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**Program RECENT (version 79-1):
reconstruction of energy-dependent
neutron cross sections from
resonance parameters in the
ENDF/B format**

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FOREWORD

The total cross-section probability (TCP) system is designed to process evaluated neutron cross-section data into continuous-energy or multigroup forms. The following figure describes the function of each code in the TCP system by contrasting the form of the data before and after code processing.

Plots of evaluated cross sections in the **ENDF/B** format can be obtained at any stage of the above processing by using the **EVALPLOT** program (UCRL-50400, Vol. 17, Part E). Comparisons between evaluated cross sections in the **ENDF/B** format and experimental data in the **ECSIL** format can be obtained by using the **ECSPLT** program (UCRL-50400, Vol. 1, Part A).

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PROGRAM RECENT (VERSION 79-1): RECONSTRUCTION OF ENERGY-
DEPENDENT NEUTRON CROSS SECTIONS FROM RESONANCE PARAMETERS
IN THE ENDF/B FORMAT

ABSTRACT

Program RECENT reconstructs energy-dependent neutron total, elastic, capture, and fission cross sections from a combination of resonance parameters and tabulated background cross sections in the ENDF/B format. Entire evaluations, not just cross sections, are output in the result file, which is in ENDF/B format. The output includes the original resonance parameters in a form that can be used in Doppler broadening and self-shielding calculations. A listing of the source deck is available on request.

INTRODUCTION

The Evaluated Nuclear Data File/Version B (ENDF/B)¹ contains data from which total, elastic, capture, and fission cross sections can be calculated as functions of neutron energy. In general these data consist of resonance parameters (in File 2) and background cross sections (in File 3). The resonance parameters can represent resolved and/or unresolved resonances in one or more of several formalisms. The background cross section is tabulated as a function of energy and may involve any of five interpolation laws between tabulated values.

In its Output mode program RECENT combines the resonance and background contributions to the cross sections, and outputs the results in File 3 of a new tape in ENDF/B format. RECENT outputs the entire ENDF/B evaluation, with cross sections linearly interpolable over the entire energy range, resonance parameters in a form that can later be used for Doppler-broadening and self-shielding calculations, and all other data (e.g., angular and energy distributions) ready for use. This simplifies the design and execution of all programs that subsequently use the data by allowing them to assume the data are linearly interpolable.

If one wishes only to obtain energy-dependent cross sections from resonance parameters it is sufficient to have an ENDF/B MAT containing only File 2 resonance parameters--one need not have File 3 background cross sections. This convention was introduced in order to give evaluators a simple way to determine the effect of a given set of resonance parameters. Background cross sections can be included at a later time as required.

In its Edit mode RECENT reads an ENDF/B file to identify the type and number of resonance parameters with each evaluation, and determines the common-core requirements for processing each isotope in the Output mode.

The availability of the resonance parameters and cross sections as output by RECENT allows the user to perform Doppler-broadening and self-shielding calculations. In the resolved-resonance region one can perform kernel broadening² and self-shielding³ or use the resonance parameters to calculate the Doppler-broadened cross sections, plus the effect of the resonances at any given temperature, minus the effect of the resonances at 0 kelvin (which has already been added into the File 3 cross sections). When the latter approach is used the cross sections will be exact at 0 kelvin, and any error introduced by approximations (such as the use of psi-chi functions) will be minimized. Similarly in the unresolved-resonance region the parameters can be used to calculate temperature-dependent, self-shielded average cross sections.

The Edit mode provides an inexpensive method of determining the type of resonance parameters used by any given set of materials. Another use of the Edit mode is to ensure that the common core allocation will not be exceeded. If the allocation (normally 7000 words) will be exceeded the program determines the amount of additional core required. The user must increase common to the required size and set MAXDEN equal to the new value before attempting to run in the Output mode.

RECENT requires the background cross sections to be linearly interpolable, so ENDF/B tapes must be processed by program LINEAR⁴ before RECENT is used. The program requires approximately 12 000 words of core storage when it is run on the Lawrence Livermore Laboratory CDC-7600 or CRAY-1. On the CRAY-1 the program requires 0.35 min (21 s) to reconstruct ²³⁵U cross sections to 1% accuracy. Execution times are about twice as long on the CDC-7600 as on the CRAY-1.

The program is written in standard Fortran IV. There are I/O instructions written especially for the CDC-7600 and CKAY-1, but alternative Fortran IV instructions are given.

METHOD

RECONSTRUCTION OF CROSS SECTIONS FROM PARAMETERS IN FILE 2

Resonance Formalisms

In the resolved-resonance region the ENDF/B format allows parameters from four resonance formalisms (see Ref. 1):

1. Breit-Wigner single-level parameters.
2. Breit-Wigner multilevel parameters.
3. Reich-Moore parameters.
4. Adler-Adler parameters.

The program reads parameters in any of these formats and computes the resonance contribution for all except Reich-Moore parameters, which are ignored.

In the unresolved-resonance region the ENDF/B format allows three kinds of parameters (see Ref. 1):

1. Constant or energy-independent parameters.
2. Energy-dependent fission widths, all other widths constant.
3. All widths energy-dependent.

If any material has no resonance parameters (i.e., no File 2), or has parameters only for non-resonant isotopes or has already been processed by RECENT (as indicated by the LRU flag--see the discussion under Limitations and Assumptions) there is no resonance contribution to add to the File 3 cross sections. In this case the remainder of the evaluation is copied unchanged to the ENDF/B result file.

If an isotope is non-resonant the effective scattering radius is given. In this case it is assumed that the potential contribution has already been added to the File 3 background (see Ref. 5), and nothing further is added to the cross section.

Energy Subdivision

RECENT subdivides the energy range for which resonance parameters are given in such a way that cross sections calculated at these energies can be linearly interpolated. All but the final stages of the subdivision process are carried out without user input; the final stage, called interval halving, requires the user to supply criteria which determine how fine the subdivision will be. The subdivision process is described below. (Parameters for the unresolved-resonance region are given at a sufficient number of energies to allow the resulting cross sections (not the parameters) to be linearly interpolated, so that no subdivision is needed.)

Subdivision into Resonance Regions. In the ENDF/B format, resonance parameters are given for each isotope that contributes to the evaluation; the evaluation can be for a single isotope or for an elemental mixture of isotopes. The data for each isotope include resonance parameters for one or more energy ranges (i.e., resolved or unresolved) using one of the above resonance formalisms.

All resonance parameters for a given evaluation are read, and the energy limits of each set of parameters, EL and EH (see Ref. 1), are combined and sorted into ascending order; duplicate energies are removed. The energy ranges defined by successive values in the resulting list are called resonance regions. RECENT determines which kinds of parameters will contribute to the cross sections in each resonance region. For example if there are resolved-resonance parameters from 1 eV to 100 eV and unresolved-resonance parameters from 80 eV to 25 keV, there will be three resonance regions: 1 to 80 eV, 80 to 100 eV, and 100 eV to 25 keV. In the 1 to 80-eV region only resolved resonances will contribute; in the 80 to 100-eV region both resolved and unresolved resonances will contribute; and in the 100-eV to 25-keV region only unresolved resonances will contribute.

Subdivision into Intervals. A table is kept of resonance energies and energies at which unresolved-resonance parameters are given. These energies are sorted into ascending order; the successive values, called nodes, are used to divide the resonance regions into intervals. For example if in the 1 to 80-eV region there are resonances at 2, 3.7, 9.2 eV, etc., the region will be

divided into intervals of 1 to 2, 2 to 3.7, 3.7 to 9.2 eV, etc. Thus each interval extends from the one resonance peak to the next. Figure 1 illustrates this process.

Subdivision into Subintervals. Each interval is next divided into subintervals. Starting at each end of the interval, and using the width of the resonance at that end, subinterval boundaries are placed 1, 2, 4, 6, 10, 20, 40, 60, and 100 half widths from the end or until the midway point between the two resonances is reached. "Midway" is defined as equidistant from the ends of the interval, in units of the half widths at the ends. Figure 1 illustrates this process. With this algorithm the interval between two narrow, widely-spaced resonances is divided into as many as twenty subintervals, while the interval between two wide, closely-spaced resonances is divided into only a few subintervals.

FIG. 1. Subdivision of a resonance region into intervals (between successive resonances) and subintervals (based on widths of nearest resonances).

FIG. 2. Subinterval halving procedure. Linear interpolation between cross sections at E_1 and E_2 does not give satisfactory approximation to correct value at E_3 , so data point at E_3 must be included. Data point at E_4 is not needed because linear interpolation between E_1 and E_3 approximates cross section at E_4 satisfactorily.

Subinterval Halving. Each subinterval is further subdivided, using an iterative interval-halving technique,⁶ until the cross section for each of the four reactions can be approximated by linear interpolation between successive energy points.

The interval-halving technique begins at the low end of the energy range of interest, and works as follows (see Fig. 2). Consider two successive energy points, E_1 and E_2 , where $E_1 < E_2$. Tentatively insert a point E_3 halfway

between E_1 and E_2 , and calculate the total, elastic, capture, and fission cross sections at each of the three points. The point at E_3 need not be inserted if at least one of the following criteria is met:

1. E_3 is closer to E_1 than the energy resolution (either six or nine digits--see ENDF/B Minimum Energy Spacing). For example if an interval extends from 123.45641 to 123.45749 both energies would be equal to 1.23457+2 in the 6-digit ENDF/B format and are thus indistinguishable.

2. All four cross sections can be approximated at the midpoint E_2 by linear interpolation from the ends of the interval to within a fractional error $\epsilon_{\max}$. The program calculates $\sigma_i(E_1)$, $\sigma_i(E_2)$, and $\sigma_i(E_3)$ for $i = 1, 2, 3, 4$ (where the indices refer to the four reactions), and approximates the cross sections at the midpoint by linear interpolation:

$$\sigma_i^*(E_2) = \frac{1}{2} [\sigma_i(E_1) + \sigma_i(E_3)] .$$

The criterion is met for reaction i if

$$\frac{\sigma_i(E_2) - \sigma_i^*(E_2)}{\sigma_i(E_2)} \leq \epsilon_{\max} .$$

3. The absolute values of all four cross sections at both ends of the interval are less than some minimum cross section of interest. If the user specifies a cross section smaller than 10^{-10} barns the program will use 10^{-10} . The specified cross section may be positive or negative, but convergence is assumed if the cross section at both ends of the interval is closer to zero than the minimum cross section. This prevents the program from needlessly homing in on the energy at which the cross section goes from positive to negative. (Negative values occasionally arise for elastic-scattering cross sections being reconstructed from single-level Breit-Wigner parameters.)

If one or more of these criteria are met the point E_3 is dropped, and the next higher subinterval (E_2 to E_7 in Fig. 2) is subdivided. If not the point E_3 is included, and the convergence tests are applied again to a point E_4 halfway between E_1 and E_3 . This procedure is continued until the entire energy range of interest has been treated.

Treatment of Distant Resonances

The user may perform exact calculations over the entire resonance region, or may treat distant resonances approximately. In some cases approximate treatment of distant resonances reduces execution time by an order of magnitude, e.g., from 30 min to 3 min. Distant resonances are defined, for any given subinterval, as those that are both a large number of half-widths (5000 in the present version of the program) and a large number of resonances (10 in the present version) outside the subinterval. Unfortunately distant resonances can have large effects on cross sections- this is particularly true for low-energy elastic cross sections and in interference minima between resonances. Therefore distant resonances cannot simply be ignored.

The exact cross section consists of contributions from the set R of all resonances:

$$\sigma(E) = \sum_R \gamma_R(E);$$

the approximate cross section consists of contributions from a subset R' of this set, excluding distant resonances:

$$\tilde{\sigma}(E) = \sum_{R'} \gamma_{R'}(E).$$

The effect of the distant resonances can be represented by the difference

$$f(E) = \sigma(E) - \tilde{\sigma}(E),$$

or by the ratio

$$r(E) = \sigma(E) / \tilde{\sigma}(E).$$

An acceptable approximate treatment of distant resonances results from assuming that the ratio $r(E)$ of the exact to the approximate cross sections is a linear function of energy within an interval or subinterval. This approach is quite accurate for both single-level and multilevel parameters. For single-level parameters the ratio is usually close to unity except for low-energy elastic cross sections; in this case, however, the cross section

becomes constant and the ratio is a slowly varying function of energy. For multilevel parameters the effect of distant resonances is largest at the peaks of resonances and diminishes between them; using a ratio in this case is therefore much more accurate than using a difference. Adler-Adler parameters are usually used to represent cross sections that vary smoothly with energy, so they present no problem in this approximation technique.

(On the other hand the assumption that the difference $f(E)$ between the exact and the approximate cross sections can be linearly interpolated throughout the interval leads to unsatisfactory results; for example with multilevel resonances one can end up with negative elastic cross sections.)

If distant resonances have a dominant effect on the magnitude of the cross section it is undesirable to use an approximation at all. Therefore if the exact and approximate cross sections at the ends of an interval differ by more than a factor of two the program reverts to exact calculations of cross sections within the interval.

The distant-resonance correction is applied to the elastic, capture, and fission cross sections. The total cross section is then taken as the sum of these three cross sections.

The user has three options available in treating distant resonances: exact calculation, approximate treatment within each subinterval (called FINE LINEAR in the output listing), or approximate treatment within each interval (called LINEAR in the output listing). Clearly, approximation within an entire interval is less exact than approximation within a subinterval.

Comparison of the exact cross sections with those obtained using the two approximation options shows that large differences occur only in the interference minima of elastic cross sections. These differences in the detailed, energy-dependent cross sections introduce little or no error into shielded or unshielded group-averaged cross sections, however.

Figure 3 shows plots of cross sections for ^{55}Mn reconstructed exactly. To the scale of the plots FINE LINEAR and LINEAR reconstructions are identical.

Although a large number of problems have been run to verify the accuracy of this method of treating distant resonances the approach should still be regarded as experimental. I would therefore appreciate hearing from any user who tries this option so that I may have the benefit of all possible operating experience as I attempt to improve this code.

FIG. 3. Exact reconstructions (distant resonances treated exactly) of neutron total, elastic, and capture cross sections on ^{55}Mn . FINE LINEAR and LINEAR reconstructions (distant resonances treated approximately over subintervals and intervals respectively) are indistinguishable from these plots.

Competitive Widths

Competitive widths are allowed in the ENDF/B format in both the resolved- and unresolved-resonance regions. In the resolved-resonance region the code ensures that competitive widths do not contribute below the threshold of the competitive reaction; it does this by setting the penetrability to zero for energies below the threshold, which effectively results in a zero competitive width.

Storage of Reconstructed Cross Sections

Each data point of reconstructed cross sections consists of five numbers: an energy and corresponding cross sections for each of the four reactions. These data points are stored in a paging system.⁶ A "page" consists of 1002 data points (5010 computer words). One page is resident in core at any time; all other data points are stored in a scratch file. With this method there is no limit to the number of pairs used to represent a given reaction.

ADDING RECONSTRUCTED CROSS SECTIONS TO BACKGROUND CROSS SECTIONS

After the resonance contribution to each of the cross sections has been calculated, and the resulting energies and cross sections stored in the paging system, RECENT combines the resonance contribution with the File 3 background cross section for each of the four reactions and writes the results in File 3. During this process each reaction is considered and processed separately. The program will abort if the interpolation law is not linear--this is why the ENDF/B tapes must be run through LINEAR before RECENT is used. If there is no background the resonance contribution is taken as the cross section and is written directly into File 3.

OUTPUT DATA THINNING

In general there will be many more data points generated than are required for linear interpolability. Figure 2 shows one reason for this. The interval-halving algorithm looks forward (to higher energies) and keeps inserting points (E_3 , E_5 , etc.) until convergence is obtained. The insertion of energy E_5 eliminates the need for energy E_3 , but this is not

recognized during the interval-halving process; the unnecessary data point at E_3 is not removed.

Another reason for the existence of unnecessary points is that, in the reconstruction process, a point is included if it is needed to produce a linearly-interpolable cross-section for any one of the four reactions. When the reactions are considered separately, however, they can be accurately represented using far fewer points. For example about 30 000 points may be generated in processing ^{238}U , but the fission cross section can be satisfactorily represented with only a few hundred points.

Backward thinning^{4,6} searches for and eliminates unnecessary energy points after the whole cross section (resonance plus background) is calculated. Since the criterion of linear interpolability is applied in thinning the user must again specify a maximum fractional error--in general, it will be similar to the one specified in interval-halving.

COMPARISON WITH RESEND

RECENT is based largely on experience gained over the last eight years in reconstructing cross sections from resonance parameters in the ENDF/B format using the RESEND code.⁷ It is worth comparing the features of these two codes to show where we are now compared to where we were eight years ago when RESEND was written. The comparison is not intended to criticize the methods used in RESEND--especially since many of the algorithms used in RESEND are mine.

1. RESEND reconstructs the total, elastic, capture, and fission cross sections and outputs them in the ENDF/B format. The cross sections are linearly interpolable in the resonance region, but may have any interpolation law outside of the resonance region.

RECENT outputs the entire evaluation, not just the reconstructed cross sections. Cross sections are linearly interpolable over their entire energy range. Resonance parameters are in a form that can later be used in Doppler-broadening and self-shielding calculations.

2. RESEND'S reconstruction algorithm starts interval-halving at successive resonance peaks (i.e., at RECENT'S "interval" level). With this approach linear interpolability is reached very slowly. For isotopes with widely spaced, narrow resonances (e.g., ^{238}U , ^{240}Pu), this algorithm reaches

6-digit accuracy in energy before adequately representing the shape of a resonance.

RECENT's reconstruction algorithm starts close to the shape of each resonance (at the subinterval level) to reach linear interpolability quickly and to ensure that all resonances are accurately represented. Comparison of RECENT output reconstructed to 1% accuracy with that reconstructed to 0.1% shows that the 1% results are everywhere within 1% of the 0.1% results. Naturally we expect this for a well-designed algorithm; RESEND output cannot pass this test.

3. In RESEND the handling of boundaries between resonance regions is awkward, involving small energy shifts to keep the parameters in two adjacent resonance regions from contributing at the boundary between the regions. In RECENT each resonance region is handled separately.

4. In RESEND one can request only a single range of MAT numbers. In RECENT one can request up to 100 ranges of MAT or ZA numbers.

5. In RESEND a single accuracy is used at all energies to reconstruct cross sections. In RECENT an energy-dependent accuracy is allowed; this can be used to minimize execution time either by tailoring the output to specific applications or by simulating experimental uncertainties in the cross section at different energies.

6. Some versions of RESEND have backward thinning and some do not. In RECENT, output data for each reaction are thinned separately, minimizing the number of data points output for each reaction (e.g., for the ²³⁸U fission cross section there are about 250 points instead of about 30 000). To simulate earlier versions of RESEND that do not have backward thinning one can use a File 2 + 3 error of 0.0.

7. Different versions of RESEND use 5 or 6 digits of accuracy; this may be inadequate for representing narrow resonances. RECENT allows up to 9-digit accuracy in calculations and output of energies if the computer's word length is long enough; this ensures correct representation of narrow resonances. The subroutines that read and write ENDF/B formatted data are the same in all TCP programs (see Conversion to Other Installations), so that the 9-digit accuracy can be maintained in subsequent processing.

8. RESEND aborts if common allocation is exceeded, and the user must guess at how much to increase allocation to correct the problem. RECENT's Edit mode determines the common allocation requirement before the program is

run in the Output mode; it also determines the number and type of resonance parameters associated with each material.

9. RECENT can be used by evaluators to determine the contribution of resonance parameters without the need to prepare File 3 background cross sections; it is sufficient to use an ENDF/B MAT that contains only resonance parameters.

10. RECENT's approximate treatment of distant resonances can be used to greatly reduce the running time in many applications. Again it must be stressed that this option should be considered to be experimental until more experience is gained with it.

PROGRAM USE--GENERAL

LIMITATIONS AND ASSUMPTIONS

This version of the program contains all conventions and recommendations of the CSEWG Resonance Subcommittee up to and including those in the summary of the May 16-17, 1979 CSEWG meeting.⁵

RECENT uses only the ENDF/B BCD format, not binary. File 2 resonance parameters must be in the ENDF/B-IV or ENDF/B-V format. The ENDF/B format is the same for File 3 in all versions of ENDF/B. RECENT copies all other sections as Hollerith, so that those sections may be in the ENDF/B-I, II, III, IV, or V formats.

RECENT will abort if any section of File 3 is not linearly interpolable. File 3 interpolation laws are checked only after the contribution of the resonance cross sections has been calculated, so that a great deal of computer time can be wasted if File 3 is not linearly interpolable. It is therefore recommended that ENDF/B tapes be linearized using program LINEAR⁴ as soon as they are received. As output from this program, File 3 cross sections will be linearly interpolable over the entire energy range, not just the resonance region.

Seven thousand words of common core are used to store resonance-parameter data. If this limit is exceeded in the Output mode the program will print an appropriate error message and abort. If this limit is exceeded in the Edit mode the program will continue counting, will not overwrite any other core, and in the output listing will notify the user of the size of common required. The user should then allocate more blank common, set MAXDEN equal to

the new allocation, recompile the program, and execute in the Output mode. The 7000-word allocation is sufficient for all present evaluations (through ENDF/B-V).

RECENT does not update the reaction index in File 1, Section 451 of each evaluation (see Ref. 1). This convention was adopted in order to avoid having to distinguish between versions of the ENDF/B format and to minimize running time. It will not affect the user unless he has a program that uses the index to perform random access. In this case program DICTION⁸ should be used to create an up-to-date reaction index after RECENT is used.

RECENT calculates the cross section by adding the resonance contribution to the File 3 background, and outputs the results as File 3 data. Outside the unresolved-resonance region, energy-dependent cross sections are given in File 3; inside the unresolved-resonance region, infinitely dilute averaged cross sections are given.

To indicate that File 3 contains the entire cross sections, and not just the background cross sections, RECENT increases by three the value of the flag LRU (see Ref. 1) associated with each section of File 2. Before processing by RECENT, LRU can have the values 0, 1, or 2, with the following significances:

- 0 indicates no resonance parameters (non-resonant isotope).
- 1 indicates resolved-resonance parameters.
- 2 indicates unresolved-resonance parameters.

After processing by RECENT these values of LRU will be changed to 3, 4, and 5, respectively, with the same significances as above, but with the added significance that reconstructed cross sections have been added to File 3.

The convention using LRU = 3, 4, or 5 is not standard in the ENDF/B format (see Ref. 1); it has been introduced only for use in this and subsequent codes that process ENDF/B-formatted data. Thus evaluators should not use this convention in preparing evaluated data for use in the ENDF/L system; e.g., do not include unresolved parameters in File 2 with LRU=5 and infinitely-dilute cross sections in File 3.

REQUIREMENTS

The I/O units are defined as follows:

<u>FILENAME*</u>	<u>UNIT</u>	<u>DESCRIPTION</u>
INPUT	5	Input cards.
OUTPUT	6	Output cards.
ENDFIN	20	Original data in ENDF/B format.
ENDFOUT	21	Final data in ENDF/B format.
SCR1	22	Scratch file for data reconstructed from resonance parameters.
SCR2	23	Scratch file for combined File 2 and File 3 data.

All read and write statements use variable I/O unit numbers. To convert to any other set of unit numbers, redefine the unit numbers on the program card and at the beginning of the program.

The program requires approximately 32 000 words of core storage on the LLL CDC-7600 or CRAY-1. On the CRAY-1 the program requires 0.35 min (21 s) to reconstruct ^{235}U cross sections to 1% accuracy, treating distant resonances exactly. Execution times are about twice as long on the CDC-7600 as on the CRAY-1.

PROGRAM USE--DETAILS

REQUESTING EVALUATED DATA FOR RECONSTRUCTION

Evaluations may be requested either by MAT number (see Ref. 1) or ZA, where $\text{ZA} = 1000Z + A$ for an isotope and $\text{ZA} = 1000Z$ for a natural element. Up to 100 MAT or ZA ranges may be requested. The ENDF/B data must be in MAT or ZA order, whichever criterion the user specifies for retrieval; this is because the program searches the library and processes evaluations which meet the retrieval criteria only until a MAT (or ZA) equal to the largest value specified is found. (For example if the user specifies the two MAT ranges 1000 to 1100 and 1200 to 1300 processing is ended as soon as a MAT larger than 1300 is found.)

* The names in the filename column only apply to the program used at Livermore. Disk files by these names are automatically assumed by the program.

To simplify requests for individual evaluations, as opposed to evaluations in ranges of MAT or ZA, RECENT has been written so that if only a minimum MAT or ZA is specified, only an evaluation with that MAT or ZA will be searched for. For example to process ^{238}U , searching by ZA, one need only specify the lower limit ZA = 92238 and make no entry for the upper limit. (See Input Cards for details.)

This program outputs the entire ENDF/B evaluation, not just the cross sections treated in the program. Thus the output from this program is complete and in a form suitable for direct use in subsequent processing codes.

ENDF/B MINIMUM ENERGY SPACING

All floating-point numbers are output with at least 6-digit accuracy. (Computers with short word length may not be able to achieve this accuracy.) In most cases this is achieved by outputting the data in what we call 6-digit Ell.4 format, which is Ell.4 format with a sixth digit replacing the "E" in the output. For example 212.617 is output as 2.12617+2 instead of 2.1262E 2.

File 3 energies may be output with up to 9-digit accuracy; this is achieved by the use of an "F" format which varies from F11.8 to F11.0 as required by the magnitude of the energy. For energies between 1 eV and 100 MeV nine full digits are available with variable "F" format. Between 10^{-3} and 1 eV the accuracy varies from six to nine digits, which is at least as accurate as 6-digit Ell.4 format. For energies less than 10^{-3} eV or greater than 100 MeV 6-digit Ell.4 format is used.

Table 1 illustrates output in 6-digit Ell.4 format. Table 2 illustrates variable "F" format.

The availability of output with up to nine digits allows improved representation of narrow resonances (p, d, etc.) in heavy even-even isotopes such as ^{232}Th , ^{238}U , and ^{240}Pu . The variable "F" format, without the "E" and the exponent numeral for the user to interpret, makes the energies easier for the user to read. (See Tables 1 and 2 to compare the readabilities of 6-digit Ell.4 and variable "F" output.) In all cases the cross sections are output in 6-digit Ell.4 format.

TABLE 1. Listing of RECENT output in 6-digit Ell.4 format (a sixth digit replaces the letter "E").

7.67500+	1	2.23333+	1	7.69990+	1	1.87232+	1	7.70680+	1	1.85671+	18014	3	1	330
7.71670+	1	2.34035+	1	7.72480+	1	3.31641+	1	7.74070+	1	6.53372+	18014	3	1	331
7.74920+	1	7.42299+	1	7.77250+	1	4.42444+	1	7.77770+	1	3.86264+	18014	3	1	332
7.78580+	1	4.15322+	1	7.81170+	1	8.14075+	1	7.83000+	1	5.36467+	18014	3	1	333
7.83760+	1	4.12985+	1	7.84900+	1	3.01950+	1	7.85570+	1	2.75757+	18014	3	1	334
7.87260+	1	2.36064+	1	7.90880+	1	2.03432+	1	7.92050+	1	1.97235+	18014	3	1	335
7.92700+	1	2.10374+	1	7.93500+	1	2.32265+	1	7.94120+	1	2.80326+	18014	3	1	336
7.96070+	1	5.08920+	1	7.96720+	1	5.77248+	1	7.99150+	1	3.37881+	18014	3	1	337
7.99410+	1	3.21047+	1	7.99950+	1	2.97114+	1	8.00140+	1	2.97793+	18014	3	1	338
8.00680+	1	3.12497+	1	8.01220+	1	3.52036+	1	8.03570+	1	5.59710+	18014	3	1	339
8.04430+	1	4.82354+	1	8.06570+	1	2.72234+	1	8.07700+	1	2.18290+	18014	3	1	340
8.09170+	1	1.96896+	1	8.09750+	1	2.04811+	1	8.10800+	1	2.20307+	18014	3	1	341
8.11040+	1	2.50404+	1	8.11590+	1	2.96808+	1	8.13510+	1	6.21002+	18014	3	1	342
8.14340+	1	6.87725+	1	8.16650+	1	4.09958+	1	8.17120+	1	3.55752+	18014	3	1	343
8.18100+	1	3.11060+	1	8.20020+	1	4.56037+	1	1.00000+	2	4.68203+	18014	3	1	344
1.00800+	2	3.47280+	2	1.01100+	2	3.27245+	2	1.02000+	2	4.17141+	18014	3	1	345
1.02700+	2	6.87060+	2	1.03200+	2	5.07002+	2	1.03800+	2	3.98933+	18014	3	1	346
1.04100+	2	3.95898+	2	1.04500+	2	4.56052+	2	1.05000+	2	6.48784+	18014	3	1	347
1.05400+	2	4.86747+	2	1.05700+	2	4.26713+	2	1.06300+	2	3.56643+	18014	3	1	348
1.06600+	2	3.56608+	2	1.07400+	2	4.76516+	2	1.08000+	2	3.26446+	18014	3	1	349
1.08300+	2	3.26412+	2	1.08600+	2	3.56377+	2	1.09000+	2	3.26331+	18014	3	1	350
1.09700+	2	3.76249+	2	1.10100+	2	3.36203+	2	1.10400+	2	2.88168+	18014	3	1	351
1.10800+	2	2.96122+	2	1.11300+	2	3.58064+	2	1.12000+	2	2.95963+	18014	3	1	352
1.12200+	2	2.95960+	2	1.13300+	2	4.35633+	2	1.13900+	2	3.25753+	18014	3	1	353
1.14100+	2	3.25740+	2	1.14700+	2	3.85670+	2	1.15700+	2	6.35555+	18014	3	1	354
1.16400+	2	4.15473+	2	1.16600+	2	3.95450+	2	1.17000+	2	4.35404+	18014	3	1	355
1.18000+	2	7.15288+	2	1.19100+	2	4.05161+	2	1.19300+	2	3.65138+	18014	3	1	356
1.19700+	2	3.85091+	2	1.20500+	2	4.34999+	2	1.21000+	2	3.34940+	18014	3	1	357
1.21500+	2	6.14883+	2	1.22100+	2	4.64813+	2	1.22300+	2	3.64790+	18014	3	1	358
1.22400+	2	3.34779+	2	1.22700+	2	3.34744+	2	1.23700+	2	4.34628+	18014	3	1	359
1.25700+	2	7.94398+	2	1.26000+	2	7.34362+	2	1.26600+	2	4.54292+	18014	3	1	360
1.27000+	2	3.94248+	2	1.27800+	2	4.34153+	2	1.28400+	2	3.44084+	18014	3	1	361
1.28600+	2	3.44060+	2	1.29400+	2	4.03968+	2	1.30100+	2	4.33887+	18014	3	1	362
1.31000+	2	6.43782+	2	1.32900+	2	6.23562+	2	1.33500+	2	5.33493+	18014	3	1	363
1.34000+	2	5.33435+	2	1.34800+	2	8.43342+	2	1.35900+	2	4.32215+	18014	3	1	364
1.36700+	2	3.53122+	2	1.37300+	2	3.63053+	2	1.37800+	2	8.82995+	18014	3	1	365
1.38200+	2	8.82949+	2	1.40000+	2	3.92740+	2	1.40800+	2	3.82671+	18014	3	1	366
1.41600+	2	5.52555+	2	1.42300+	2	3.82474+	2	1.42700+	2	3.32427+	18014	3	1	367
1.43500+	2	3.32335+	2	1.44000+	2	3.82277+	2	1.45200+	2	6.02138+	18014	3	1	368
1.46000+	2	3.92045+	2	1.46200+	2	3.92022+	2	1.47000+	2	4.91299+	18014	3	1	369
1.47400+	2	3.91833+	2	1.47700+	2	3.91848+	2	1.48900+	2	5.41709+	18014	3	1	370
1.49700+	2	3.81617+	2	1.50400+	2	2.91536+	2	1.51000+	2	2.91466+	18014	3	1	371
1.51700+	2	3.31385+	2	1.53000+	2	5.11234+	2	1.53900+	2	4.01130+	18014	3	1	372
1.54200+	2	4.01095+	2	1.55000+	2	4.51003+	2	1.55700+	2	4.70922+	18014	3	1	373
1.56300+	2	4.50832+	2	1.57000+	2	3.60771+	2	1.57200+	2	3.70748+	18014	3	1	374
1.57500+	2	3.70715+	2	1.58500+	2	4.70597+	2	1.59000+	2	4.10340+	18014	3	1	375
1.59500+	2	3.80422+	2	1.59900+	2	3.80435+	2	1.60800+	2	4.60331+	18014	3	1	376
1.61300+	2	3.80273+	2	1.61600+	2	3.80238+	2	1.63000+	2	5.10076+	18014	3	1	377

TABLE 2. Listing of RECENT output in variable "F" format, showing automatic transition from F11.7 to F11.6 (e.g., in first column).

76.7500000	2.23333+	1	76.9990000	1.67232+	1	77.0880000	1.95571+	18014	3	330
77.1570000	2.34035+	1	77.2490000	3.31641+	1	77.4070000	8.53372+	18014	3	331
77.4920000	7.42299+	1	77.7250000	4.42444+	1	77.7700000	3.86264+	18014	3	332
77.8580000	4.15322+	1	78.1170000	5.14075+	1	78.3000000	3.36457+	18014	3	333
78.3760000	4.12955+	1	78.4900000	3.01950+	1	78.5670000	2.75757+	18014	3	334
78.7260000	2.36054+	1	79.0680000	2.03432+	1	79.2050000	1.97235+	18014	3	335
79.2700000	2.10374+	1	79.3500000	2.33265+	1	79.4120000	2.80328+	18014	3	336
79.6070000	5.08920+	1	79.6720000	5.77248+	1	79.9150000	3.37881+	18014	3	337
79.9410000	3.21047+	1	79.9950000	2.97114+	1	80.0140000	2.97783+	18014	3	338
80.0680000	3.12497+	1	80.1220000	3.52036+	1	80.3570000	5.59710+	18014	3	339
80.4430000	4.82354+	1	80.6570000	2.72234+	1	80.7700000	2.16290+	18014	3	340
80.9170000	1.98896+	1	80.9750000	2.04911+	1	81.0600000	2.20307+	18014	3	341
81.1040000	2.50404+	1	81.1590000	2.96508+	1	81.3510000	6.21002+	18014	3	342
81.4340000	6.87725+	1	81.6650000	4.09958+	1	81.7120000	3.65752+	18014	3	343
81.8100000	3.71060+	1	82.0020000	4.56037+	1	100.00000	4.66203+	18014	3	344
100.800000	3.47280+	1	101.100000	3.27245+	1	102.00000	4.17141+	18014	3	345
102.700000	6.87060+	1	103.200000	5.07002+	1	103.800000	3.58933+	18014	3	346
104.100000	3.96898+	1	104.500000	4.86852+	1	105.000000	6.46794+	18014	3	347
105.400000	4.86747+	1	105.700000	4.26713+	1	106.300000	3.58643+	18014	3	348
106.600000	3.56608+	1	107.400000	4.76516+	1	108.000000	3.26448+	18014	3	349
108.300000	3.26412+	1	108.600000	3.56377+	1	109.000000	3.26331+	18014	3	350
109.700000	3.76249+	1	110.100000	3.36203+	1	110.400000	2.66168+	18014	3	351
110.800000	2.96122+	1	111.300000	3.56064+	1	112.000000	2.95983+	18014	3	352
112.200000	2.95960+	1	113.300000	4.35833+	1	113.900000	3.25763+	18014	3	353
114.100000	3.25740+	1	114.700000	3.85670+	1	115.700000	6.35555+	18014	3	354
116.400000	4.15473+	1	116.600000	3.95450+	1	117.000000	4.35404+	18014	3	355
118.000000	7.15288+	1	119.100000	4.05161+	1	119.300000	3.65138+	18014	3	356
119.700000	3.85091+	1	120.500000	4.34999+	1	121.000000	5.34941+	18014	3	357
121.500000	8.14883+	1	122.100000	4.64813+	1	122.300000	3.64790+	18014	3	358
122.400000	3.34779+	1	122.700000	3.34744+	1	123.700000	4.34628+	18014	3	359
125.700000	7.94396+	1	126.000000	7.34362+	1	126.600000	4.54292+	18014	3	360
127.000000	3.94246+	1	127.800000	4.34153+	1	128.400000	3.44084+	18014	3	361
128.600000	6.43782+	1	129.400000	4.03968+	1	130.100000	4.93687+	18014	3	362
131.000000	6.43782+	1	132.900000	6.23562+	1	133.500000	5.93493+	18014	3	363
134.000000	5.33435+	1	134.800000	8.43342+	1	135.900000	4.33215+	18014	3	364
136.700000	3.53122+	1	137.300000	3.63053+	1	137.800000	2.82995+	18014	3	365
138.200000	2.82949+	1	140.000000	3.92740+	1	140.600000	3.82671+	18014	3	366
141.600000	5.52555+	1	142.300000	3.82474+	1	142.700000	3.32427+	18014	3	367
143.500000	3.32335+	1	144.000000	3.82277+	1	145.200000	6.02138+	18014	3	368
146.000000	3.92045+	1	146.200000	3.92022+	1	147.000000	4.41929+	18014	3	369
147.400000	3.91883+	1	147.700000	3.91848+	1	148.900000	5.41708+	18014	3	370
149.700000	3.81617+	1	150.400000	2.91536+	1	151.000000	2.91463+	18014	3	371
151.700000	3.31385+	1	153.000000	5.11234+	1	153.900000	4.01130+	18014	3	372
154.200000	4.01095+	1	155.000000	4.51003+	1	155.700000	4.70922+	18014	3	373
156.300000	4.50852+	1	157.000000	3.80771+	1	157.200000	3.70748+	18014	3	374
157.500000	3.70713+	1	158.500000	4.70597+	1	159.000000	4.10540+	18014	3	375
159.500000	3.80482+	1	159.900000	3.80435+	1	160.800000	4.60331+	18014	3	376
161.300000	3.80275+	1	161.600000	3.80238+	1	163.000000	5.10076+	18014	3	377

In 6-digit output the energies E_1 and E_2 will be distinguishable if

$$E_2 \geq E_1 + 0.00001 \times 10^N,$$

where

$$\begin{aligned} N &= \log_{10}(E_1)^*, & E_1 &\geq 1, \\ &= \log_{10}(E_1) - 1, & E_1 &< 1. \end{aligned}$$

Therefore an interval will no longer be subdivided if

$$E_2 < E_1 + D,$$

where

$$\begin{aligned} D &= 0.00001 \times 10^{\log_{10}(E_1)^*}, & E_1 &\geq 1, \\ &= 0.000001 \times 10^{\log_{10}(E_1)^*}, & E_1 &< 1. \end{aligned}$$

SPECIFYING MAXIMUM FRACTIONAL ERROR

The maximum fractional errors used in reconstructing cross sections and in thinning the combined cross sections can be specified as energy-dependent error laws, each represented by up to twenty (energy, error) pairs. The energies must be in ascending order and given in eV; the errors must be positive and given as decimal fractions (not as percents). If only one pair is given the error is taken as constant for all energies. If more than one pair is given the error is taken to vary linearly between tabulated values and to be constant outside the energy limits given.

(Generally the error laws can be identical. However if the user wishes to obtain output as precise as possible and is willing to pay the penalty of additional output points he can specify a small (0.001) or zero error for thinning.)

* Use only the integer portion of the logarithm.

For example the following error law specifies 0.1% maximum error below 100 eV, error varying linearly from 0.1% at 100 eV to 1% at 1 keV, and 1% error above 1 keV:

<u>energy-eV</u>	<u>fractional error</u>
0.0	0.001
100.0	0.001
1000.	0.01
1.0E+10	0.01

(The form above makes clear how the error is to vary over the entire energy range of interest; the first and last of the (energy, error) pairs could be left out, because of the convention that errors are taken as constant outside of the energy range specified.)

RECENT execution time can be greatly reduced if the error law is tailored for specific applications. For example the error law given above gives thermal cross sections for ^{238}U accurate to 0.1% without wasting computer time in calculating the effects of the many narrow resonances in the 1 to 3 keV energy range. If the error law required 0.1% accuracy at all energies execution would take three to five times as long. In addition, by minimizing the number of data points output, well-tailored error laws such as this one can reduce the cost of any subsequent processing (e.g., Doppler broadening² or group averaging³).

INPUT CARDS

<u>Card</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
1	1-11	I11	Retrieval criterion (0 indicates MAT, 1 indicates ZA).
	12-22	E11.4	File 2 minimum absolute cross section, in barns (if a value less than 10^{-10} is input the program will use 10^{-10}).

23-33	I11	Minimum energy spacing flag (0 indicates 6-digit minimum energy spacing for calculations, 6-digit Ell.4 output; 1 indicates 9-digit minimum energy spacing for calculations, 6-digit Ell.4 output; 2 indicates 9-digit minimum energy spacing for calculations, variable 9-digit "F" format output).
34-44	I11	Operating mode (0 indicates Output; 1 indicates Edit).
45-55	I11	Distant-resonance treatment (0 indicates exact; 1 indicates linear ratio over sub-intervals; 2 indicates linear ratio over intervals).

If the first input card is left blank the five variables just described will each be read as zero. Evaluations will be found by MAT number, using a minimum cross section of 10^{-10} barn, with 6-digit accuracy in energy in both calculations and output; the program will be in the Output mode and distant resonances will be treated exactly. Only if the user wishes to modify these standard conditions will he need to enter anything on the first input card.

<u>Card</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
2-N	1-11	I11	Minimum MAT or ZA.
	12-22	I11	Maximum MAT or ZA. Up to 100 MAT or ZA ranges may be specified, one range per card. If no value is inserted for maximum MAT or ZA only the single MAT or ZA given as the minimum value will be searched for. The list is terminated by a blank card.
Vary	1-11	Ell.4	Energy for File 2 error law.
	12-22	Ell.4	Error for File 2 error law.
Vary	1-11	Ell.4	Energy for File 2 + 3 error law.
	12-22	Ell.4	Error for File 2 + 3 error law.

The File 2 and File 2 + 3 error laws may be described by linearly interpolable functions of up to 20 energy-error pairs, one pair per card. The input for each law is terminated by a blank card. If only one point is given the error law is assumed to be constant over the entire energy range. Energies must be in ascending order in eV. Errors must be decimal fractions, not percents. For File 2 the errors must be positive.

ERROR MESSAGES

1. OVER 1000 RESONANCES--EXECUTION TERMINATED

The core allocation for resolved resonances plus energies at which unresolved parameters are given has been exceeded. Increase the core allocation of ENODE, WIDTH, and LENGTH, and set MAXMOD equal to the new allocation size.

2. NO RESONANCE PARAMETERS--MATERIAL COPIED

3. ALREADY PROCESSED BY RECENT--MATERIAL COPIED

The LRU flags in File 2 indicate the resonance contribution has already been added into File 3.

4. INTERPOLATION LAW IS NOT LINEAR-LINEAR

```

MAT/MF/MT = 1261 3 1
-----
      NBT      INT
      37       5
      1502     2
  
```

EXECUTION TERMINATED

The data must be run through program LINEAR⁴ before using this program.

5. FIND2 INDEX ERROR IPT2/ILOW2/IHIGH2 = 6 15 312

EXECUTION TERMINATED

6. FIND3 INDEX ERROR IPT3/ILOW3/HIGH3 = 6 15 312

EXECUTION TERMINATED

7. FIND23 INDEX ERROR IPT23/ILO23/THI23 = 6 15 312
EXECUTION TERMINATED

These last three messages are diagnostic warnings which have been left at critical points in the code for protection against user changes which violate the logic of the program. These messages cannot occur in normal operation.

8. COMMON STORAGE CAPACITY 7000 EXCEEDED--EXECUTION TERMINATED
Run in the Edit Mode to determine common allocation requirements. Increase common allocation, set MAXDEN equal to the new allocation, recompile, and execute again.
9. OVER 100 RANGES--EXECUTION TERMINATED
A maximum of 100 MAT or ZA ranges is allowed.
10. OVER 20 RANGES--EXECUTION TERMINATED
Each error law (File 2 or File 2 + 3) may be described by no more than 20 energy-error pairs.
11. ERROR MUST BE POSITIVE--EXECUTION TERMINATED
The errors for the File 2 error law must be positive; otherwise iteration will not converge.
12. ENERGIES MUST BE IN ASCENDING ORDER--EXECUTION TERMINATED
The energies in each error law must be in ascending order.
13. SCRATCH I/O ERROR--EXECUTION TERMINATED
This can only occur (unless it results from a computer malfunction) if the resonance-region data generate more than 400 000 data points and exceed the present disk file allocation of 2 000 000 words. Increase File 2 error and re-run.
14. ENDFIN INITIALIZATION ERROR
15. ENDFOUT CLOSING ERROR

16. SCRI DESTROY ERROR

These errors indicate that the program is having trouble locating, creating, closing or destroying a disk file. If the program cannot initialize ENDFIN the ENDF/B format data are either not on disk or have the wrong filename. If the program cannot initialize ENDFOUT, SCRI, or SCR2, it is having trouble locating disk space in order to create a file; it will keep trying.

17. MAT/MF/MT = 1261 2 151

ILLEGAL INTERPOLATION CODE = 0

18. MAT/MF/MT = 1261 2 151

ILLEGAL LOG INTERPOLATION USING NEGATIVE VALUES

INTERPOLATION CODE = 5

X1, Y1, X2, Y2, X = 1.2300E 2 0.0000E 0 2.1400E 2 1.0000E 0
1.8730E 2

19. MAT/MF/MT = 1261 2 151

ILLEGAL INTERPOLATION OVER ZERO LENGTH INTERVAL

X1;X2 = 1.2300E 2 1.2300E 2

These three error messages indicate an error or inconsistency in the interpolation law for the unresolved parameters. Check and correct ENDF/B data.

20. MAT/MF/MT = 1261 2 151

ADLER-ADLER PARAMETERS WITH LI = 1 ONLY VALID IN ENDF/A

Program cannot handle partial evaluations in which only some of the Adler-Adler parameters are given.

21. MAT/MF/MT = 1261 2 151

A MAXIMUM OF 10 J STATES ALLOWED

22. MAT/MF/MT = 1261 2 151

SUM OF J STATES IS NOT EQUAL TO 2L + 1

23. MAT/MF/MT = 1261 2 151

J STATE MUST BE GIVEN EXPLICITLY FOR EACH RESONANCE

Check ENDF/B format and data for multilevel parameters.

INPUT AND OUTPUT EXAMPLES

INPUT CARD EXAMPLE

Below are input cards required for the following problem:

Consider ^{235}U ; retrieve it by MAT number, which is 1261. Consider all cross sections larger in absolute value than 10^{-8} barns. Use 9-digit accuracy in energy for the calculation and 6-digit output. Run in the Output mode. Treat distant resonances exactly. For File 2 reconstructions between 0 and 100 eV use 0.1% accuracy; between 100 eV and 1 keV vary the accuracy from 0.1 to 1.0%; above 1 keV use 1% accuracy. In combining Files 2 and 3 do not perform any output thinning, i.e., use 0% error.

[illegible]

CONTENTS OF OUTPUT-MODE AND EDIT-MODE LISTINGS

The Output-mode and Edit-mode listings contain the following information:

- The user's input parameters, with explanations.
- The label from the ENDF/B tape.
- The MAT and ZA for each material processed. For each resonance region

in the material the listing gives the following further information:

- The energy range of the region, in eV.
- The type of parameters used.
- The number of resonances or energies at which unresolved-resonance parameters are given.
- The number of data points generated in the region (zero, in the edit mode).

- The number of resonances and unresolved-resonance energies.
- The number of data points generated.
- The number of data points in File 3, before and after the resonance contributions are added, for each of the four reactions.
- A comparison of the common-core allocation with the amount of common core used.
- An explanation of the terminology used in the listing.

EXAMPLE OUTPUT LISTINGS

Tables 3 to 5 give examples of output for three problems. Table 3 is the output listing from a run in the Edit mode with ENDF/B Tape 409. Table 4 is the output listing from a reconstruction of ^{235}U cross sections to 1% accuracy; Table 5 represents the same problem with an energy-dependent accuracy.

TABLE 3. Output listing from run in Edit mode with ENDF/B Tape 409, showing information available without actual reconstruction of cross sections.

POINTWISE DATA FROM RESONANCE PARAMETERS IN ENDF/B FORMAT (RECENT 79-11)													

RETRIEVAL CRITERIA----- MAT													
FILE 2 MINIMUM CROSS SECTION- 1.0000E-10													
MINIMUM ENERGY SPACING----- 6 DIGITS													
ENERGY OUTPUT FORMAT----- STANDARD													
OUTPUT OR EDIT----- EDIT													
DISTANT RESONANCE TREATMENT-- EXACT													
MAT RANGES----- MINIMUM MAXIMUM													
FILE 2 RECONSTRUCTION ERROR-- ENERGY ERROR													
FILE 2 * 3 COMBINATION ERROR-- ENERGY 1.0000E-02 ERROR													
----- 0 1.0000E-02													

TAPES LABEL-----													
ENDF/B-IV TAPE 409----- 29-AUG-74----- 409-----													

TARGET----- FILE 2----- FILE 3-----													

7A MAT # ENERGY RANGE REGION TYPE MODES POINTS COMMON # IN TOTAL OUT IN OUT IN OUT IN OUT													

25035 1197 * 1.0000E-05 RESOLVED SLBW 25 0 0 280 # 0 0 0 0 0 0 0 0													
* 8.0000E+04 25 0 0 0 0 0 0 0 0 0 0 0 0													
92233 1260 * 7.9000E-01 RESOLVED SLBW 74 0 0 810 # 0 0 0 0 0 0 0 0													
* 6.0000E+01 74 0 0 0 0 0 0 0 0 0 0 0 0													
92238 1262 * 1.0000E+00 RESOLVED SLBW 410 0 0 0 0 0 0 0 0 0 0 0 0													
92238 1262 * 4.5000E+04 UNRESOLVED ALL 423 0 4413 # C 0 0 0 0 0 0 0 0													
92237 1263 * 8.0000E-01 RESOLVED SLBW 168 0 0 0 0 0 0 0 0 0 0 0 0													
92237 1263 * 1.3000E+02 UNRESOLVED ALL 132 0 0 0 0 0 0 0 0 0 0 0 0													
* 4.0000E+04 360 0 6584 # 0 0 0 0 0 0 0 0													
22000 1286 * NO RESONANCE PARAMETERS MATERIAL COPIED #													

PRESENT COMMON ALLOCATED----- 7000 WORDS													
MAXIMUM COMMON REQUIRED----- 6584 WORDS													

TERMINOLOGY-----													
GENERAL-----													
NODES - NUMBER OF RESONANCES, OR ENERGIES AT WHICH UNRESOLVED PARAMETERS ARE GIVEN													
WHICH LIE WITHIN RESONANCE REGION (E 0, NEGATIVE ENERGY RESONANCES NOT INCLUDED)													
POINTS - NUMBER OF DATA POINTS GENERATED IN EACH RESONANCE REGION AND FOR ENTIRE													
RESONANCE REGION													
COMMON - NUMBER OF WORDS OF BLANK COMMON USED BY EACH MATERIAL													
(CHECK ABOVE FOR CURRENT ALLOCATION AND REQUIREMENTS)													

RESOLVED PARAMETERS-----													
SLBW - SINGLE LEVEL BREIT-WIGNER													
MLBW - MULTI-LEVEL BREIT-WIGNER													
R-M - REICH-MOORE (PARAMETERS READ " " NOT USED)													
A-A - ADLER-ADLER													

UNRESOLVED PARAMETERS-----													
CON - CONSTANT, OR ENERGY INDEPENDENT PARAMETERS													
FIS - FISSION WIDTHS ENERGY DEPENDENT													
ALL - ALL WIDTHS ENERGY DEPENDENT													

TABLE 4. Output listing from RECENT reconstruction of ^{235}U cross with 1% allowable error at all energies.

```

POINTWISE DATA FROM RESONANCE PARAMETERS IN ENDF/B FORMAT (RECENT 79-1)
-----
RETRIVAL CRITERIA----- MAT
FILE 2 MINIMUM CROSS SECTION----- 1.0000E-06
MINIMUM ENERGY SPACING----- 5 DIGITS
ENERGY OUTPUT FORMAT----- STANDARD
OUTPUT OR EDIT----- OUTPUT
DISTANT RESONANCE TREATMENT----- EXACT
MAT RANGES----- MINIMUM MAXIMUM
FILE 2 RECONSTRUCTION ERROR----- 1261 1261
ENERGY ERROR
FILE 2 + 3 COMBINATION ERROR----- 0. 1.0000E-02
ENERGY ERROR
0. 1.0000E-02
-----
TAPE LABEL
ENDF/B-IV TAPE 407 12-JUL-74 407
-----
TARGET # FILE 2 # FILE 3
-----
2A MAT # ENERGY RESONANCE REGION TYPE NODES POINTS COMMON # IN TOTAL ELASTIC FISSION CAPTURE
92235 1261 # 1.0000E+00 RESOLVED SLW 126 3830 #
92235 1261 # 8.2000E+01 UNRESOLVED ALL 118 118 #
# 2.5000E+04 244 3950 5680 # 744 3107 710 1180 741 3508 748 3866
-----
PRESENT COMMON ALLOCATED----- 7000 WORDS
MAXIMUM COMMON REQUIRED----- 5680 WORDS
-----
TERMINOLOGY
GENERAL
-----
NODES - NUMBER OF RESONANCES, OR ENERGIES AT WHICH UNRESOLVED PARAMETERS ARE GIVEN
WHICH LIE WITHIN RESONANCE REGION (E.G. NEGATIVE ENERGY RESONANCES NOT INCLUDED)
POINTS - NUMBER OF DATA POINTS GENERATED IN EACH RESONANCE REGION AND FOR ENTIRE
RESONANCE REGION
COMMON - NUMBER OF WORDS OF BLANK COMMON USED BY EACH MATERIAL
(CHECK ABOVE FOR CURRENT ALLOCATION AND REQUIREMENTS)
-----
RESOLVED PARAMETERS
-----
SLW - SINGLE LEVEL BREIT-WIGNER
RLW - MULTILEVEL BREIT-WIGNER
R-R - REICH-MORSE (PARAMETERS READ BUT NOT USED)
A-A - ADLER-ADLER
-----
UNRESOLVED PARAMETERS
-----
CON - CONSTANT, OR ENERGY INDEPENDENT PARAMETERS
FISS - FISSION WIDTHS ENERGY DEPENDENT
ALL - ALL WIDTHS ENERGY DEPENDENT
-----

```

TABLE 5. Output listing from RECENT reconstruction of ^{235}U cross sections with 0.1% allowable error for energies up to 100 eV, error increasing linearly to 1% at 1 keV, and 1% error above 1 keV.

```

POINTWISE DATA FROM RESONANCE PARAMETERS IN ENDF/B FORMAT (RECENT 76-1)
-----
RETRIEVAL CRITERIA-----
FILE 2 MINIMUM CROSS SECTION----- 1.0000E-06
MINIMUM ENERGY SPACING----- 8 DIGITS
ENERGY OUTPUT FORMAT----- STANDARD
OUTPUT OR EDIT----- OUTPUT
DISTANT RESONANCE TREATMENT----- EXACT
RAT RANGES----- MINIMUM MAXIMUM
                     1251 1251
FILE 2 RECONSTRUCTION ERROR--
                     0. ENERGY ERROR
                     1.0000E+02 1.0000E-03
                     1.0000E+03 1.0000E-02
                     1.0000E+09 1.0000E-02
FILE 2 + 3 COMBINATION ERROR--
                     0. ENERGY ERROR
                     1.0000E+02 1.0000E-03
                     1.0000E+03 1.0000E-02
                     1.0000E+09 1.0000E-02
-----
TAP: LABEL
ENDF/B-IV TAPE 407 12-JUL-74 407
-----
TARGET # FILE 2 # FILE 3
ZA MAT # ENERGY RESONANCE REGION TYPE NODES POINTS COMMON # TOTAL ELASTIC FISSION CAPTURE
IN OUT IN OUT IN OUT
92235 1261 # 1.0000E+00 RESOLVED SLBW 126 12608 #
92235 1261 # 6.2000E+01 UNRESOLVED ALL 116 116 #
          # 2.5000E+04 244 12728 5680 # 744 10014 710 3904 741 11173 746 12309
-----
MAXIMUM COMMON REQUIRED----- 5680 WORDS
PRESENCE COMMON ALLOCATED----- 7000 WORDS
TERMINOLOGY
-----
GENERAL
-----
NODES - NUMBER OF RESONANCES OR ENERGIES AT WHICH UNRESOLVED PARAMETERS ARE GIVEN
        WHICH LIE WITHIN RESONANCE REGION (E.G. NEGATIVE ENERGY RESONANCES NOT INCLUDED)
POINTS - NUMBER OF DATA POINTS GENERATED IN EACH RESONANCE REGION AND FOR ENTIRE
        RESONANCE REGION
COMMON - NUMBER OF WORDS OF BLANK COMMON USED BY EACH MATERIAL
        (CHECK ABOVE FOR CURRENT ALLOCATION AND REQUIREMENTS)
-----
RESOLVED PARAMETERS
-----
SLBW - SINGLE LEVEL BREIT-WIGNER
MLBW - MULTILEVEL BREIT-WIGNER
R-M - REICH-MOORE (PARAMETERS READ BUT NOT USED)
A-A - ADLER-ADLER
-----
UNRESOLVED PARAMETERS
-----
CON - CONSTANT OR ENERGY INDEPENDENT PARAMETERS
FISS - FISSION WIDTHS ENERGY DEPENDENT

```


OPERATION

OPERATION AT LLL

At L' compiled, loaded, ready-to-execute versions of this program are available from photostore for either the CDC-7600, with the command

```
RD .193025: PROGRAMS [RECENT INRECENT]
```

or the CRAY-1, with the command

```
RD .193025: PROGRAMS: CRAY-1 [RECENT INRECENT]
```

After these files are read from photostore file INRECENT should be renamed INPUT and edited to select the options that the user requires.

The program is small enough (32 000 words) to run at a low priority during the day.

The program will automatically use the disk filenames described below:

The program is designed to be compiled using the CHAT compiler for the CDC-7600 or the CIVIC compiler for the CRAY-1.

CONVERSION TO OTHER INSTALLATIONS

This edition of RECENT has been designed for use either on a LLL CDC-7600 or CRAY-1 or for export to any other installation that uses Fortran IV. Most of the coding in this program is in standard Fortran. When an instruction takes different forms for the LLL CDC-7600 or CRAY-1 it is present in three different forms--one for each of the LLL computers and one in standard Fortran. Each card in the group of three is inserted as a comment card, and is labelled "CDC-7600", "CRAY-1", or "EXPORT" (this last label designates any other machine using standard Fortran). To use the code on any given computer activate the appropriate instruction type in each set by eliminating the comment-card identifier "C" and the label, and leave the other two instructions in the set as inactive comment cards.

To convert this program for use on another computer see the following I/O subroutines which contain machine-dependent coding:

DROPIT At LLL this subroutine creates a copy of the loaded program, which is then executed; the original program is not affected. In Fortran IV the subroutine does nothing and simply returns.

IBLOCK This routine does the scratch I/O; in Fortran IV this is equivalent to binary I/O. Operation of RECENT can be greatly improved by using the most efficient scratch I/O available at your installation.

IOFILE Opens, closes, creates, and destroys disk files. In Fortran IV the subroutine simply returns.

This use of subroutines for I/O will be maintained in future versions of this code. Therefore it is recommended that instead of replacing the calls to these subroutines you supply equivalent subroutines for your computer. Your versions of DROPIT, IBLOCK, and IOFILE will be compatible with all future versions of this code, and this will minimize your maintenance problem. These same subroutines are also used by SIGNAL,² GROUPE,³ and LINEAR⁴; once converted, they can be used in all four programs.

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REFERENCES

1. D. Garber, C. Dunford and S. Pearlstein, *Data Formats and Procedures for the Evaluated Nuclear Data, File, ENDF*, Brookhaven National Laboratory, Upton, NY, BNL-NCS-50496 (ENDF-102), Vol. 1 (1975).
2. D. E. Cullen, *Program SIGMAL (Version 79-1): Doppler Broaden Evaluated Cross Sections in the Evaluated Nuclear Data File/Version B (ENDF/B) Format*, Lawrence Livermore Laboratory, Livermore, CA, UCRL-50400, Vol. 17, Part B, Rev. 2 (1979).
3. D. E. Cullen, *Program GROUPIE (Version 79-1): Calculate Bondarenko Self-Shielded Cross Sections and Multiband Parameters from Evaluated Data in the Evaluated Nuclear Data File/Version B (ENDF/B) Format*, Lawrence Livermore Laboratory, Livermore, CA, UCRL-50400, Vol. 17, Part D (1979).
4. D. E. Cullen, *Program LINEAR (Version 79-1): Linearize Data in the Evaluated Nuclear Data File/Version B (ENDF/B) Format*, Lawrence Livermore Laboratory, Livermore, CA, UCRL-50400, Vol. 17, Part A, Rev. 2 (1979).
5. Minutes of Cross Section Evaluation Working Group (CSEWG) Meeting, May 16-17, 1979, National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY, private communication.
6. D. E. Cullen, O. Ozer, and C. R. Weisbin, "Tabular Cross Section File Generation and Utilization Techniques," in *Proceedings of Conference on Nuclear Cross Sections and Technology*, NBS Spec. Publ. 425, Vol. I, Washington, DC (1975), pp. 419-421.
7. O. Ozer, *RESEND: A Program to Preprocess ENDF/B Materials with Resonance Files into a Pointwise Form*, Brookhaven National Laboratory, Upton, NY, BNL-17134 (1973).
8. D. E. Cullen, "Program DICTION," in *Description of the ENDF/B Processing Codes and Retrieval Subroutines*, Brookhaven National Laboratory, Upton, NY, BNL-50300 (ENDF-110) (1971).