langle D_0\rangle / G_l$ because G_0 = 1 regardless of the value of target spin. The values of G_l are given in Table A2.

Table A 2. Sum of Statistical Factors

I	$l = 0$	$l = 1$		$l = 2$	
	G_0	G_1	$(g_{11}+g_{14})/G_1$	G_2	$(g_{21}+g_{26})/G_2$
0	1	3	1	5	1
1/2	1	9/4	2/3	15/4	2/3
1	1	2	1/2	20/6	1/2
3/2	1	2	1/2	25/8	2/5
≥2	1	2	1/2	3	1/3

Applying the weight of Eq. (A6') to each pdf's results in

$$P\left(g\Gamma_n \middle| l=0\right) = \frac{exp\left(-\dfrac{g\Gamma_n}{2S_0\left\langle D_0\right\rangle\sqrt{E}V_0}\right)}{\sqrt{2\pi\ S_0\left\langle D_0\right\rangle\sqrt{E}V_0\, g\Gamma_n}}, \tag{A7}$$

$$P\left(g\Gamma_n \middle| l=1\right) = \frac{1}{G_1}\left(\frac{g_{11}+g_{14}}{\sqrt{2\pi\, G_1 S_1\left\langle D_1\right\rangle\sqrt{E}V_1\, g\Gamma_n}} + \frac{g_{12}+g_{13}}{2\,G_1 S_1\left\langle D_1\right\rangle\sqrt{E}V_1}\right) exp\left(-\frac{g\Gamma_n}{2G_1 S_1\left\langle D_1\right\rangle\sqrt{E}V_1}\right)$$

$$= \left(\frac{(g_{11}+g_{14})/G_1}{\sqrt{2\pi\, S_1\left\langle D_0\right\rangle\sqrt{E}V_1\, g\Gamma_n}} + \frac{1-(g_{11}+g_{14})/G_1}{2\,S_1\left\langle D_0\right\rangle\sqrt{E}V_1}\right) exp\left(-\frac{g\Gamma_n}{2S_1\left\langle D_0\right\rangle\sqrt{E}V_1}\right), \text{ and} \tag{A8}$$

$$P\left(g\Gamma_n \middle| l=2\right) = \frac{1}{G_2}\left(\frac{g_{21}+g_{26}}{\sqrt{2\pi\, G_2 S_2\left\langle D_2\right\rangle\sqrt{E}V_2\, g\Gamma_n}} + \frac{g_{22}+g_{23}+g_{24}+g_{25}}{2\,G_2 S_2\left\langle D_2\right\rangle\sqrt{E}V_2}\right) exp\left(-\frac{g\Gamma_n}{2G_2 S_2\left\langle D_2\right\rangle\sqrt{E}V_2}\right)$$

$$= \left(\frac{(g_{21}+g_{26})/G_2}{\sqrt{2\pi\, S_2\left\langle D_0\right\rangle\sqrt{E}V_2\, g\Gamma_n}} + \frac{1-(g_{21}+g_{26})/G_2}{2\,S_2\left\langle D_0\right\rangle\sqrt{E}V_2}\right) exp\left(-\frac{g\Gamma_n}{2S_2\left\langle D_0\right\rangle\sqrt{E}V_2}\right). \tag{A9}$$

A.3. Distinguishing *s*- and *p*-wave resonances with (2*J*+1) law

Consider a simplified problem of distinguishing *s*- and *p*-wave resonances. Applying Eqs. (A7) and (A8) to Eq. (1) in the text, the probability for a *p*-wave may be written as:

$$P(l=1\,|\,g\Gamma_n)=\left[1+\frac{1}{G_1}\sqrt{\frac{S_1V_1}{S_0V_0}}\,\frac{exp\left\{\dfrac{g\Gamma_n}{2\langle D_0\rangle\sqrt{E}}\left(\dfrac{1}{S_1V_1}-\dfrac{1}{S_0V_0}\right)\right\}}{\alpha+(1-\alpha)\sqrt{\dfrac{\pi\, g\Gamma_n}{2\sqrt{E}\langle D_0\rangle S_1V_1}}}\right]^{-1}, \tag{A10}$$

where $G_1 = 3$, $\alpha = 1$ for I = 0 nuclide, $G_1 = 9/4$, $\alpha = 2/3$ for I = 1/2, and $G_1 = 2$, $\alpha = 1/2$ for I ≥ 1.

Reference Appendix A

[A1] McLane, V. *et al*., Ed., "ENDF-102: Data Formats and Procedures for the Evaluated Nuclear Data File ENDF-6," Appendix D, BNL-NCS-44945, Rev.2/97, Brookhaven National Lab. (1997)

Appendix B. Source Listing of SUGGEL

```
      program suggel
c
c   GENERAL DESCRIPTION:
c   1.This program suggests the orbital angular momentum (l) of a resonance
c     from the magnitude of its g*Gamma_n.
c   2.Such suggestion is based on the probability that a resonance with gGn
c     is an l-wave. The probability is calculated by using the Bayesian
c     theorem on the conditional probability.
c   3.Physics Models and Assumptions:
c     - Each resonance is characterized by l and resonance spin (J).
c       Two channels are allowed for some J's for l>0 in case of I>0 target.
c     - Reduced neutron widths (gGn^l) follow the Chi-square distribution
c       (dof=1 for multiplicity(mu)=1 and dof=2 for mu=2).
c     - The neutron strength function of (l,J) resonances is assumed as
c       S_lJ = mu_lJ*S_l, and
c     - Bethe level density formula is adopted:
c       the level density is proportional to (2J+1)*exp{-(J+1/2)^2/2sigma^2},
c       the density is assumed to be constant over energy.
c   4.To take the finite resolution of measurement into account, this program
c     adjusts a priori probabilities via an input variable "frac".
c     - The measurement efficiency, as one of the output, may be considered
c       as "frac" in the input that corrects a priori probabilities. It is
c       obtained from the missing level estimation (MLE).
c     - The MLE is performed for every wave.
c
c   INPUT:
c     unit 5: standard input in the namelist format:
c             First line contains " &indata", and last line " &end".
c     unit 2: if partyp=0, a file containing (En,Gn) data in SAMMY.PAR format
c             otherwise, a file containing (En,gGn) data in RSAP.GAMMA format
c   OUTPUT:
c     unit 3: standard output list
c     unit 4: a file containing (En,Gn,spin group) data in SAMMY.PAR format
c
c   Written by S-Y. Oh (syoh@kaeri.re.kr), KAERI.
c   Last modification: Aug. 22, 2000
c
      parameter (nrs=10000)
      common /data1/ spin,awri,rr,sigsq
      common /data2/ dd(3),stn(3),vv(3),pcut
      common /tbl/ aj(12),g(12),wt(12),wtl(3)
      common /ajseed/ seed
      dimension probl(3),frac(3),priori(3),dth(3),nth(3),effi(3)
      dimension sumggn(3),nr(3),stnew(3),stnm(3),lsam(18),ajsam(18)
      dimension ggnl(nrs,3),anth(3),avggn(3),nmle(3)
      dimension sumold(3),nrold(3),stno(3)
      integer partyp,optj
      character*24 parin,fout,parout
      character*13 assj(2)
      character*1 flagl,flagg,txt(65),txt2(15),wave(3),flgmle(3)
      data pi/3.141593/,eps/0.00001/,wave/'s','p','d'/
      data assj/'most probable','random'/
      namelist /indata/parin,partyp,fout,parout,eini,efin,awri,spin,pcut
     *   ,optj,scattr,disp,sigcon,bn,pair,denpar,stn,dzero,frac,lsam
     *   ,ajsam
      data pi/3.141593/,eps/0.00001/,wave/'s','p','d'/
      data assj/'most probable','random'/
```

```
c
c  parin = input (En, Gn or gGn) data file name [En in eV, Gn or gGn in meV]
c  partyp = type of the neutron width in parin file:
c           if 0, Gn in SAMMY.PAR format; otherwise, g*Gn in rsap.gamma format
c  fout = standard output file name
c  parout = output resonance parameter file name in SAMMY.PAR format
c  eini [eV] = lower energy boundary to be analized
c  efin [eV] = upper energy boundary to be analized
c  pcut = probability cutoff: L will be altered for a resonance of which prob.
c         is higher than pcut.
c  optj = option for J assignment: If optj = 0, most probable J is assigned,
c         otherwise, J is assigned randomly.
c  awri = atomic mass of target nuclide
c  spin = spin of the target nuclide
c  scattr [fm] = scattering radius
c  disp = spin dispersion parameter (sigma):
c         if = 0, calculate it with parameters such as bn, pair, and denpar
c         if (2J+1) law is wanted, enter a large number (e.g., 999)
c  sigcon = constant for the calculation of spin dispersion parameter,
c           sigma^2=sigcon*sqrt(denpar*U)*awri^(2/3)
c  bn [MeV] = neutron separation energy for calculating disp
c  pair [MeV] = pairing energy
c  denpar [1/MeV] = level density parameter
c  stn(3) [1.E-04] = neutron strength functions of s-, p-, and d-wave
c  dzero [eV] = s-wave avg level spacing
c  frac(3) = fraction of number of measured resonances to the theoretical
c            number of resonances for each l
c  lsam(i) = l value of spin group i (i= 1 to max. 18) in SAMMY.PAR file
c  ajsam(i) = J value of spin group i (i= 1 to max. 18) in SAMMY.PAR file
c
      open(5,file='suggel.inp',status='old')
      read(5,indata)
      close(5)
c
      awri=awri/1.008665
      rr=scattr*0.1                                    ! R' in 1.E-12
      if(rr.le.eps) then
        rr=0.123*awri**0.33333+0.08
      end if
      sigsq=disp*disp
      if(disp.le.eps) then
        sigsq=denpar*(bn+(eini+efin)/2000000.-pair)
        sigsq=sigcon*sqrt(sigsq)*(awri+1.)**(2./3.)
c       sigsq=0.0494*sqrt(sigsq)*(awri+1.)**(2./3.)  ! From Mughabghab 98
c       sigsq=0.146*sqrt(sigsq)*(awri+1.)**(2./3.)   ! From Facchini 68
      end if
      ck=0.002196771*rr*awri/(awri+1.)                 ! for wave number calc.
      vv(1)=1.                                         ! s-wave penetrability
      do i=1,3
        stn(i)=stn(i)*0.0001                           ! in null dimension
      end do
      flagg=' '
      if(partyp.ne.0) flagg='g'
      if(optj.ne.0) optj=1
      seed=19
c
      open(2,file=parin,status='old')
      open(3,file=fout,status='unknown')
      open(4,file=parout,status='unknown')
c
c     Preparing table of weights for each term identified by l and J
```

```
c
      call calcg(spin,sigsq)
      sumwtl=0.
      do i=1,3
        frac(i)=amax1(eps,frac(i))
        priori(i)=wtl(i)                          ! keep theoretical
        wtl(i)=priori(i)*frac(i)
        sumwt=sumwt+wtl(i)
        dd(i)=dzero*priori(1)/priori(i)           ! use theoretical <D>
      end do
      do i=1,3
        wtl(i)=wtl(i)/sumwt
      end do
c
      write(3,300)
     * flagg,parin,eini,efin,stn*10000,dd(1),spin,awri,pcut,assj(optj+1)
      if(scattr.ge.eps) then
        write(3,302) scattr
        if(disp.ge.eps) write(3,304) disp
        write(3,306)
        if(disp.lt.eps) write(3,304) sqrt(sigsq)
      else
        if(disp.ge.eps) write(3,304) disp
        write(3,306)
        write(3,302) rr*10.
        if(disp.lt.eps) write(3,304) sqrt(sigsq)
      end if
      write(3,308)
     *  wtl,amin1(wtl(1)/wtl(2),1000.),amin1(wtl(1)/wtl(3),1000.)
  300  format(' ------------------------------'/
     *       ' ***  PROGRAM SUGGEL v.1.0  ***'/
     *       ' ------------------------------'//
     *      ' * Input (En,',a1,'Gn) data file name = ',a12//
     *      ' * Input Variables:'/
     *      '     Energy range under consideration [eV] =  ',1pe11.4,
     *      ' to',e11.4/
     *      '     n. strength function (s,p,d) [1E-04]  = ',0p3f7.3/
     *      '     s-wave avg level spacing [eV]         =  ',1pe11.4/
     *      '     target spin                           = ',0pf7.3/
     *      '     atomic weight (AWRI)                  = ',f7.3/
     *      '     probability cutoff for renewal of L   = ',f7.3/
     *      '     J assignment                          =   ',a13)
  302  format('     scattering radius (AP) [fm]           = ',f7.3)
  304  format('     spin dispersion parameter (sigma)     = ',f7.3)
  306  format(/' * Calculated Quantities from the input:')
  308  format('     A priori probabilities, s, p, and d   = ',3f7.3/
     1       '     p & d level spacing, relative to s    = ',2f7.3//
     2' ---- ---------- ----------- -----------------  -------',
     3'    -------'/ ' nres     En     Reduced ',
     4'Gn     Probability        L          J'/
     4'         (eV)       (eV)       s     p     d    old new',
     4'    old new'/
     5' ---- ---------- ----------- ----- ----- -----  --- ---',
     5'    --- ---')
c
      write(*,610) priori
  610  format('A priori probabilities with infinitesimal resolution ='
     *       ,3f6.3)
      ifirst=1
      nres=0
      do i=1,3
```

```
        nr(i)=0
        sumggn(i)=0.
        nrold(i)=0
        sumold(i)=0.
      end do
      enmax=0.0
      enmin=1.0E+7
 910  continue                              ! continue for the next resonance
      flagl=' '
      nres=nres+1
c
c     Now read (En,Gn) file:
c     If partyp=0, read Gamma_n from "parin" file and calculate g*G_n
c     otherwise, read g*Gamma_n from rsap.gamma
c
      if(partyp.eq.0) then
        call samr(eini,efin,en,gn,ids,txt,txt2,endflg)
        lold=lsam(ids)
        ajold=ajsam(ids)
        width=gn*(2.*ajold+1.)/(2.*(2.*spin+1.))          ! width = g*Gn in eV
      else
        call rsapr(eini,efin,en,gn,gamgam,ifirst,endflg)
        width=gn                                          ! orginally gn = gGn
        ifirst=0
        lold=0
      end if
      if(endflg.ge.999.) go to 990
      enmax=amax1(en,enmax)
      enmin=amin1(en,enmin)
      vv(2)=penet(ck,en,1)
      vv(3)=penet(ck,en,2)
c
c     The main calculation
c
      call bayes(en,width,optj,lnew,ajnew,probl)           ! width = g*G_n
c
      if(partyp.ne.0) then
        lold=lnew
        ajold=ajnew
      end if
      if(lnew.ne.lold.and.probl(lnew+1).lt.pcut) then
        lnew=lold
        ajnew=ajold
        flagl='?'
      end if
      if(lnew.ne.lold) flagl='*'
      redw=1./sqrt(en)/vv(lnew+1)                  ! in eV
      nr(lnew+1)=nr(lnew+1)+1
      ggnl(nr(lnew+1),lnew+1)=width*redw
      sumggn(lnew+1)=sumggn(lnew+1)+width*redw
      gnew=(2.*ajnew+1.)*0.5/(2.*spin+1.)
      Gn=width/gnew                                ! Conserve gGn instead of Gn
      Gnl=Gn*redw                                  ! Now G_n^l
      nrold(lold+1)=nrold(lold+1)+1
      sumold(lold+1)=sumold(lold+1)+width/sqrt(en)/vv(lold+1)
c
      write(3,310)
     *   nres,en,Gnl,(probl(i),i=1,3),lold,lnew,flagl,ajold,ajnew
 310  format(i4,1x,1p2e11.4,1x,0p3f6.3,2i4,1x,a1,2x,2f4.1)
c
      idsnew=99
```

```
      do i=1,18
        if(lnew.eq.lsam(i).and.ajnew.eq.ajsam(i)) idsnew=i
      end do
      if(flagl.eq."?") idsnew=ids
      if(partyp.eq.0) then
        write(4,410) (txt(i),i=1,22),Gn*1000.,(txt(i),i=34,65),idsnew
 410    format(22a1,1pe11.4,32a1,i2)
      else
        write(4,420) en,gamgam*1000.,Gn*1000.,idsnew
 420    format(1p3e11.4,22x,' 0 0 0 0 0',i2)
      end if
c
c     Now move to the next resonance
c
      go to 910
c
 990  continue
      dtheo=dzero*priori(1)                        ! = 1/(1/D0+1/D1+1/D2)
      efin=enmax+dtheo/2.
      eini=enmin-dtheo/2.
      write(3,320) eini,efin
 320  format
     * (/' * : L has been altered from the original assignment.'
     *  /' ? : L should be altered, but the probability is too low.'
     *//'  Energy range has been adjusted to',1pe11.4,' ~',e11.4,' eV.'
     *//33x,14x,'s',10x,'p',10x,'d'/
     *  33x,4x,' ---------- ---------- ----------')
c
      do i=1,3
        stnm(i)=sumggn(i)/(efin-eini)/(2*i-1)
        stno(i)=sumold(i)/(efin-eini)/(2*i-1)
c       avggn(i)=stn(i)*dd(i)*(2*i-1)                  ! use input stn for MLE
        avggn(i)=stnm(i)*dd(i)*(2*i-1)                 ! use new stn for MLE
      end do
      write(3,330)
      write(3,332) nrold,stno*10000.
      write(3,334)
      write(3,332) nr,stnm*10000.
 330  format( '  Original assignment:')
 332  format( '    Number of resonances           = ',3i11/
     *        '    Strength function [1E-04]      = ',3f11.3)
 334  format(/'  New assignment:')
c
c     Missing Level Estimation: Avg. gG_n^l from MLE's for every wave.
c     However, <D> and S are based on the results for a certain wave.
c       If(max. meas. effi. ge.1.0), ref. wave is the wave showing max. effi.
c       Otherwise, s-wave is the ref.
c
      if(nr(1).ge.nrs.or.nr(2).ge.nrs.or.nr(3).ge.nrs) then
        write(*,'("...Warning...No. of resonances exceeds the array "
     *           ,"size. Reduce the energy interval.")')
        stop
      end if
c
      call missl(ggnl,nr,anth,avggn,flgmle)
c
      do i=1,3
        nmle(i)=anth(i)+0.5
      end do
      iii=1
      rr2=anth(2)*priori(1)/priori(2)
```

```
      rr3=anth(3)*priori(1)/priori(3)
      if(anth(1).lt.rr2) iii=2
      if(rr2.lt.rr3) iii=3
      do i=1,3
        dth(i)=(efin-eini)/anth(iii)*priori(iii)/priori(i)
        ann=(efin-eini)/dth(i)
        nth(i)=ann+0.5
        effi(i)=nr(i)/ann
        frac(i)=amin1(1.,effi(i))
        stnew(i)=avggn(i)/dth(i)/(2.*i-1.)
        if(flgmle(i).eq.'?') stnew(i)=stn(i)
      end do
      effimx=effi(1)
      fff=frac(1)
      jjj=1
      do i=2,3
        if(effi(i).gt.effimx) then
          effimx=effi(i)
          fff=frac(i)
          jjj=i
        end if
      end do
      do i=1,3
        frac(i)=frac(i)/fff
      end do
      if(jjj.ge.2) then
        frac(1)=1.
        if(jjj.eq.3) frac(2)=1.
      end if
c
      write(3,340)
     * (avggn(i),flgmle(i),i=1,3),(nmle(i),flgmle(i),i=1,3),wave(iii)
      write(3,332) nth,stnew*10000.
      write(3,342) effi,dth,frac
 340  format(/'  From the Missing Level Estim.,'/
     *        '    Avg. g*red.width [eV]          =  ',1p3(e10.3,a1)/
     *        '    Expected no. of resonances     =  ',3(i10,a1)//
     *        '  Based on the "',a1,'"-wave MLE:')
 342  format( '    Measurement efficiency         = ',3f11.3/
     *        '    Avg. level spacing [eV]        = ',1p3e11.3//
     *        '  Recommended frac (as the input)  = ',0p3f11.3)
c
      stop
      end
c.....................................................................
      subroutine calcg(spin,sigsq)
c
c     For neutron up to d-wave.
c     Each group (i) is identified by l and J:
c       i= 1 and 2 for s-wave, i= 3~6 for p-wave, and i= 7~12 for d-wave;
c       J in ascending order
c     Calculated quantities are:
c       aj(12) = J of lj group
c       g(12)  = g (statistical factor)
c       wt(12) = weight (a priori probability to belong to lj group)
c       wtl(3) = a priori probability to belong to l-wave
c                (assuming infinitesimal resolution in this subroutine)
c
      common /tbl/ aj(12),g(12),wt(12),wtl(3)
      data eps/0.01/
      dens(x,y)=(2.*x+1.)*exp(-(x+0.5)*(x+0.5)*0.5/y)
```

```
c s-wave
      aj(1)=spin-0.5
      aj(2)=spin+0.5
c p-wave
      aj(3)=abs(spin-1.)-0.5
      aj(6)=spin+1.5
      do i=4,5
        aj(i)=aj(i-1)+1.
      end do
      do i=4,5
        if(aj(i).ge.aj(6)-eps) aj(i)=-0.5              ! makes weight = 0.
      end do
c d-wave
      ajmin=abs(abs(spin-2.)-0.5)
      aj(7)=ajmin
      if(spin.eq.2.) aj(7)=-0.5
      aj(12)=spin+2.5
      do i=8,11
        aj(i)=aj(i-1)+1.
      end do
      do i=8,11
        if(aj(i).ge.aj(12)-eps) aj(i)=-0.5
      end do
c
      denom=0.5/(2.*spin+1.)
      do i=1,12
        g(i)=(2.*aj(i)+1.)*denom
        wt(i)=dens(aj(i),sigsq)
        if(aj(i).le.-eps) g(i)=1.            ! to avoid "divided by zero"
      end do
      sumwts=wt(1)+wt(2)
      sumwtp=wt(3)+wt(4)+wt(5)+wt(6)
      sumwtd=wt(7)+wt(8)+wt(9)+wt(10)+wt(11)+wt(12)
      sumwt=sumwts+sumwtp+sumwtd
      wtl(1)=sumwts/sumwt
      wtl(2)=sumwtp/sumwt
      wtl(3)=sumwtd/sumwt
      do i=1,2
        wt(i)=wt(i)/sumwts
      end do
      do i=3,6
        wt(i)=wt(i)/sumwtp
      end do
      do i=7,12
        wt(i)=wt(i)/sumwtd
      end do
c
      return
      end
c.....................................................................
      subroutine samr(eini,efin,en,width,ids,txt,txt2,endflg)
c     .PAR file could be out of sorting in energy
      character*1 txt(65),txt2(15)
      endflg=1.
 910  continue
      read(2,205,end=990) txt,txt2
 205  format(65a1,15a1)
      if(txt(5).ne.' ') then
        backspace 2
        read(2,210) en,gn,ids
 210    format(f11.3,11x,e11.4,22x,10x,i2)
```

```
        width=gn*0.001                          ! in eV
        if(en.lt.eini.or.en.gt.efin) then
          write(4,205) txt,txt2
          go to 910
        end if
      else
 911    continue
        write(4,205) txt,txt2
        read(2,205,end=990) txt,txt2
        go to 911
      end if
      return
c
 990  endflg=9999.
      return
      end
c.....................................................................
      subroutine rsapr(eini,efin,en,gn,gamgam,ifirst,endflg)
      character*7 last
      if(ifirst.eq.0) go to 110
      do i=1,4
        read(2,210) last
 210    format(a7)
      end do
      read(2,*) dum,dum,dum,gamgam
      do i=1,8
        read(2,210) last
      end do
 110  continue
      read(2,210) last
      if(last.eq."  PKFIN") go to 990
      backspace 2
      read(2,*) idum,en,dum,dum,dum,dum,gn
      if(en.lt.eini) go to 110
      if(en.gt.efin) go to 990
      return
 990  endflg=999.
      return
      end
c.....................................................................
      subroutine bayes(en,ggn,jopt,lnew,ajnew,probl)
c
c  Calculating the probability to be a l-wave (probl(3)) and
c                              to have J (probj(12)), and
c  Suggesting new l and J
c
      common /data2/ dd(3),stn(3),vv(3),pcut
      common /tbl/ aj(12),g(12),wt(12),wtl(3)
      common /ajseed/ seed
      dimension cl(12),probl(3),probj(12),term(12),each(12),ppp(3)
      data pi/3.14159/,eps/1.E-19/,alarge/1.E+38/
c
      do i=1,12
        j=1
        if(i.ge.3) j=2
        if(i.ge.7) j=3
        cl(i)=2.*sqrt(en)*vv(j)*stn(j)*dd(j)
      end do
      do i=1,12
        term(i)=wt(i)/cl(i)/g(i)
        each(i)=wt(i)*exp(-term(i)*ggn)
```

```
        if(i.le.3.or.i.eq.6.or.i.eq.7.or.i.eq.12) then     ! for dof=1
          if(term(i).gt.1./eps.and.ggn.lt.eps) then
            each(i)=alarge
          else
            each(i)=each(i)*sqrt(term(i)/pi/ggn)
          end if
        else
          each(i)=each(i)*term(i)                          ! for dof=2
        end if
      end do
c
      ppp(1)=each(1)+each(2)
      ppp(2)=each(3)+each(4)+each(5)+each(6)
      ppp(3)=each(7)+each(8)+each(9)+each(10)+each(11)+each(12)
      pall=ppp(1)*wtl(1)+ppp(2)*wtl(2)+ppp(3)*wtl(3)
      almax=0.
      do i=1,3
        probl(i)=ppp(i)*wtl(i)/pall
        if(probl(i).gt.almax) then
          almax=probl(i)
          lnew=i-1
        end if
      end do
c
      iini=lnew*lnew+lnew+1
      ifin=lnew*lnew+3*lnew+2
      if(jopt.eq.0) then
c
c     Suggest most probable J: for only terms belonged to lnew
c
        ajmax=0.
        do i=iini,ifin
          probj(i)=probl(lnew+1)*each(i)/ppp(lnew+1)
          if(probj(i).gt.ajmax) then
            ajmax=probj(i)
            ajnew=aj(i)
          end if
        end do
        return
      else
c
c     Assign J randomly (instead of deterministic J assignment above)
c
        cdf=0.
        crit=rand(seed)
        do i=iini,ifin
          cdf=cdf+wt(i)
          if(crit.le.cdf) then
            ajnew=aj(i)
            return
          end if
        end do
      end if
      return
      end
c.....................................................................
      function penet(ck,en,l)
      rksq=ck*ck*abs(en)
      if(l.eq.0) penet=1.
      if(l.eq.1) penet=rksq/(1.+rksq)
      if(l.eq.2) penet=rksq*rksq/(9.+3.*rksq+rksq*rksq)
```

```
      return
      end
c.....................................................................
      subroutine missl(ggnl,nr,anth,avggn,flgmle)
c
c     Returns expected (theoretical) no. of resonances and avg. gGn^l
c       obtained from the Missing Level Estimation.
c     Integration from cut0(=1/4, adjustable) to cut1(=5).
c     E.g., for s-wave with (2J+1) law, qth=1.2063, ath=1.5705, cdfth=0.6171
c
      parameter (nsr=10000)
      dimension ggnl(nsr,3),nr(3),anth(3)
     *         ,qth(3),ath(3),cdfth(3),avggn(3)
      character*1 flgmle(3)
      data cut0/0.25/,cut1/5.0/
      cut=cut0
      cutu=cut1
      do i=1,3
        flgmle(i)=' '
      end do
c
      do 100 i=1,3
        if(nr(i).lt.2) then
          anth(i)=1.
          avggn(i)=ggnl(1,i)
          flgmle(i)='?'
          go to 100
        end if
        call sort(nr(i),ggnl(1,i))
 910    continue
        call theo(cut,cutu,qth,ath,cdfth)
        qmm=0.
        am=0.
        mm=0
        nskip=0
        do 110 j=nr(i),1,-1
          if(i.ge.2.and.ggnl(j,i)/avggn(i).gt.cutu) then
            nskip=nskip+1
            go to 110
          end if
          am=am+ggnl(j,i)
          qmm=qmm+sqrt(ggnl(j,i))
          mm=mm+1
          qm=mm*am/qmm/qmm
          if(qm.ge.qth(i)) go to 900
 110    continue
        write(*,'("...Warning... Integration for MLE (l=",i1,")",
     *   " will be adjusted to ",f5.2," ~",f5.2)') i-1,cut+0.1,cutu
        cut=cut+0.1
        if(cut.ge.cutu) then
          write(*,'("...Missing Level Estim. for l=",i1,
     *              " is unavailable.")') i-1
          anth(i)=nr(i)
          cut=cut0
          flgmle(i)='?'
          pause
          go to 100
        end if
        go to 910
 900    anth(i)=mm/cdfth(i)
        am=am/mm
```

```
        avggn(i)=am/ath(i)
        cut=cut0
 100  continue
      return
      end
c.....................................................................
      subroutine theo(cut0,cutu,qth,ath,cdfth)
      common /tbl/ aj(12),g(12),wt(12),wtl(3)
      dimension qth(3),ath(3),cdfth(3),xpt(3),rxpt(3)
      dimension pup(12),xpup(12),rxpup(12)
      dimension tt(12),terf(12),texp(12),p(12),xp(12),rxp(12),mul(12)
      data pi/3.141593/,eps/1.E-20/,mul/3*1,2*2,2*1,4*2,1/
      external erf
c
c     Integrate x_lo(=cut0) to inf. for s-wave
c     Integrate x_lo to x_up(=cutu) for p- and d-wave
c     Integrate x_up to inf. first (ii=1)
c
      cut=cutu
      do ii=1,2
      do i=1,12
        tt(i)=wt(i)/2./g(i)*cut
        if(i.ge.7) tt(i)=tt(i)*5.
        if(i.ge.3.and.i.le.6) tt(i)=tt(i)*3.
        if(tt(i).le.eps) tt(i)=eps
        terf(i)=erf(sqrt(tt(i)))
        texp(i)=exp(-tt(i))
        if(mul(i).eq.1) then
          p(i)=wt(i)*(1.-terf(i))
          xp(i)=wt(i)/tt(i)*cut*
     *          ( sqrt(tt(i)/pi)*texp(i)+0.5*(1.-terf(i)) )
          rxp(i)=wt(i)/sqrt(tt(i)/cut*pi)*texp(i)
        else
          p(i)=wt(i)*texp(i)
          xp(i)=wt(i)/tt(i)*cut*(tt(i)+1.)*texp(i)
          rxp(i)=wt(i)*( sqrt(cut)*texp(i)+
     *                   sqrt(pi/tt(i)*cut)*0.5*(1.-terf(i)) )
        end if
        if(ii.eq.1) then
          if(i.gt.3) then
            pup(i)=p(i)
            xpup(i)=xp(i)
            rxpup(i)=rxp(i)
          else
            pup(i)=0.
            xpup(i)=0.
            rxpup(i)=0.
          end if
        else
          p(i)=p(i)-pup(i)
          xp(i)=xp(i)-xpup(i)
          rxp(i)=rxp(i)-rxpup(i)
        end if
      end do
      cut=cut0
      end do
c
      do i=1,3
        cdfth(i)=0.
        xpt(i)=0.
        rxpt(i)=0.
```

```
        j1=i*i-i+1
        j2=i*i+i
        do j=j1,j2
          cdfth(i)=cdfth(i)+p(j)
          xpt(i)=xpt(i)+xp(j)
          rxpt(i)=rxpt(i)+rxp(j)
        end do
        qth(i)=xpt(i)*cdfth(i)/rxpt(i)/rxpt(i)
        ath(i)=xpt(i)/cdfth(i)
      end do
      return
      end
C.....................................................................
C  (C) Copr. 1986-92 Numerical Recipes Software <=s='%.
      FUNCTION erf(x)
      REAL erf,x
CU    USES gammp
      REAL gammp
      if(x.lt.0.)then
        erf=-gammp(.5,x**2)
      else
        erf=gammp(.5,x**2)
      endif
      return
      END
C  (C) Copr. 1986-92 Numerical Recipes Software <=s='%.
      FUNCTION gammp(a,x)
      REAL a,gammp,x
CU    USES gcf,gser
      REAL gammcf,gamser,gln
      if(x.lt.0..or.a.le.0.)pause 'bad arguments in gammp'
      if(x.lt.a+1.)then
        call gser(gamser,a,x,gln)
        gammp=gamser
      else
        call gcf(gammcf,a,x,gln)
        gammp=1.-gammcf
      endif
      return
      END
C  (C) Copr. 1986-92 Numerical Recipes Software <=s='%.
      SUBROUTINE gser(gamser,a,x,gln)
      INTEGER ITMAX
      REAL a,gamser,gln,x,EPS
      PARAMETER (ITMAX=100,EPS=3.e-7)
CU    USES gammln
      INTEGER n
      REAL ap,del,sum,gammln
      gln=gammln(a)
      if(x.le.0.)then
        if(x.lt.0.)pause 'x < 0 in gser'
        gamser=0.
        return
      endif
      ap=a
      sum=1./a
      del=sum
      do 11 n=1,ITMAX
        ap=ap+1.
        del=del*x/ap
        sum=sum+del
```

```
        if(abs(del).lt.abs(sum)*EPS)goto 1
11    continue
      pause 'a too large, ITMAX too small in gser'
1     gamser=sum*exp(-x+a*log(x)-gln)
      return
      END
C  (C) Copr. 1986-92 Numerical Recipes Software <=s='%.
      SUBROUTINE gcf(gammcf,a,x,gln)
      INTEGER ITMAX
      REAL a,gammcf,gln,x,EPS,FPMIN
      PARAMETER (ITMAX=100,EPS=3.e-7,FPMIN=1.e-30)
CU    USES gammln
      INTEGER i
      REAL an,b,c,d,del,h,gammln
      gln=gammln(a)
      b=x+1.-a
      c=1./FPMIN
      d=1./b
      h=d
      do 11 i=1,ITMAX
        an=-i*(i-a)
        b=b+2.
        d=an*d+b
        if(abs(d).lt.FPMIN)d=FPMIN
        c=b+an/c
        if(abs(c).lt.FPMIN)c=FPMIN
        d=1./d
        del=d*c
        h=h*del
        if(abs(del-1.).lt.EPS)goto 1
11    continue
      pause 'a too large, ITMAX too small in gcf'
1     gammcf=exp(-x+a*log(x)-gln)*h
      return
      END
C  (C) Copr. 1986-92 Numerical Recipes Software <=s='%.
      FUNCTION gammln(xx)
      REAL gammln,xx
      INTEGER j
      DOUBLE PRECISION ser,stp,tmp,x,y,cof(6)
      SAVE cof,stp
      DATA cof,stp/76.18009172947146d0,-86.50532032941677d0,
     *24.01409824083091d0,-1.231739572450155d0,.1208650973866179d-2,
     *-.5395239384953d-5,2.5066282746310005d0/
      x=xx
      y=x
      tmp=x+5.5d0
      tmp=(x+0.5d0)*log(tmp)-tmp
      ser=1.000000000190015d0
      do 11 j=1,6
        y=y+1.d0
        ser=ser+cof(j)/y
11    continue
      gammln=tmp+log(stp*ser/x)
      return
      END
c.....................................................................
      SUBROUTINE SORT(N,RA)
      DIMENSION RA(N)
      L=N/2+1
      IR=N
```

```
10    CONTINUE
        IF(L.GT.1)THEN
          L=L-1
          RRA=RA(L)
        ELSE
          RRA=RA(IR)
          RA(IR)=RA(1)
          IR=IR-1
          IF(IR.EQ.1)THEN
            RA(1)=RRA
            RETURN
          ENDIF
        ENDIF
        I=L
        J=L+L
20      IF(J.LE.IR)THEN
          IF(J.LT.IR)THEN
            IF(RA(J).LT.RA(J+1))J=J+1
          ENDIF
          IF(RRA.LT.RA(J))THEN
            RA(I)=RA(J)
            I=J
            J=J+J
          ELSE
            J=IR+1
          ENDIF
        GO TO 20
        ENDIF
        RA(I)=RRA
      GO TO 10
      END
```

Appendix C. Program LADDER

C.1. Introduction

The program LADDER is used to generate Reich-Moore type pseudo resonance parameters. It produces a parameter file in SAMMY.PAR format. Samplings are performed as follows; these are basically same to the methods used in the program URR [Le90].

- Resonance energy: random sampling from the cumulative Wigner distribution,
- Neutron width and fission width: random sampling from χ^2 distribution (degree of freedom of one or two) by using the rejection technique, and
- Radiative width: constant.

C.2. Input Description

Table C1 shows a sample input; input for the generation of pseudo ^{235}U resonance parameters. Description of input variables follows the table. The input is prepared in free format.

Table C 1. Sample Input of LADDER

```
233.0351
0.,200.
3
2
1.143,3,1.143e-4,1,0.1625,0.1625,3,0.038
0.889,4,0.889e-4,1,0.086,0.086,2,0.038
0.0,0,0.0,0,0.0,0.0,0,0.0
4
1.600,2,1.920e-4,1,0.2115,0.2115,3,0.024
1.143,3,2.743e-4,2,0.0625,0.0625,1,0.024
0.889,4,2.134e-4,2,0.1995,0.1995,3,0.024
0.727,5,0.872e-4,1,0.0625,0.0625,1,0.024
0.0,0,0.0,0,0.0,0.0,0,0.0
6
2.667,1,1.334e-4,1,0.250,0.250,2,0.038
1.600,2,1.600e-4,2,0.250,0.250,2,0.038
1.143,3,1.143e-4,2,0.1625,0.1625,3,0.038
0.889,4,0.889e-4,2,0.0860,0.0860,2,0.038
0.727,5,0.727e-4,2,0.250,0.250,3,0.038
0.615,6,3.075e-5,1,0.250,0.250,2,0.038
0.0,0,0.0,0,0.0,0.0,0,0.0

# Set as S0=1.0, S1=1.2, S2=0.5, D0=0.5, D1=D0/2, D2=D0/3 eV
```

Card 1: mass of the target nuclide

Card 2: lower and upper energy boundary [eV]

Card 3: number of *l* states

For each *l*,

Card 4: number of J states

Card 5+ (one card for each J): level spacing [eV], value of J, average reduced neutron width [eV], multiplicity of J, average first fission width [eV], average second fission width [eV], number of fission channels, average gamma width [eV]

Card next: 0.0 (this card terminates cards set for each *l*.)

Repeat above cards set for all *l*.

Last card: blank

C.3. Source Listing

```
      program ladder
c
c This program generates Reich-Moore type resonance parameter in a
c form suitable to the code SAMMY.  Parameters are sample according
c to the appropriate probability density function.  Level spacings are
c Sample from a Wigner distribution.  Level width are sample from
c chi-squared distribution with corresponding degrees of freedom.
c
      character*20 file
      integer*4 seed
c
      parameter (id=150000)
      dimension ds(id), ee(id), gg(id),
     *          gn(id), gf1(id), gf2(id), nnn(id),
     *          nff(id), gnn(id), gnf1(id), gnf2(id),
     *          aj(id), ajj(id), v(3)
c
      common seed
c
      write(6,'("Input filename:"$)')
      read(5,'(a)') file
      open(unit=1, file=file,status='unknown')
c
      write(6,'("Output filename:"$)')
      read(5,'(a)') file
      open(unit=2, file=file,status='unknown')
c
      seed = 19
      ak0 = 0.002196771
c
c     write(*,*) ' Read some pertinente stuff'
c
      read(1,*) awri
c
c     write(*,*) 'Enter energy boundaries'
c
      read(1,*) ei, ef
```

```
c
c     write(*,*) ' Enter number of l states'
c
      read(1,*) l
c
c     write(*,*) ' Enter data for each j state'
c
      is = 0
      i = 0
      do il = 1, l
        read(1,*) js
        ip = 0
 1      read(1,*) d, aj1, gnav, nn, gfavg1, gfavg2, nf, ggavg
        if ( d .eq. 0.0) go to 2
        ip = ip + 1
        is = is + 1
        ajj(ip) = is
        ds(ip) = d
        gn(ip) = gnav / nn
        gf1(ip) = gfavg1 / nf
        gf2(ip) = gfavg2 / nf
        gg(ip) = ggavg
        nnn(ip) = nn
        nff(ip) = nf
        go to 1
c
 2      continue
        do j = 1, js
          nn = nnn(j)
          nc = nn + nff(j)
          er = ei
          do e = ei, ef, ds(j)
            i = i + 1
c
c Sample d from a Wigner distribution
c
            rr = -alog(amax1(rand(seed), 0.00001))
            x = 1.128379 * ds(j) * sqrt(rr)
            er = er + x
            ee(i) = er
c
c Calculates Penetrabilities
c
            ak = ak0 * sqrt(ee(i)) * awri / (awri + 1.0)
            r = 0.123 * awri ** (1.0/3.0) + 0.08
            rho = ak * r
            rho2 = rho * rho
            rho4 = rho2 * rho2
            v(1) = 1.0
            v(2) = rho2 / (1.0 + rho2)
            v(3) = rho4 / (9.0 + 3.0 * rho2 + rho4)
c
c Ends penetrabilities calculations
c
            gnp = gn(j) * v(il) * sqrt(ee(i))
            gn1 = 0.0
            gf11 = 0.0
            gf12 = 0.0
c
c Gamma width and spin
c
```

```
            gg(i) = gg(j)
            aj(i) = ajj(j)
c
c Sample neutron width from a Porter-Thomas distribution
c
            do inc = 1, nc
 3            r1 = -alog(amax1(rand(seed), 0.00001))
              r2 = -alog(amax1(rand(seed), 0.00001))
              if ( 2.0 * r1 .lt. (r2-1) * (r2-1)) go to 3
              if(inc .le. nn) gn1 = gn1 + r2 * r2 * gnp
              if(inc .gt. nn) then
c
c First fission channel
c
                gf11 = gf11 + r2 * r2 * gf1(j)
c
c Second fission channel
c
 4              r1 = -alog(amax1(rand(seed), 0.00001))
                r2 = -alog(amax1(rand(seed), 0.00001))
                if ( 2.0 * r1 .lt. (r2-1) * (r2-1)) go to 4
                gf12 = gf12 + r2 * r2 * gf2(j)
              endif
            enddo
c
c Neutron width
c
            gnn(i) = gn1
c
c Sign for the first fission channel
c
            sn = 2.0 * rand(seed) - 1.0
            if (sn .eq. 0.0) then
              sign = 1.0
            else
              sign = sn / abs(sn)
            endif
            gnf1(i) = sign * gf11
c
c Sign for the second fission channel
c
            sn = 2.0 * rand(seed) - 1.0
            if (sn .eq. 0.0) then
              sign = 1.0
            else
              sign = sn / abs(sn)
            endif
            gnf2(i) = sign * gf12
          enddo
        enddo
c
      enddo
      nr = i
      call order(nr, ee, gg, gnn, gnf1, gnf2, aj)
      do i = 1, nr
c
        gg(i) = gg(i) * 1000.0
        gnn(i) = gnn(i) * 1000.0
        gnf1(i) = gnf1(i) * 1000.0
        gnf2(i) = gnf2(i) * 1000.0
        jj = aj(i)
```

```
c
c SAMMY format for .par files
c
        if (ee(i) .lt. 10.0) then
          write(2,1000) ee(i), gg(i), gnn(i), gnf1(i), gnf2(i), jj
          else if (ee(i) .gt. 10.0 .and. ee(i) .lt. 100.0) then
          write(2,1001) ee(i), gg(i), gnn(i), gnf1(i), gnf2(i), jj
        else if (ee(i) .gt. 100.0 .and. ee(i) .lt. 1000.0) then
          write(2,1002) ee(i), gg(i), gnn(i), gnf1(i), gnf2(i), jj
        else if (ee(i) .gt. 1000.0 .and. ee(i) .lt. 10000.0) then
          write(2,1003) ee(i), gg(i), gnn(i), gnf1(i), gnf2(i), jj
        else if (ee(i) .ge. 10000.0 .and. ee(i) .lt. 100000.0) then
          write(2,1004) ee(i), gg(i), gnn(i), gnf1(i), gnf2(i), jj
        else
          write(2,1005) ee(i), gg(i), gnn(i), gnf1(i), gnf2(i), jj
        endif
      enddo
c
      stop
 1000 format(f11.9, 4(1pe11.4),' 0 0 0 0 0',i2)
 1001 format(f11.8, 4(1pe11.4),' 0 0 0 0 0',i2)
 1002 format(f11.7, 4(1pe11.4),' 0 0 0 0 0',i2)
 1003 format(f11.6, 4(1pe11.4),' 0 0 0 0 0',i2)
 1004 format(f11.5, 4(1pe11.4),' 0 0 0 0 0',i2)
 1005 format(f11.2, 4(1pe11.4),' 0 0 0 0 0',i2)
      end
c
c   Random number generation
c
      function rnmaxf(t)
      integer*4 seed
      common seed
      data ff/0.0/
      u= exprnf(u)
      if(ff) 3, 1, 3
 1    r1 = ran(seed)
      r2 = ran(seed)
      r1sq = r1 * r1
      r2sq = r2 * r2
      rsq = r1sq + r2sq
      if(rsq - 1.0) 2, 2, 1
 2    w = exprnf(w)/rsq
      ff = 1.0
      rnmaxf = (r2sq * w + u) * t
      go to 4
 3    ff = 0.0
      rnmaxf = (r1sq * w + u) * t
 4    return
      end
      function exprnf(a)
      real i
      integer*4 seed
      common seed
      i = 0.0
 1    x = ran(seed)
      z = x
 2    y = ran(seed)
      if(z - y) 5, 5, 3
 3    z = ran(seed)
      if(z - y) 2, 4, 4
 4    i = i + 1.0
```

```
      go to 1
 5    exprnf = x + i
      return
      end
c
c  Order
c
      subroutine order(n, x, y, z, v, w, ay)
c
      dimension x(n), y(n), z(n), v(n), w(n), ay(n)
      n1 = n - 1
      do 2 i = 1, n1
        i1 = i + 1
        do 1 j = i1, n
          if (x(i) .le. x(j)) go to 1
c
          temp = x(i)
          x(i) = x(j)
          x(j) = temp
c
          temp = y(i)
          y(i) = y(j)
          y(j) = temp
c
          temp = z(i)
          z(i) = z(j)
          z(j) = temp
c
          temp = v(i)
          v(i) = v(j)
          v(j) = temp
c
          temp = w(i)
          w(i) = w(j)
          w(j) = temp
c
          temp = ay(i)
          ay(i) = ay(j)
          ay(j) = temp
c
 1      continue
 2    continue
      return
      end
```

INTERNAL DISTRIBUTION

1. Central Research Library
2. Laboratory Records-RC
3-4. Laboratory Records-OSTI
5. Herve Derrien
6. Felix C. Difilippo
7. Chia Y. Fu
8. Jess C. Gehin
9. Norman Maurice Greene
10. Klaus H. Guber
11. Francisco Braga Guimaraes
12. David M. Hetrick
13. Calvin M. Hopper
14. Daniel T. Ingersoll
15. Bernadette Lugue Kirk
16. Paul Edward Koehler
17. Michael A. Kuliasha
18. Duane C. Larson
19. Nancy M. Larson
20-24. Luiz C. Leal
25. Andy Loebl
26. Cecil V. Parks
27. S. Raman
28. John Paul Renier
29. Royce O. Sayer
30. Michael Scott Smith
31. Timothy E. Valentine
32. Robert Michael Westfall
33. John E. White
34. R. R. Winters
35-39. RSICC

EXTERNAL DISTRIBUTION

40. S. M. Austin, NSCL/Cyclotron Lab, Michigan State University, East Lansing, MI 48824
41. C. Bastien, Central Bureau for Nuclear Measurements, Steenweg op Retie, 2240 Geel, Belgium
42. H. Beer, Forschungszentrum Karlsruhe, IK, BAV 425, Postfach 3640, D-76021, Karlsruhe, Germany
43. R. Block, Rensselaer Polytechnic Institute, Troy, NY 12180-3590
44. O. Bouland, DER/SPRC/LEPH, Batiment 230, Centre d=Etudes de CADARACHE, 13108, Saint Paul-lez-Durance, France
45. A. Brusegan, Central Bureau for Nuclear Measurements, Steenweg op Retie, 2240 Geel, Belgium
46. David Buchan, Ontario Hydro P41 E1 Pickering Nuclear Generating Station, 1675 Montgomery Park Rd., Pickering Ontario, CANADA L1V 2R5
47. J. Burke, Gaerttner LINAC Laboratory, Rensselaer Polytechnic Institute, Department of Environmental and Energy Engineering, Troy, NY 12180-3590
48. D. Cabrilla, U.S. Department of Energy, NE-40, 19901 Germantown Road, Germantown, MD 20874-1290
49. D. E. Carlson, U.S. Nuclear Regulatory Commission, Reactor and Plant System Branch, Division of System Research, Office of Nuclear Regulatory Research, MS T-10 G6, RM T-10, 17, Washington, DC 20555-0001
50. R. F. Carlton, Middle Tennessee State University, Department of Chemistry and Physics, Murfreesboro, TN 37132
51. E. Caro, Lockheed Martin Corporation, P.O. Box 1072, Schenectady, NY 12301-1072
52. M. B. Chadwick, Los Alamos National Laboratory, MS B243 T-16, Los Alamos, NM 87545
53. J. Chang, Korea Atomic Energy Research Inst., Nuclear Data Evaluation Lab., P. O. Box 105, Yusung, Taejon 305-600, Korea

54. Y. Danon, Gaerttner LINAC Laboratory, Rensselaer Polytechnic Institute, Department of Environmental and Energy Engineering, Troy, NY 12180-3590
55. C. Dunford, Brookhaven National Laboratory, Bldg 197D, National Nuclear Data Center, Upton, NY 11973
56. P. Finck, Argonne National Laboratory, Reactor Analysis Division, Bldg 208, Argonne, IL 60439
57. C. M. Frankle, Los Alamos National Laboratory, NIS-6MS J562, Los Alamos, NM 87545
58. W. Furman, Frank Laboratory of Neutron Physics, JINR, Dubna, Russia
59. S. Ganesan, Head, Nuclear Data Section, Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, Tamilnadu, India
60. Victor Gavron, Los Alamos National Laboratory, P.O. Box 1663 NIS-5 MS-E540, Los Alamos, NM 87545
61. Thomas B. Gosnell, Lawrence Livermore National Laboratory, 7000 East Avenue L-175, Livermore, CA 94550
62. F. Gunsing, Centre D'Etudes De Saclay, F-Saclay - 91191, Gif-sur-Yvette Cedex, France
63. G. M. Hale, Los Alamos National Laboratory, T-2, MS B243, Los Alamos, NM 87545
64. A. Hasegawa, Nuclear Data Center Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, lbaraki-ken 319-11, Japan
65. R. P. Jacqmin, DER/SPRC/LEPH, Batiment 230, Centre d'Etudes de CADARACHE, 13408, Saint Paul-lez-Durance, France
66. M. Jaeger, Inst. F. Strahlenphysik, Allmandring 3, Stuttgart D-70569, Germany
67. N. Janeva, Bulgarian Academy of Sciences, 72, Boul, Tzarigradsko shosse, Sofia 1784, Bulgaria
68. H. C. Johnson, U.S. Department of Energy, EM-21 Forrestal, 1000 Independence Ave. SW, Washington, DC 20585
69. F. Kappeler, Forschungszentrum Karlsruhe, IK, BAV 425, Postfach 3640, D-76021, Karlsruhe, Germany
70. Lambros Lois, U.S. Nuclear Regulatory Commission, 08 E23, 11555 Rockville Pike, Rockville, MD 20852-2746
71. G. Leinweber, Gaerttner LINAC Laboratory, Rensselaer Polytechnic Institute, Dept. of Environmental and Energy Engineering, Troy, NY 12180-3590
72. R. Little, Los Alamos National Laboratory, X-TM, MS B226, Los Alamos, NM 87545
73. M. Lubert, Gaerttner LINAC Laboratory, Rensselaer Polytechnic Institute, Department of Environmental and Energy Engineering, Troy, NY 12180-3590
74. C. Lubitz, Knolls Atomic Power Laboratory, P. O. Box 1072, Schenectady, NY 12301
75. R. E. MacFarlane, Los Alamos National Laboratory, T-2, MS B243, Los Alamos, NM 87545
76. C. Mounier, CEN Saclay, DMT/SERMA/LENR, , 91191 Gif Sur Yvette Cedex, France
77. D. Muir, IAEA Nuclear Data Section, Wagramerstr. 5, P. O. Box 100, A-1400, Wien, Austria
78. C. Nordborg, OECDNEA, Le Seine St-Germain 12, Boulevard Iles, 92130, Issy-les-Moulineaux, France
79. A. Nouri, OECD/NEA Data Bank, Le Seine Saint Germain 12 Bd des Iles, 92130 Issy-les-Moulineaux, France

80-84. S. Y. OH, Nuclear Data Evaluation Lab., Korea Atomic Energy Research Institute, P. O. Box 105, Yusung Taejon, 305-600 Korea

85. C. Raepsaet, CEN Saclay, DMT/SERMA/LEPP, 91191, Gif Sur Yvette Cedex, France
86. M. Salvatores, DRN/P, Batiment 707, C. E. CADARACHE, 13108, Saint Paul-lez-Durance, France
87. E. Sartori, OECDNEA, Le Seine St-Germain 12, Boulevard Iles, 92130, Issy-les-Moulineaux, France
88. R. Shelley, Central Bureau for Nuclear Measurements, Steenweg op Retie, 2240 Geel, Belgium
89. K. Shibata, Japan Atomic Energy Research Institute, Nuclear Data Center, Tokai-mura Naka-gun, Ibaraki-ken 319-11, Japan

90. Mihaela Sin, Bucharest University Nuclear Physics Department, P.O. Box MG-11, RO-76900 Bucharest-Magurele, Romania
91. D. L. Smith, Argonne National Laboratory, TD-360-L106, Argonne, IL 60544
92. H. Takano, Japan Atomic Energy Research Institute, Nuclear Data Center, Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan
93. C. Wagemans, Central Bureau for Nuclear Measurements, Steenweg op Retie, 2240 Geel, Belgium
94. J. J. Wagschal, Racah Institute of Physics, The Hebrew University of Jerusalem, 91904 Jerusalem, Israel
95. H. Weigmann, Central Bureau for Nuclear Measurements, Steenweg op Retie, 2240 Geel, Belgium
96. J. P. Weinman, Lockheed Martin Corporation, P.O. Box 1072, Schenectady, NY 12301-1072
97. C. Werner, Rensselaer Polytechnic Institute, Residence Hall, 1999 Burdette Ave, Troy, NY 12180-3711
98. R. M. White, Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94550
99. K. Yoo, Korea Atomic Energy Research Inst., Nuclear Data Evaluation Lab., P. O. Box 105, Yusung, Taejon 305-600, Korea