



**AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS**

**LUBRA — A CODE TO CALCULATE POINT AND GROUP CROSS SECTIONS,
EFFECTIVE RESONANCE INTEGRALS AND DOPPLER COEFFICIENTS FOR
RESONANCE ABSORBERS IN HOMOGENEOUS REACTORS, USING
BREIT-WIGNER SINGLE-LEVEL RESONANCE PARAMETERS**

by

MISS E. KLETZMAYR

October 1966

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ABSTRACT

The LUBRA complex of codes is designed to produce (i) point cross sections, (ii) infinitely dilute resonance integrals, (iii) effective resonance integrals based on the different approximations presently available and optionally modified to include particle size effects, (iv) Doppler coefficients, also based on the various models, and (v) group averaged cross sections, using Breit-Wigner single-level resonance parameters and other basic data only.

The complex currently comprises five individual programmes coded in FORTRAN IV for an IBM 7040 computer and linked together by a specialised monitor system to permit the use of LUBRA as a single entity.

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1. INTRODUCTION

1.1 General Remarks

Almost all studies of reactor physics require some knowledge of resonance absorption cross sections; the accurate evaluation of derived quantities, such as effective resonance integrals and Doppler coefficients, usually demands a time-consuming and intricate series of calculations. The Theoretical Physics Section of the A.A.E.C.'s Physics Division has already prepared a number of uncorrelated resonance absorption programmes, such as RPD006 and RPD008 (Doherty 1963, unpublished) and RP047 (Kletzmayer 1964, unpublished), which are oriented towards special tasks and duplicate computation of several resonance contour integrals. Furthermore, there is no standard sequence of codes which include the statistical region and the evaluation of Doppler coefficients for each of the existing approximations to the resonance integral.

The LUBRA complex of codes described in this report was written to provide a single flexible entity which encompasses the various important aspects of resonance absorption in homogeneous systems. Each of the five codes treats a different aspect of resonance absorption and by using the tape monitor system the complex may be run as a single unit without operator intervention. The theory of resonance absorption employed assumes that there is no interference or overlapping between neighbouring resonance levels, and uses the Breit-Wigner single-level formula.

1.2 Outline of Individual Codes

LUBRA 0: The first code in the series is designed to generate capture, fission, and total cross sections at specific energy points in the thermal and resonance energy regions. The programme provides options whereby the formula may be evaluated in its asymmetric, symmetric, or "resonance-removed" form, allowing for the calculation of "resonance-included" cross sections, and the removal of resonances from experimental cross section data or the addition of the resonance contributions to resonance-removed cross section data at each required energy point. Different formula options may be used for each resonance or group of successive resonances. Three different methods of generating the energy grid are incorporated. For non-zero temperatures, resonances are always Doppler broadened, but an option allows the user to select any range of resonances to be treated at zero temperature. LUBRA 0 is essentially a translation of the IBM 1620 code, RPD008, written by Doherty (1963, unpublished) but modified and extended to comply with the format of the other LUBRA codes and the monitor system as a whole.

LUBRA 1: This code evaluates the infinitely dilute resonance integral of resonance absorbers from Breit-Wigner single-level resonance parameters between any two arbitrary energy limits. The treatment of the unresolved resonance region includes an estimate of the statistical distribution of Γ_n^0 and the contributions from higher ℓ -states. A spectrum with energy dependence $E^{\delta-1}$ may be used in the calculations to simulate an epithermal spectrum, with $\delta = 0$ signifying a $1/E$ flux. The contribution of the tail of a single negative energy resonance can be included, allowing the resonance integral to be evaluated from any lower energy limit. A negative energy resonance may be either read in as part of the data or evaluated from the thermal capture and fission cross sections at a given estimate of the negative resonance energy. LUBRA 1 is essentially a translation of the IBM 1620 code, RPD006, written by Doherty (1963 unpublished), again modified to fit within the monitor system.

LUBRA 2: This code is designed to evaluate the effective absorption resonance integrals of resonance absorbers, both in homogeneous systems and in dispersed particles, from a selection of the existing approximations in the resolved resonance region and from the Narrow Resonance model in the statistical region, using the Breit-Wigner single-level resonance parameters. The unresolved resonance integral includes the statistical distributions of Γ_n^0 and Γ_f (Greebler and Goldman 1962) and an estimate of the contributions from higher orbital angular momentum states. Some of these aspects had been included, though superficially, in a series of IBM 1620 programmes RP047, (Kletzmayer 1964, unpublished).

LUBRA 3: This code generates the Doppler coefficients for resonance absorbers in homogeneous systems and dispersed particles for each of the five approximations to the effective resonance integral treated in LUBRA 2 in the resolved resonance region and for the Narrow Resonance model in the statistical region again using the Breit-Wigner single-level resonance parameters. The

Doppler coefficients may be either averaged over a temperature range ΔT (using the difference of resonance integrals previously determined at two particular temperatures), or evaluated at a particular temperature T [using a differentiation routine for $J(\phi, \beta)$]. In the treatment of Doppler coefficients in the unresolved region the statistical distributions of Γ_n^0 and Γ_f are included as for LUBRA 2. The contributions from higher orbital angular momentum states have not been included in the evaluation of the unresolved Doppler coefficient at a particular temperature T , but the effect (which is negligible for thermal systems) can be obtained from the averaged value.

LUBRA 4: The last code, in the present state of the complex, is both an editing programme, in that it calculates further nuclear data using the results obtained by LUBRA 0, presenting the output in any format provided by the user, and a cross section group averaging code which uses any arbitrary flux provided by the user, or a flux spectrum calculated by the code, and point cross sections from LUBRA 0. It also includes the effect of fission interference on the fission cross sections of the fissile nuclides, following the method of Feshbach, Porter and Weisskopf (1954). Furthermore, allowance can be made for a new and more accurate theory for the averaging of resonance-removed cross sections, which gives a more realistic energy dependence of cross sections in the groups containing resonances. This is a particularly important feature for preparing accurate group cross section libraries for the code GYMEA (Pollard and Robinson 1966).

2. LUBRA 0 (POINT CROSS SECTIONS GENERATING CODE)

2.1 Theory

2.1.1 Formula Options for Capture and Fission Cross Sections

Using the Breit-Wigner single-level formula for generating cross sections from resonance parameters, the capture cross section, $\sigma_{n\gamma}$, at an energy E_j due to a single resonance at energy E_r , may be obtained from:

$$\sigma_{n\gamma}(E_j) = R + B C \psi(x, \theta) S, \quad 2.1$$

where

$$C = 2.608 \times 10^6 \frac{\Gamma_n g_J \Gamma_\gamma}{\Gamma^2 E_r},$$

$\psi(x, \theta)$ = the Doppler broadened line shape function,

$$x = \frac{2}{\Gamma} (E_j - E_r),$$

and θ , E_r , Γ_n , Γ_γ , Γ_f , and g_J are as defined in Section 8.

The symbols R , B , and S in Equation 2.1 relate to the various options offered by the code. S , the option referring to the asymmetric, symmetric, or "resonance-removed" form of the single-level approximation is defined as:

$$S = \begin{cases} \sqrt{\frac{E_r}{E_j}} & \text{for "asymmetric" formula (option 1)} \\ 1 & \text{for "symmetric" formula (option 2)} \\ \sqrt{\frac{E_r}{E_j}} - 1 & \text{for "resonance-removed" formula (option 3)} \\ & \text{[i.e. generation of } 1/v \text{ tail of resonance].} \end{cases}$$

R and B relate to the option which allows the calculation of either:

- (i) "resonance-included" cross sections, or
- (ii) the removal of resonances from experimental cross sections, or
- (iii) the addition of the resonance contributions to input cross sections.

Option (i) sets $R = 0$, and $B = +1$ to give the "resonance-included" cross sections:

$$\sigma_{n\gamma}(E_j) = 2.608 \times 10^6 \frac{\Gamma_n g_J \Gamma_\gamma}{\Gamma^2 E_r} \psi(x, \theta) S \quad ;$$

Option (ii) sets:

$R = \sigma_{n\gamma}^*(E_j)$, the experimental cross sections read into the code, and

$B = -1$, to yield cross sections with the resonances removed, giving:

$$\sigma_{n\gamma}(E_j) = \sigma_{n\gamma}^*(E_j) - 2.608 \times 10^6 \frac{\Gamma_n g_J \Gamma_\gamma}{\Gamma^2 E_r} \psi(x, \theta) S \quad ; \quad \text{and}$$

Option (iii) uses $R = \sigma_{n\gamma}^*$, $B = +1$, to add the resonance contributions to "resonance-removed" cross section data giving:

$$\sigma_{n\gamma}(E_j) = \sigma_{n\gamma}^*(E_j) + 2.608 \times 10^6 \frac{\Gamma_n g_J \Gamma_\gamma}{\Gamma^2 E_r} \psi(x, \theta) S$$

In all cases the fission cross sections are obtained from:

$$\sigma_{nf}(E_j) = R + B C \psi(x, \theta) S \left(\frac{\Gamma_f}{\Gamma_\gamma} \right) \quad , \quad \text{with } R = \sigma_{nf}^*(E_j) \text{ when required.}$$

2.1.2 Total Cross Sections

The option $IRT = 1$ allows the calculation of the total cross sections at energies E_j from the formula:

$$\sigma_{tot}(E_j) = \sigma_o \psi(x, \theta) \sqrt{\frac{E_r}{E_j}} + \left(g_J \frac{\Gamma_n}{\Gamma} \sigma_o \sigma_b \right)^{\frac{1}{2}} \chi(x, \theta) + \sigma_b \quad , \quad 2.2$$

where $\sigma_o = \text{peak height of resonance } E_r$,

$$= 2.608 \times 10^6 \times \frac{\Gamma_n g_J}{\Gamma E_r}$$

$\psi(x, \theta)$, $\chi(x, \theta)$ are the line-shape function and its associated function, defined by:

$$\psi(x, \theta) = \frac{\theta}{2\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\frac{1}{4}\theta^2(x-y)^2} \frac{dy}{1+y^2} \quad ,$$

and
$$\chi(x, \theta) = \frac{\theta}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\frac{1}{4}\theta^2(x-y)^2} \frac{y}{1+y^2} dy \quad ,$$

and the second term on the right hand side of Equation 2.2 arises from the scattering-interference effects.

[$\psi(x, \theta)$, $\chi(x, \theta)$ are both obtained from subroutine PSICHI, described in Appendix A.1].

For $T = 0^\circ\text{K}$ and unbroadened resonances,

$$\psi(x, \theta) = \frac{1}{1+x^2}, \quad \chi(x, \theta) = \frac{x}{1+x^2}$$

2.1.3 Energy Grids

The energy points at which cross sections are to be generated by the code are either:

- (i) pre-determined by the user and supplied to the code in units of eV or MeV,
- or (ii) may be calculated by the code in one of two ways:
- (a) The energy points may be generated at equal lethargy or energy intervals (du or dE) between any two given lethargy limits (u_H, u_L) or energy limits (E_L, E_H).
 - (b) Energy points may be assumed to follow the contour of each resonance, clustering around the resonance in an even distribution, such that:

$$E_j = (E_r)_i \pm m_j \frac{\Gamma_i}{2},$$

where

$$m_j = -n_i (dn_i) + n_i,$$

n_i being half the number of energy points required around resonance $(E_r)_i$ and dn_i the integral increment in n_i .

Since n_i may be different for each resonance, overlap of energy mesh points between successive resonances may occur. To overcome this problem arbitrary "cut-off" points mid-way in energy between any two successive resonance peaks are set up by the code:

$$(E_c)_i = \frac{1}{2}(E_r)_i + \frac{1}{2}(E_r)_{i+1};$$

each energy point E_j is tested against this limit and discarded:

$$\text{if } E_j < (E_c)_i \quad \text{for } m_j < 0$$

$$\text{and } E_j \geq (E_c)_{i+1} \quad \text{for } m_j > 0.$$

In this way an energy grid, continuous over all the input resonances, can be generated. This option allows a detailed study of the shape of each resonance.

2.2 Operating Instructions

2.2.1 Input Specifications

The input to LUBRA 0 consists mainly of cards. There is however, an option allowing tape input of resonance parameters and the set of energy-cross section values. The data deck contains the following:

- I(i) a title card, containing any alphameric information starting in column 2 and not exceeding 71 characters,
- I(ii) a card containing, in format (A1,3X11,1XA6),

either TAPE n, RESNUC for tape	}	input of the resonance parameter data,
or CARD for card		

where n = the tape unit number (0 to 4 on IBM 7040), and RESNUC is the

nuclide identification which must be the same as the heading preceding each set of resonance parameters on tape (see Section 7.4.1) e.g. *bU233.

I(iii) the set of resonance parameters (u , E_r , Γ_n , Γ_γ , Γ_f , g_j , ID, Z, A, where ID = 17) on cards or tape as specified above, in the standard format (F7.3, E11.3, 4E10.2, 5XI2,I3,I4) of the A.A.E.C. Nuclear Data Card Library (Doherty 1964 a), terminated by a blank card or tape record (Details of tape contents are given in Section 7.4.1). This deck must be omitted if these parameters are already in core from a previous LUBRA run (See Section 7.2.3).

I(iv) a card punched in format (A1,4(1XI1),1XA1,1XI1,1XE10.3) containing the input and output options (LIN,LOUT), the input and output tape unit numbers (LTIN,LTOU) if required, the energy option LEN, the energy unit option MEV, the option IRT and the potential scattering cross section of the resonance absorber (σ_b). All numbers must be separated by commas. The options are defined as follows:

LIN = $\begin{cases} C & \text{for card input of energy-cross section data,} \\ T & \text{for tape input thereof,} \end{cases}$

LOUT takes the values 1 to 7 with $\begin{cases} 1 & \text{for printer} \\ 2 & \text{for punch} \\ 4 & \text{for tape} \end{cases}$ output. Any desired combination of output units is obtained by setting LOUT equal to the sum of the numbers

connected with the peripheral devices to be used. For example:

LOUT = 3(=1+2) both prints and punches the output.

LTIN, LTOU may take the values 0 to 4 on the IBM 7040 system:

LEN = $\begin{cases} 0 & \text{if two consecutive runs have the same energy grid,} \\ 1 & \text{if specific energy values are provided by either card or tape input;} \\ & \text{an option used mainly for the addition or subtraction of resonance} \\ & \text{contributions to or from experimental cross sections,} \\ 2 & \text{if the energy points are generated at equal lethargy or energy intervals} \\ & \text{between any two given lethargy or energy limits,} \\ 3 & \text{if the code is to generate the energy grid by setting up any required} \\ & \text{number of points around each resonance to trace its contour.} \end{cases}$

If LEN = 1, the energies may be read either in MeV or eV, so that the option MEV must be set equal to M for the former unit and left blank for the latter unit.

If LEN = 2, the grid may be calculated at equal energy intervals dE between limits E_L and E_H if the MEV field contains an E, and at equal lethargy intervals du between u_H and u_L if MEV is left blank.

IRT = 1 for calculation of the total cross sections, σ_{tot} ,

= 0 (or blank) if the above option is not required.

[The σ_b field may be left blank if IRT = 0.]

I(v) the next card contains, in format (2I4,E10.3),

NOP = the number of different sets of formula options (if $NOP \leq 1$, the whole resonance region is treated with one option),

NDBR = the number of groups of resonances which are not to be Doppler broadened (if temperature is 0°K , NDBR = 0; also if all resonances are broadened NDBR = 0),

TEMP = temperature in degrees Kelvin.

- I(vi) a card containing the group partitioning for the different formula options, in format I3, each separated by a comma, (for example bb6, bb9, b20, implies the first 6 resonances, the next 9, the next 20, etc.), and must be omitted if NOP \leq 1 (or blank).
- I(vii) a card containing the formula options corresponding to the above partitioning as two digit numbers (IJ) separated by commas, [for example 31, 32, 22, . . .], where the first digit (I) refers to the particular form of the single-level approximation with:

$$I = \begin{cases} 1 - \text{for } \underline{\text{asymmetric}} \text{ form} \\ 2 - \text{for } \underline{\text{symmetric}} \text{ form} \\ 3 - \text{for } \underline{\text{"resonance-removed"}} \text{ form,} \end{cases}$$

and the unit digit (J) refers to the second option, that is:

$$J = \begin{cases} 1 - \text{for } \underline{\text{"resonance included"}} \text{ cross section calculation} \\ 2 - \text{for the removal of resonances from input cross sections} \\ 3 - \text{for the addition of resonance contributions to the input cross sections.} \end{cases}$$

- I(viii) this card contains the partitioning of resonances into Doppler broadened and unbroadened resonances and must be omitted if the option is not required, [for example bb1-b10, b40-b49, . . . means that resonances 1 to 10 and 40 to 49 (both limits inclusive) are not to be Doppler broadened].
- I(ix) the next set of cards depends on the particular choice of option LEN, and only one of the following subsections is applicable.
- (a) If LEN = 0, or if the energy grid is the same as for the immediately preceding problem, no energy cards are required.
- (b) If LEN = 1 and LIN = C, the next set of cards contains the energy-cross section values for the (n, γ) reaction, terminated by a blank card, followed, if $\Gamma_f \neq 0$, by the set of energy-cross section cards for the (n, f) reaction, again terminated by a blank card, in the format (7X2E12.5). If the energy values only are required (for example, for "resonance-included" cross section evaluation) the cross section fields may be left blank. For $\Gamma_f \neq 0$, the energy fields may be left blank provided the energies of the σ_{nf} block are the same as those for the $\sigma_{n\gamma}$ block and in the same order. No cards are needed for the fission cross sections if $\Gamma_f = 0$ for all resonances.
- A similar input is required on the tape unit specified by LTIN, if LIN = T.
- (c) For LEN = 2, the next card after I(viii) must contain, in format (3E10.3), either:
- (i) the upper lethargy limit u_H , the lethargy step du , and the lower lethargy limit u_L , if MEV is left blank, or
- (ii) the lower energy limit E_L , the energy step dE , and the upper energy limit E_H , if MEV = E.
- (d) For LEN = 3, the next card after I(viii) contains the set of numbers n_i (1 to JR), dn_i ($i = 1$ to JR), where JR is the total number of resonances read in, in format (I3) each separated by a comma, where
- $$n_i = \text{half the number of energy points around resonance } (E_r)_i, \\ [E_j = (E_r)_i \pm m_j \Gamma/2]$$
- and $dn_i = \text{interval between these energy points } [m_j = -n_i(dn_i) + n_i]$.

I(x) the last n cards of the input contain the output formats for the capture, fission, and total cross sections respectively, where:

n = 3 if all three formats are required (in above order),

n = 2 if either the total, or the fission cross sections are missing, in which case the appropriate format follows the capture cross section format,

and

n = 1 if the capture cross section only is generated by the code.

If the formats for a repeat problem are the same as those of the immediately preceding job, the appropriate formats need not be read in again. A card containing SAMEbFORMATS in columns 1 to 12 should be used instead.

Sections I(i) to I(x) describe the complete input required for the generation of the cross sections for a particular nuclide.

Exit from LUBRA 0 to the monitor is achieved by terminating the input deck with an END card (E in column 1). However, LUBRA 0 may be continued in two ways:

(1) A CONTINUE card (C in column 1) will restart the code, allowing the generation of cross sections for the same resonance parameters with a different combination of formula options, temperature, and energy grid. This card must then be followed by:

(i) a title card (as described above),

(ii) either a card containing an S in column 1 (for example SAMEbOPTIONS) if all variables defined in I(iv) above remain the same, in which case section I(iv) is omitted and the rest of the data deck consists of I(v) to I(x) inclusive,

or a blank card if a new set of options described in I(iv) is required, in which case the rest of the data follows items I(iv) to I(x) above.

N.B. If the card "SAMEbOPTIONS" is used, the total cross section is not calculated again and the code sets IRT = 0.

(2) A card containing NEXT (N in column 1) will return control to I(i) above for another run of LUBRA 0 with an entirely new set of data (that is, different nuclide).

2.2.2 Output Specifications

The output on all peripheral devices is in the form of a lethargy-energy-cross section table in the format specified by the user with appropriate headings and spacings between successive blocks of cross sections. A table of the resonance parameters is produced as part of the printed and punched output only.

For tape output, the beginning of the entire LUBRA 0 output is marked by the record:

STARTbOFbLUBRA0bOUTPUT

and the whole file is terminated by the record:

ENDbLUBRA0bJOBS.

The output file of each individual problem is terminated by the Hollerith characters: ENDbOFbFILE.

All records on tape are 72 characters long.

2.2.3 Limitations

The limitations imposed by LUBRA 0 result from the size of the computer memory only and consequently can be overcome for larger computers. The dimension statements of this code limit the number of resonances of any one resonance absorber to 300, the total number of energy mesh points for each cross section to 1000, and the partitioning of resonances with respect to formula option and Doppler broadening to 100 sections each.

If a very fine energy grid is required so that the number of cross section points exceeds the dimensions specified (that is, 1000) by the code, the energy range must be divided up into several regions and each set of points (<1000) run separately using a series of CONTINUE cards (Section 2.2.1).

3. LUBRA 1 (INFINITELY DILUTE RESONANCE INTEGRALS)

3.1 Theory

A brief outline of the theory used in LUBRA 1 follows: Details are given by Doherty (1964 b).

3.1.1 The Resolved Resonance Integral

The infinitely dilute capture resonance integral between the limits E_L and E_H due to a resonance at energy E_r in a $1/E$ flux is defined by the Breit-Wigner single-level formula:

$$I_r = 6.52 \times 10^5 \frac{\Gamma_n \Gamma_\gamma g_J}{\sqrt{E_r}} \int_{E_L}^{E_H} \frac{E^{-\frac{3}{2}}}{(E-E_r)^2 + \frac{\Gamma^2}{4}} dE, \quad (3.1)$$

$$= 6.52 \times 10^5 \frac{\Gamma_n \Gamma_\gamma g_J}{\sqrt{E_r}} I_r',$$

$$\text{where } I_r' = 2 \left[\frac{1}{a^2 y_1} + \frac{a-b^2}{4a^3 b} \ell_n \left\{ \frac{(y_1 + \frac{b}{2})^2 + c^2}{(y_1 - \frac{b}{2})^2 + c^2} \right\} + \frac{b^2-3a}{4a^3 c} \left\{ \pi - \tan^{-1} \left(\frac{y_1 - \frac{b}{2}}{c} \right) - \tan^{-1} \left(\frac{y_1 + \frac{b}{2}}{c} \right) \right\} \right],$$

$$\text{and } a^2 = E_r^2 + \frac{\Gamma^2}{4}$$

$$b^2 = 2(E_r + a)$$

$$c^2 = 0.5(a - E_r)$$

$$y_1 = \sqrt{E_L},$$

and the upper limit E_H is assumed to be $+\infty$.

The total resolved resonance integral I_R is therefore given by the sum over all the individual integrals:

$$I_R = \sum_r I_r$$

Fission integrals are treated similarly.

3.1.2 The Unresolved Resonance Integral

In a $1/E$ flux the unresolved resonance integral including the statistical distribution of Γ_n^0 and contributions from higher ℓ -states is given by Doherty (1964 b) as:

$$I_U^\ell = a \sum_{i=0}^{n-1} \left\{ \int_0^\infty P_1(\Gamma_n^0) d\Gamma_n^0 \int_{E_i}^{E_{i+1}} \frac{\langle \Gamma_n^0 \rangle \sqrt{E} \theta_\ell^{-2}}{(\bar{\Gamma}_\gamma + \langle \Gamma_f \rangle + \langle \Gamma_n^0 \rangle \theta_\ell^{-2} \sqrt{E})} \frac{dE}{E^2} \right\}, \quad 3.2$$

where $a = 4.08 \times 10^6 \frac{\bar{\Gamma}_\gamma g_J}{D}$,

θ_ℓ^{-2} is the penetration probability for $\ell = 0$ to 4 taken from the table of Weinberg and Wigner (1958),

$P_1(\Gamma_n^0)$ is as defined in Appendix B.1,

and D , $\langle \Gamma_n^0 \rangle$, $\bar{\Gamma}_\gamma$, $\langle \Gamma_f \rangle$, and g_J are as defined in Section 8.

Writing $B = \frac{(\bar{\Gamma}_\gamma + \langle \Gamma_f \rangle) \theta_\ell^{-2}}{\langle \Gamma_n^0 \rangle \sqrt{E_i}}$, each of the integrals in the

above equation is evaluated analytically by LUBRA 1. The integration limits are determined from:

$$E_{i+1} = E_i \left(\frac{E_H}{E_R + \frac{D}{2}} \right)^{\frac{1}{100}},$$

giving one hundred steps between $E_1 = E_R + \frac{D}{2}$ and the upper integration limit E_H , which is supplied by the input, with the steps smaller at lower energies where the integrand is largest. E_R is the energy of the highest resolved resonance.

3.1.3 Non 1/E Fluxes

Following Doherty (1964b), LUBRA 1 multiplies the infinitely dilute resonance integral for each resolved resonance by the factor E^δ to estimate the effect of spectra with energy dependence $E^{\delta-1}$.

The unresolved integral for $E^{\delta-1}$ spectra is evaluated from:

$$I_U^\ell = a \int_0^\infty P_1(\Gamma_n^0) d\Gamma_n^0 \int_{E_R + \frac{D}{2}}^{E_H} \frac{\langle \Gamma_n^0 \rangle \sqrt{E}}{(\bar{\Gamma}_\gamma + \langle \Gamma_f \rangle + \langle \Gamma_n^0 \rangle \sqrt{E})} \frac{dE}{E^{2-\delta}} \quad 3.3$$

Doherty felt that the effort of coding the above double integration would not be justified and hence the correction factor:

$$\left(1 + \frac{3\delta}{2}\right) \left[E_R + \frac{D}{2}\right]^\delta,$$

is used for all calculations involving non 1/E fluxes in the unresolved region.

3.2 Operating Instructions

3.2.1 Input Specifications

The input to LUBRA 1 consists of the following items:

- I(i) a title card containing up to 71 alphanumeric characters starting in column 2;
- I(ii) an option card containing the input option for the resonance parameters (LIN), the output option (LOUT) for the final results, the input and output tape unit numbers (LTIN, LTOU) if required, the options N1, N2, N3, N4 and the nuclide label RESNUC in format (A1,6(1X11), 1X14, 1XA6), all numbers separated by a comma, where:

LIN = input device option for the resonance parameters = $\begin{cases} \text{C (or blank) for cards,} \\ \text{T for tape,} \end{cases}$

LOUT = output option for all results = $\begin{cases} 1 - \text{ for printer,} \\ 2 - \text{ for punch,} \\ 4 - \text{ for tape.} \end{cases}$

Any combination of output units may be used by giving LOUT the appropriate value, for example LOUT = 3 will produce both printed and punched output.

N1 = $\begin{cases} + 1 \text{ if a negative energy resonance is included in the set of input} \\ \text{resonance cards (or tape),} \\ 0 \text{ (or blank) otherwise,} \end{cases}$

N2 = $\begin{cases} + 1 \text{ for negative energy resonance parameter calculation,} \\ 0 \text{ (or blank) otherwise,} \end{cases}$

N3 = $\begin{cases} + 1 \text{ if unresolved resonance parameters for the } \ell = 0 \text{ state are provided as} \\ \text{input either on a card or tape,} \\ 0 \text{ (or blank) if the average parameters are to be calculated by the code,} \end{cases}$

N4 = $\begin{cases} \text{number of energies in the unresolved resonance region for which average} \\ \text{parameters are to be calculated,} \\ 0 \text{ (or blank) if this option is not required,} \end{cases}$

and RESNUC, the nuclide label, identifies the correct set of resonance parameters on the specified tape (for example *bU233). RESNUC = blank for card input of parameters.

- I(iii) a card containing the coefficient δ used in the assumed flux, $E^{\delta-1}$, and the lower and upper energy limits of integration (E_L , E_H) in format (3E10.3).
- I(iv) for LIN = C only, the set of resonance parameter cards in the standard format (F7.3, E11.3, 4E10.2, 5XI2, I3, I4), terminated by a blank card; if LIN = T, this set must be one of the files on the input tape specified by LTIN. However, this section must be omitted if the resonance parameters are already available in the core of the computer.
- I(v) for N3 = +1 and LIN = C, the next card contains the average resonance parameters [$D, \langle \Gamma_n^0 \rangle, \bar{\Gamma}_\gamma, \langle \Gamma_f \rangle, g_J, ID, Z, A$, where ID = 18], for the $\ell = 0$ orbital momentum state in format (7XE11.3, 4E10.2, 5XI2, I3, I4); for LIN = T, the average resonance parameters must follow the set of resolved parameters on tape;
- I(vi) for N2 = +1 only, the next card contains the thermal capture and fission cross sections as well as the estimated energy of the negative resonance [format (3E10.3)];
- I(vii) for N4 > 0 only, the next card contains the N4 required energies in the statistical region for which resonance parameters are to be calculated. [format (7E10.3)].

Items I(i) to I(vii) are the complete input for any one specific problem and LUBRA 1 may be terminated here by an END card (E in column 1). However, the code may be re-started in one of 3 ways:

- (1) A CONTINUE card (C in column 1) will repeat the preceding problem with a different value for at least one of the options N1, N2, N3, or N4. This card must be followed by:
 - (i) a title card as described above,
 - (ii) a new option card containing N1, N2, N3, N4 in format (3(I1,1X),I4), each separated by a comma,and (iii) if N1 = +1 only, a card containing the negative energy resonance parameters in the standard format.

The rest of the input depends on the values of options N2, N3 and N4.

- (2) A FLUX card (F in column 1) will repeat the preceding problem with a different spectrum $E^{\delta-1}$ or different energy limits (or both). This card must be followed by (i) a title card plus (ii) a card containing values for δ , E_L , E_H as described in I(iii) above. However, if the energy limits for this problem remain the same as for the preceding job, the E_L, E_H fields may be left blank.
- (3) A NEXT card (N in column 1) will return control to the beginning of the programme and requires a completely new set of data [I(i) to I(vii)]. This allows the calculation of resonance integrals for a different resonance absorber or a change of input/output options for the same absorber.

3.2.2 Output Specifications

The output on all peripheral devices is labelled sufficiently well to ensure full understanding. The beginning of the entire set of LUBRA 1 jobs on tape is marked by the Hollerith record STARTbOFbLUBRA1bOUTPUT, the end of the whole chain file by ENDbLUBRA1bJOBS, while the output of each individual problem is terminated by the ENDbOFbFILE record.

All tape records are 72 characters in length.

3.2.3 Limitations

As for LUBRA 0, the limitations imposed on LUBRA 1 are primarily due to the computer memory size. The dimensions specified by this code allow for 300 resolved resonances and 1000 arbitrary energy points in the unresolved region for which average parameters can be evaluated. A further limitation is the inclusion of a single negative resonance only, whether the parameters are read as part of the input or calculated by the code.

4. LUBRA 2 (EFFECTIVE RESONANCE INTEGRALS IN HOMOGENEOUS SYSTEMS)

4.1 THEORY

4.1.1 The Resolved Resonance Integral

Since the exact analytical solution to the slowing down equation is not generally possible, some approximation must be used to yield an estimate of the effective resonance integral. The usual treatment of resonance absorption involves one of two assumptions:

- (i) That the resonance width is so narrow with respect to the average neutron energy loss per collision that a single collision throws a resonance neutron completely out of the resonance region. This yields the narrow resonance (N.R.) approximation.
- (ii) That the neutron suffers negligible energy loss on collision with an absorber nucleus and hence requires a very large number of such collisions to traverse the resonance; at the same time it is assumed that the neutron is scattered right out of the resonance on its first collision with a moderator nuclide. These assumptions lead to the 'narrow resonance infinite absorber' model (N.R.I.A.).

These two formulae, however, give accurate results for very few resonances only and hence several 'intermediate resonance' formulae have been developed to give a better representation of the real resonance. There are several different approaches to this problem. The three 'intermediate resonance' formulae incorporated into LUBRA 2 and described in detail below, all introduce an arbitrary parameter λ (or μ) which characterizes the location, between narrow and wide resonance approximations, of the actual resonance.

♦ Narrow Resonance Approximation [N.R.]

ICODE = 1

Under assumption (i) set out above, the narrow resonance formula for the effective resonance integral is:

$$I_1 = (\sigma_M + \sigma_b) \int_{\text{res}} \frac{\sigma_a(E)}{\sigma(E) + \sigma_M} \frac{dE}{E} \quad , \quad 4.1$$

where σ_a , σ are the absorption and total cross sections of the absorber nuclide (both are functions of energy),

σ_M , σ_b are as defined in Section 8.

Using the relations:

$$x = \frac{2}{\Gamma} (E - E_r)$$

$$\sigma_a = \frac{\Gamma_a}{\Gamma} \sigma_0 \psi(x, \theta)$$

$$\sigma = \sigma_0 \psi(x, \theta) + \sigma_b$$

where σ_0 is the peak height of the resonance,

$$= 2.608 \times 10^6 \frac{\Gamma_n g_J}{\Gamma E_r} \quad ,$$

$$\Gamma_a = \Gamma_\gamma + \Gamma_f \quad ,$$

$\psi(x, \theta)$ is the Doppler broadened line-shape function defined in Section 2.1.2,

and taking $\frac{1}{E_r}$ outside the integral sign, then:

$$I_1 = \frac{\Gamma_a \sigma_0}{E_r} \beta_1 J(\theta, \beta_1) \quad , \quad 4.2$$

where $J(\theta, \beta_1) = \int_0^\infty \frac{\psi(x, \theta)}{\psi(x, \theta) + \beta_1} dx \quad ,$

$$\beta_1 = \frac{\sigma_M + \sigma_b}{\sigma_0} \quad .$$

For $T = 0^\circ\text{K}$ the above formula reduces to:

$$I_1 = \frac{\Gamma_a \sigma_0}{E_r} \cdot \frac{\pi}{2} \left(1 + \frac{1}{\beta_1} \right)^{-\frac{1}{2}} \quad . \quad 4.3$$

♦ Narrow Resonance Infinite Absorber Model [N.R.I.A.]

ICODE = 2

Using assumption (ii) above, this approximation yields the formula:

$$I_o = \sigma_M \int_{\text{res}} \frac{\sigma_a(E)}{\sigma_a(E) + \sigma_M} \frac{dE}{E} \quad . \quad 4.4$$

Following the N.R. approximation method with symbols defined as above, the N.R.I.A. formula becomes (for $T > 0^\circ\text{K}$):

$$I_o = \frac{\Gamma_a \sigma_o}{E_r} \beta_o J(\theta, \beta_o) \quad , \quad 4.5$$

where $\beta_o = \frac{\Gamma}{\Gamma_a} \frac{\sigma_M}{\sigma_o} \quad .$

For $T = 0^\circ\text{K}$ this reduces to

$$I_o = \frac{\Gamma_a \sigma_o}{E_r} \frac{\pi}{2} \left(1 + \frac{1}{\beta_o}\right)^{-\frac{1}{2}} \quad . \quad 4.6$$

♦ Goldstein and Cohen λ -Method [I.R.(1)]

ICODE = 3

In their treatment of resonance absorption Goldstein and Cohen (1962) introduced an arbitrary parameter λ into the flux, and determined its value by equating successive orders of approximation to the effective resonance integral. The effective resonance integral is thus defined as:

$$I_\lambda = (\sigma_M + \lambda \sigma_b) \int_{\text{res}} \frac{\sigma_a(E)}{\sigma_a(E) + \lambda \sigma_s(E) + \sigma_M + \lambda \sigma_b} \frac{dE}{E} \quad , \quad 4.7$$

with λ determined by iteration from the transcendental equation obtained at $T = 0^\circ\text{K}$:

$$\lambda = 1 - \frac{\tan^{-1} x_{1\lambda}}{x_{1\lambda}} \quad ,$$

where $x_{1\lambda} = \frac{2E_r}{\Gamma} (1 - \alpha) \left[\left(1 + \frac{1}{\beta_1}\right)^{\frac{1}{2}} + \left(1 + \frac{1}{\beta_\lambda}\right)^{\frac{1}{2}} \right]^{-1} \quad ,$

$$\beta_1 = \frac{\sigma_M + \sigma_b}{\sigma_o} \quad ,$$

$$\beta_\lambda = \frac{\Gamma}{\Gamma_a + \lambda \Gamma_n} \frac{\sigma_M + \lambda \sigma_b}{\sigma_o} \quad ,$$

$$\alpha = \left(\frac{A-1}{A+1}\right)^2 \quad ; \quad A = \text{mass number of absorber nuclide.}$$

The formula for the effective resonance integral at temperatures $> 0^\circ\text{K}$ can be written:

$$I_\lambda = \frac{\Gamma_a \sigma_o}{E_r} \beta_\lambda J(\theta, \beta_\lambda) \quad , \quad (\beta_\lambda \text{ defined as above}) \quad , \quad 4.8$$

which reduces, for $T = 0^\circ\text{K}$, to:

$$I_\lambda = \frac{\Gamma_a \sigma_0}{E_r} \frac{\pi}{2} \left(1 + \frac{1}{\beta_\lambda}\right)^{-\frac{1}{2}} \quad . \quad 4.9$$

♦ Goldstein and Cohen μ -Method [I.R. (2)]

ICODE = 4

A second approximation, formulated by Goldstein and Cohen (1962), which eliminates the process of iteration on λ , involves the use of a linear trial function in the form of a linear combination of the N.R. and N.R.I.A. fluxes and the equating of the first and second order approximations to the resonance integral.

The effective resonance integral obtained this way is:

$$\begin{aligned} I_\mu &= \frac{1}{1+\mu} [I_0 + \mu I_1] \quad , \\ &= \frac{\Gamma_a \sigma_0}{E_r} \frac{1}{1+\mu} [\beta_0 J(\theta, \beta_0) + \mu \beta_1 J(\theta, \beta_1)] \quad , \end{aligned} \quad 4.10$$

where β_1, β_0 are the β 's defined for the N.R. and N.R.I.A. approximations respectively,

and:

$$\mu = \frac{2\left(1 + \frac{1}{\beta_1}\right)(\sigma_M + \sigma_b)(1 - X_{01})}{\left(1 + \frac{1}{\beta_0}\right)^{\frac{1}{2}} \left\{ \left(1 + \frac{1}{\beta_0}\right)^{\frac{1}{2}} + \left(1 + \frac{1}{\beta_1}\right)^{\frac{1}{2}} \right\} \sigma_M X_{11}} \quad ,$$

where $X_{\kappa\lambda} = \frac{\tan^{-1} x_{\kappa\lambda}}{x_{\kappa\lambda}} \quad ,$

$$x_{\kappa\lambda} = \frac{2E_r}{\Gamma} (1 - \alpha) \left[\left(1 + \frac{1}{\beta_\kappa}\right)^{\frac{1}{2}} + \left(1 + \frac{1}{\beta_\lambda}\right)^{\frac{1}{2}} \right]^{-1} \quad ,$$

$$\beta_\kappa = \frac{\Gamma}{\Gamma_a + \kappa\Gamma_n} \frac{\sigma_M + \kappa\sigma_b}{\sigma_0} \quad .$$

At $T = 0^\circ\text{K}$, the resonance integral becomes:

$$I_\mu = \frac{\Gamma_a \sigma_0}{E_r} \frac{\pi/2}{1+\mu} \left\{ \left(1 + \frac{1}{\beta_0}\right)^{-\frac{1}{2}} + \left(1 + \frac{1}{\beta_1}\right)^{-\frac{1}{2}} \mu \right\} \quad . \quad 4.11$$

♦ Modified λ -Method [I.R. (3)]

ICODE = 5

McKay, Keane, and Pollard (1965) proposed a modified effective resonance integral which takes account of the slowing down properties of the moderating nuclides. They define the effective resonance integral as:

$$I_\lambda = f(p) \sigma_p \lambda \int_{res} \frac{\sigma_a(E)}{\sigma_a(E) + \lambda_a \sigma_s(E) + \sigma_p \lambda} \frac{dE}{E} \quad 4.12$$

with $f(p) = \frac{2}{1+p}$,

where:

$$p = \exp \left\{ - \frac{I_\lambda}{\bar{\xi}(\sigma_M + \sigma_b)} \right\}, \quad 4.13$$

$$\sigma_{p\lambda} = \frac{\sum_{\text{all nuclides in the system}} \lambda_i N_i \sigma_{bi}}{N_{abs}}$$

$$\bar{\xi} = \frac{\sum_{\text{all nuclides in the system}} \xi_i N_i \sigma_{bi}}{N_{abs}} \bigg/ \frac{\sum_{\text{all nuclides in the system}} N_i \sigma_{bi}}{N_{abs}}$$

where N_i are the atomic densities of the nuclides in the homogeneous system,

σ_{bi} their corresponding scattering cross sections, and

N_{abs} is the atomic density of the absorber nuclide.

'Best' values of the λ_i are given by the generalized formula (obtained at $T = 0^\circ\text{K}$):

$$\lambda_i = 1 - \frac{\alpha_i}{x_i} \left\{ \left(1 + \frac{1}{\beta_\lambda} \right)^{\frac{1}{2}} + \left(1 + \frac{1}{\beta_\lambda} \right)^{\frac{1}{2}} \right\} \tan^{-1} \left\{ \frac{x_i}{\left(1 + \frac{1}{\beta_\lambda} \right)^{\frac{1}{2}} + \alpha_i \left(1 + \frac{1}{\beta_\lambda} \right)^{\frac{1}{2}}} \right\},$$

where $x_i = \frac{2E_r}{\Gamma} (1 - \alpha_i)$, $\alpha_i = \left(\frac{A_i - 1}{A_i + 1} \right)^2$, A_i is the mass number of the i^{th} nuclear species,

$$\beta_\lambda = \frac{\Gamma}{\Gamma_a + \lambda_a \Gamma_n} \frac{\sigma_{p\lambda}}{\sigma_o}$$

Again the λ_i are found by an iterative procedure. λ_a is the λ -value for the absorber nuclide.

The value of p may be found from Equation 4.13 by a single iteration using $f(p) = 1$ as a first approximation in the definition of I_λ [Equation 4.12]. McKay, Keane, and Pollard (1965) found that this procedure was generally not only more expeditious but also more accurate than using the limiting value of p .

For $T > 0^\circ\text{K}$, the effective resonance integral is:

$$I_\lambda = \frac{\Gamma_a \sigma_o}{E_r} f(p) \beta_\lambda J(\theta, \beta_\lambda), \quad 4.14$$

which reduces to:

$$I_\lambda = \frac{\Gamma_a \sigma_o}{E_r} \frac{\pi}{2} f(p) \left(1 + \frac{1}{\beta_\lambda} \right)^{-\frac{1}{2}} \text{ at } T = 0^\circ\text{K} \quad 4.15$$

For temperatures greater than zero degrees absolute all approximations may be written in the general form:

$$I_{\text{eff}} = \frac{\Gamma_a \sigma_o}{E_r} f(p) \beta_\lambda J(\theta, \beta_\lambda) \quad , \quad 4.16$$

where $f(p) = 1$ for all except the modified λ -method,

$\lambda = 1$ yields the N.R. formula,

and $\lambda = 0$ the N.R.I.A. formula.

$$\text{For } T = 0^\circ\text{K} \quad \beta_\lambda J(\theta, \beta_\lambda) = \frac{\pi}{2} \left(1 + \frac{1}{\beta_\lambda} \right)^{-\frac{1}{2}} \quad . \quad 4.17$$

4.1.2 Effect of Particles Dispersed in Homogeneous Systems

The effect of small particles of fertile material dispersed in a homogeneous system, each of diameter d microns, has been analysed by Keane (1964), leading to essentially the same expressions for the above approximations to the effective resonance integral, but with the scattering cross section σ_M replaced everywhere by:

$$\sigma_p = \frac{\sigma_M}{1 + aN_p d \sigma_M} \quad ,$$

where a is the effective particle constant, which has a value between $3/8$ and $2/3$,

and N_p is the number of fertile nuclides per c.c. of particle and is given by:

$$N_p = \frac{N_{H(\text{abs})}}{\sum_{\substack{\text{all nuclides} \\ \text{in particle}}} \left[\frac{N_{H_i} A_{P_i}}{0.6023 \rho_{P_i}} \right]} \quad ,$$

where N_H, A_p, ρ_p are defined in Section 4.2.1, I(iv).

4.1.3 The Unresolved Resonance Integral

An attempt has been made to give proper treatment to the unresolved resonance region. The statistical distributions of Γ_n^0 and Γ_f as well as the contributions of higher ℓ -states have been incorporated in the narrow resonance formula. It was assumed that any variations in the unresolved resonance integral due to the use of different approximations would have little effect on the overall resonance integral.

♦ The Statistical Distributions of Γ_n^0 and Γ_f

Using the statistical distributions of Γ_n^0 and Γ_f proposed by Porter and Thomas (1956) and following the method of Greebler and Goldman (1962) the unresolved resonance integral (using the N.R. model) for the $\ell = 0$ momentum state is given by:

$$I_U|_{\ell=0} = \frac{(\sigma_M + \sigma_b)}{40 D} \sum_{j=1}^4 \sum_{i=1}^{10} (\bar{\Gamma}_\gamma + \Gamma_{fj}) \int_{E_1}^{E_2} \langle J(\theta, \beta) \rangle_{\ell=0} \frac{dE_r}{E_r} \quad .$$

Details of the mathematical analysis involved in obtaining the above expression for $I_U|_{\ell=0}$ are given in Appendix B.1.

♦ Higher ℓ -States

For the sake of simplicity of analysis, the higher ℓ -state contributions were included in the integral by assuming that the effective resonance integral in the unresolved resonance region including the higher ℓ -states varies by the same factor as the infinitely dilute resonance integral calculated in the statistical region by Doherty (1964b).

Denoting the infinitely dilute resonance integral which includes the higher ℓ -state contribution by $I_{\infty|\ell}$ and the integral for the $\ell=0$ state by $I_{\infty|\ell=0}$, then the modified effective resonance integral in the statistical region is given by:

$$I_U|\ell = I_U|\ell=0 \times \frac{I_{\infty|\ell}}{I_{\infty|\ell=0}}$$

4.2 Operating Instructions

4.2.1 Input Specifications

All data for LUBRA 2 are read from cards but resonance parameters may be read from tape if required. The input deck consists of the following:

- I(i) a title card containing alphameric information up to 71 characters starting in column 2;
- I(ii) a card containing the various options catered for by the code:

ICODE, LIN, LOUT, LTIN, LTOUT, INFO, JFUN, IRR, JAVA and RESNUC in format (I1, 1XA1, 4(1X11), 2(1XA1), 1X11, 1XA6), separated by commas, where the formula option is:

$$ICODE = \begin{cases} 1 & \text{N.R. approximation} \\ 2 & \text{N.R.I.A. approximation} \\ 3 & \text{Goldstein and Cohen } \lambda\text{-method} \\ 4 & \text{Goldstein and Cohen } \mu\text{-method} \\ 5 & \text{Modified } \lambda\text{-method,} \end{cases}$$

$$LIN = \text{input device option for the resolved and unresolved resonance parameters} = \begin{cases} C & \text{for cards} \\ T & \text{for tape,} \end{cases}$$

$$LOUT = \text{output option} = \begin{cases} 1 & \text{for printer} \\ 2 & \text{for punch} \\ 4 & \text{for tape} \end{cases}$$

Again any combination of output units may be used by giving LOUT the appropriate value, for example 3 = 1 + 2 means both printer and punch output.

LIN, LTOUT are the input/output tape units required (left blank if not used),

$$INFO = \begin{cases} 0 & \text{(or blank) for output of total resolved, unresolved, and whole region resonance integrals,} \\ 1 & \text{if detailed information } (\lambda\text{'s, individual resonance integrals, } p\text{'s) is required for each resolved resonance,} \end{cases}$$

N.B. For tape output INFO should always be set to 1,

$$JFUN = \begin{cases} R & \text{(or blank) uses RESJ block (Doherty, 1964 c),} \\ B & \text{uses the routine of Bell, Buckler, and Pull (1963)} \end{cases} \text{ to evaluate the J-function,}$$

$$IRR = \begin{cases} R & \text{for calculation of resolved resonance integral only,} \\ U & \text{for evaluation of unresolved resonance integral only,} \\ B & \text{(or blank) for calculation of total resonance integral over the resolved and statistical regions,} \end{cases}$$

$$\text{JAVA} = \begin{cases} 1 & \text{if average resonance parameters in the statistical region are} \\ & \text{read in from a card or tape,} \\ 0 & \text{(or blank) if they are calculated by the code, or if they are not} \\ & \text{required, and} \end{cases}$$

RESNUC is the nuclide label required to identify the specific set of resonance parameters on tape [Section 7.4.1]. The RESNUC field is left blank for card input of resonance data.

I(iii) a card containing, in format (5I4,3E10.3), the following quantities:

NSIG = the number of absorber nuclide concentrations required to calculate the potential scattering cross sections of the moderator per absorber nuclide, (see I(v)), (maximum = 20),

NRAD = the number of particle sizes (maximum = 20),

NRES = the number of resolved resonance parameter cards (maximum = 300),

NNUC = the total number of nuclides in the system (maximum = 20),

NMOD = the number of moderators (for example Be, O, C) (maximum < 20),

TEMP = temperature in degrees Kelvin,

AP = the effective particle constant, a, following Keane (1964).

I(iv) The next set of NNUC cards in format (1XA2,I3,1P4E12.5) contains all information required for the nuclides in the system.

Each card contains data for one nuclide only and is arranged as follows:

Item 1: NUCL = nuclide identification, that is, 2-letter symbol (for example TH),

Item 2: A = mass number of that particular nuclide,

Item 3: N_H = atomic density ($\times 10^{-24}$) of the nuclide in a homogeneous system,

Item 4: σ_b = corresponding potential scattering cross section,

Item 5: A_p = mass number of nuclide or compound (for example ThO_2) present in particles,

Item 6: ρ_p = corresponding density,

with items 5, 6 omitted if calculations are performed for homogeneous mixtures only.

The N_H field for the last nuclear species (resonance absorber) may be left blank.

I(v) The next card or set of cards in format (7E10.3) contains the NSIG (≤ 20) atomic density values ($\times 10^{-24}$) of the heavy absorber, required for a number of systems in the calculation of the potential scattering cross section of the moderator per absorber nuclide from:

$$\sigma_M = \sum_{i=1}^{\text{NMOD}} \frac{N_{H_i} \sigma_{b_i}}{N_{\text{absorber}}}$$

I(vi) a card (or cards) in format (7E10.3) containing the NRAD (≤ 20) particle sizes (diameters in microns), and may be a blank card for homogeneous calculations.

I(vii) If LIN = C, the set of resonance parameter cards (u , E_r , Γ_n , Γ_γ , Γ_f , g_J , ID, Z, A where ID = 17) in format (F7.3, E11.3, 4E10.2, 5X12, I3, I4), the standard format of the A.A.E.C. Nuclear Data Card Library (Doherty 1964a). This deck must be omitted if the resonance data are already stored in core.

If LIN = T, the resonance parameters must be on the specified input tape preceded by a heading record, containing the identifying nuclide label (see Section 7.4.1).

I(viii) If JAVA = 1 only, the average parameter card or record on tape (u_R , D, $\langle \Gamma_n^0 \rangle$, Γ_γ , $\langle \Gamma_f \rangle$, g_J , ID, Z, A, where ID = 18) in the same format as the resolved parameters.

Paragraphs I(i) to I(viii) describe the complete input for the evaluation of the effective resonance integrals of a single resonance absorber at a particular temperature and formula option for a number of absorber nuclide concentrations and particle sizes.

Exit from LUBRA 2 to the LUBRA.monitor is achieved by an END card (E in column 1). However, the programme may be re-started in one of the following ways:

- (1) A CONTINUE card (C in column 1) will repeat the preceding problem for a different value of ICODE, JFUN or INFO (or all three), and must be followed by a title card and an option card containing ICODE, INFO, JFUN in format (2(I1,1X),A1), separated by commas.
- (2) A card containing TEMP (T in column 1) should be used if the preceding problem requires re-running for the same formula option but different temperature, and must be followed by a title card plus temperature card (temperature in degrees Kelvin in format E10.3).
- (3) A NEXT card (N in column 1) will return control to paragraph I(i) above. This option must be used if a new set of parameters or different mixture of nuclides is required.

4.2.2 Output Specifications

There should be no difficulties in interpreting the output, as the results are clearly labelled for all options. The entire LUBRA 2 output on tape is preceded by the Hollerith record STARTbOFbLUBRA2bOUTPUT and completed with the ENDbLUBRA2bJOBS message with each individual problem terminated by an ENDbOFbFILE record. All tape records are 72 characters long.

4.2.3 Limitations

The dimensions specified in LUBRA 2 limit the number of resonances of any one particular absorber to 300, the number of nuclear species in the system to 20, the number of absorber concentrations (specified by σ_M) to 20 and the number of particle sizes (diameter specified in microns) to 20.

Only one formula option and one temperature may be treated during each run. The appropriate use of a series of CONTINUE and TEMP cards provides a facility whereby all formula options and a range of temperatures may be investigated.

The evaluation of the unresolved resonance integral is very time-consuming owing to the lengthy numerical integration procedure. However, since for most absorbers in well-moderated systems the contribution of the unresolved resonance region to the total resonance integral is less than 10 per cent. of the resolved integral, the routine which evaluates the statistical contribution should be used with discretion to prevent unnecessary waste of computing time.

Although it is possible to derive an analytic expression from which the unresolved resonance integral at $T = 0^\circ\text{K}$ may readily be evaluated, the additional effort was not considered worthwhile in view of the fact that the formula established for non-zero temperatures gives sufficiently accurate results for $T = 0^\circ\text{K}$ calculations.

5. LUBRA 3 (DOPPLER COEFFICIENTS FOR RESONANCE ABSORBERS)

5.1 Theory

The Doppler coefficient for resonance absorption is defined as:

$$D_c = \frac{1}{p} \frac{\partial p}{\partial T}, \quad 5.1$$

where p is the resonance escape probability and T is the temperature in degrees Kelvin. However, we have the relation:

$$p = \exp \left\{ - \frac{I_{\text{eff}}}{\bar{\xi} (\sigma_M + \sigma_b)} \right\}, \quad 5.2$$

where I_{eff} is the effective resonance integral of the absorber nuclide, $\bar{\xi}$ is the average logarithmic energy loss per collision of the mixture, defined in Section 8.

N.B. To include the effect of small particles of fertile material dispersed in the homogeneous system, σ_M is replaced everywhere by

$$\sigma_p = \frac{\sigma_M}{1 + aN_p d \sigma_M} \quad \text{following the method of Keane (1964).}$$

Substituting Equation 5.2 in Equation 5.1, the Doppler coefficient may be expressed in terms of the effective resonance integral:

$$D_c = - \frac{1}{\bar{\xi} (\sigma_M + \sigma_b)} \frac{\partial I_{\text{eff}}}{\partial T}.$$

5.1.1 Resolved Resonance Region

♦ Exact Doppler Coefficient at a Particular Temperature

(a) The Doppler Coefficient at Non Zero Temperatures

Using the general expression for the effective resonance integral, expressed in terms of the J -function, and defined in LUBRA 2:

$$I_{\text{eff}} = \frac{\Gamma_a \sigma_o}{E_r} f(p) \beta \lambda J(\theta, \beta \lambda),$$

and setting $f(p) = 1$ for all models except the modified λ -method which is treated separately below:

$$\begin{aligned} \frac{\partial I_{\text{eff}}}{\partial T} &= \frac{\Gamma_a \sigma_o}{E_r} \beta \lambda \frac{\partial J(\theta, \beta \lambda)}{\partial T}, \\ &= \frac{\Gamma_a \sigma_o}{E_r} \beta \lambda \frac{\partial J(\theta, \beta \lambda)}{\partial \theta} \frac{\partial \theta}{\partial T}, \\ &= \frac{\Gamma_a \sigma_o}{E_r} \beta \lambda \left(\frac{-\theta}{2T} \right) \frac{\partial J(\theta, \beta \lambda)}{\partial \theta}, \quad \left(\text{since } \theta = \frac{\Gamma}{2} \sqrt{\frac{A}{kTE_r}} \right). \end{aligned}$$

Consequently, the Doppler coefficient is:

$$D_c = \frac{1}{\bar{\xi} (\sigma_M + \sigma_b)} \frac{\Gamma_a \sigma_o}{E_r} \frac{\theta}{2T} \beta \lambda \frac{\partial J(\theta, \beta \lambda)}{\partial \theta}.$$

The derivative of the J-function with respect to θ can easily be shown to be:

$$\frac{-4 \beta_\lambda}{\theta^3} \int_0^\infty \frac{\psi'^2}{(\psi + \beta_\lambda)^3} dx, \quad 5.3$$

where $\psi' = \frac{\partial \psi(x, \theta)}{\partial x}$.

However, numerical evaluation of the above integral, though yielding accurate results, is too time-consuming to warrant its use by the code. Instead, a very much faster and equally accurate routine which uses quadratic interpolation between J-function values obtained from the Bell, Buckler, and Pull subroutine (Appendix A.2) calculates:

$$\frac{\partial J(\theta, \beta_\lambda)}{\partial \theta} \text{ for all values of } \theta \text{ and } \beta_\lambda.$$

Hence, the Doppler coefficient may be written:

$$D_c = G \beta_\lambda J'_\lambda, \quad 5.4$$

where $G = \frac{1}{\xi (\sigma_M + \sigma_b)} \frac{\Gamma_a \sigma_o}{E_r} \frac{\theta}{2T}$,

$$J'_\lambda = \frac{\partial J(\theta, \beta_\lambda)}{\partial \theta}$$

Equation 5.4 may now be applied to the various approximations to the effective resonance integral.

(1) N.R. approximation (ICODE = 1):

$$D_c = G \beta_1 J'_1,$$

where $\beta_1 = \frac{\sigma_M + \sigma_b}{\sigma_o}$,

and J'_1 is defined like J'_λ with $\lambda = 1$.

(2) N.R.I.A. approximation (ICODE = 2):

$$D_c = G \beta_o J'_o \quad \text{with } \beta_o = \frac{\Gamma \sigma_M}{\Gamma_a \sigma_o},$$

and J'_o is defined like J'_λ with $\lambda = 0$.

(3) Goldstein and Cohen λ -method (ICODE = 3):

$$D_c = G \beta_\lambda J'_\lambda,$$

where $\beta_\lambda = \frac{\Gamma}{\Gamma_\gamma + \lambda \Gamma_n} \left(\frac{\sigma_M + \lambda \sigma_b}{\sigma_o} \right)$

(4) Goldstein and Cohen μ -method (ICODE = 4):

$$D_c = \frac{G}{1+\mu} [\beta_0 J_0' + \mu \beta_1 J_1'] ,$$

$$\text{where } \mu = \frac{2 \left(1 + \frac{1}{\beta_1}\right) (\sigma_M + \sigma_b) (1 - X_{01})}{\left(1 + \frac{1}{\beta_0}\right)^{\frac{1}{2}} \left\{ \left(1 + \frac{1}{\beta_0}\right)^{\frac{1}{2}} + \left(1 + \frac{1}{\beta_1}\right)^{\frac{1}{2}} \right\} \sigma_M X_{11}} ,$$

and X_{01} , X_{11} are as defined in Section 4.1.1 under "Goldstein and Cohen μ -Method".

(5) Modified λ -method (ICODE = 5):

Since the effective resonance integral is defined as:

$$I_{\text{eff}} = \frac{\Gamma_a \sigma_0}{E_r} f(p) \beta_\lambda J(\theta, \beta_\lambda) ,$$

$$\text{where } f(p) = \frac{2}{1+p} ,$$

the Doppler coefficient evaluated from $D_c = \frac{1}{p} \frac{\partial p}{\partial T}$ is determined from the expression

$$D_c = G f^*(p) \beta_\lambda J_\lambda' ,$$

$$\text{where } \beta_\lambda = \frac{\Gamma}{\Gamma_a + \lambda_a \Gamma_n} \frac{\sigma_p \lambda}{\sigma_0} , \quad \text{as for Section 4.1.1 ,}$$

G , J_λ' are as defined in Equation 5.4 ,

$$\text{and } f^*(p) = \frac{2}{(1+p_0)^2} [1 + p_0 - p_0 \ln p_0] ,$$

where p_0 , the first iteration on the resonance escape probability p , is defined as:

$$p_0 = \exp \left\{ - \frac{1}{\xi (\sigma_M + \sigma_b)} \frac{\Gamma_a \sigma_0}{E_r} \beta_\lambda J(\theta, \beta_\lambda) \right\} .$$

(b) The Doppler Coefficient at Zero Degrees Kelvin

To obtain a definition for the Doppler coefficient at zero temperature, the derivative of the J -function with respect to θ must be expressed in terms of the integral given in Equation 5.3.

$$\text{Hence } D_c = - \frac{f^*(p)}{\xi (\sigma_M + \sigma_b)} \frac{\Gamma_a \sigma_0}{E_r} \frac{2 \beta_\lambda^2}{\theta^2 T} \int_0^\infty \frac{\psi'^2}{(\psi + \beta_\lambda)^3} dx . \quad 5.5$$

Using the asymptotic value of the line shape function,

$$\psi = \frac{1}{1+x^2} , \quad \text{this integral reduces to:}$$

$$\frac{4}{\beta_\lambda^3} \int_0^\infty \frac{x^2}{(1+x^2)(b_\lambda^2+x^2)^3} dx ,$$

where $b_\lambda^2 = \frac{1 + \beta_\lambda}{\beta_\lambda}$.

Thus the Doppler coefficient at $T = 0^\circ\text{K}$ may be written in a form similar to Equation 5.4 as:

$$D_c = G^* \beta_\lambda J'_\lambda ,$$

where $G^* = - \frac{8k}{A} \frac{\Gamma_a}{\Gamma^2} \frac{\sigma_o}{\xi(\sigma_M + \sigma_b)} f^*(p)$,

$$J'_\lambda = \frac{4}{\beta_\lambda^2} \int_0^\infty \frac{x^2}{(1+x^2)(b_\lambda^2+x^2)^3} dx, \text{ which is evaluated analytically to:}$$

$$J'_\lambda = -2\pi\beta_\lambda \left\{ 1 - \frac{1}{b_\lambda} - \frac{1}{2b_\lambda(1+\beta_\lambda)} \left(1 + \frac{3}{4\beta_\lambda} \right) \right\} ,$$

and $f^*(p) = \frac{2}{(1+p_o)^2} [1 + p_o - p_o \ln p_o]$ for the modified λ -method,

= 1 for the other four models.

♦ Average Doppler Coefficient

The Doppler coefficient may also be calculated as an average value over a range of temperatures from:

$$\bar{D}_c = - \frac{1}{\xi(\sigma_M + \sigma_b)} \frac{\Delta I_{\text{eff}}}{\Delta T} \text{ for all models except the modified } \lambda\text{-method,}$$

where ΔI_{eff} is the difference between the effective resonance integrals evaluated at the two end-points of the temperature range ΔT . However, for the modified λ -method it is more convenient to calculate the Doppler coefficient from the definition:

$$\bar{D}_c = \frac{1}{p_{\text{av}}} \frac{\Delta p}{\Delta T} , \text{ where } \Delta p \text{ is the difference between the resonance escape}$$

probabilities at the two end-points of the temperature range ΔT , and p_{av} is the average escape probability between the two temperature limits.

5.1.2 Unresolved Resonance Region

The Doppler coefficient in the unresolved region for the $\ell = 0$ orbital angular momentum state including the effect of the statistical distributions of Γ_n^o and Γ_f and based on the N.R. model is given by:

$$D_c |_{\ell=0} = \frac{1}{80 \xi \text{TD}} \sum_{j=1}^4 \sum_{i=1}^{10} (\bar{\Gamma}_\gamma + \Gamma_{fj}) \int_{E_1}^{E_2} \left\langle \theta \frac{\partial I}{\partial \theta} \right\rangle_{\ell=0} \frac{dE_r}{E_r}$$

The detailed analysis is described in Appendix B.2.

The effect of higher orbital angular momentum states on the Doppler coefficient at a specific temperature has been omitted, since the theory employed in LUBRA 2 need not necessarily be valid for unresolved Doppler coefficients. An estimate of the contributions from $\ell > 0$ states can be obtained from the averaged value of D_c .

5.2 Operating Instructions

5.2.1 Input Specifications

The basic input to LUBRA 3, whether from cards or tape, is identical to that of LUBRA 2 with the exception of the second card which contains one additional option, ITP, and an extra card inserted after I(ii) if the entire input is from cards. The input consists of the following information:

- I(i) a title card containing alphameric information in columns 2 to 72;
- I(ii) a card containing the options ICODE, LIN, LOUT, LTIN, LTOU, INFO, ITP, IRR, JAVA in format (I1, 1XA1, 4(1XI1), 3(1XA1), 1XI1), where:

$$\text{ITP} = \begin{cases} T & \text{for calculation of } D_c \text{ at a temperature } T, \\ R & \text{for calculation of average } D_c \text{ over a temperature range } \Delta T. \end{cases}$$

N.B. ITP may be left blank for card input.

If ITP=R, the input/output units specified by LTIN/LTOU must not be 1, since this option makes use of a scratch tape on unit 1. Moreover, this option always requires tape input.

For card input only [LIN=C(or blank)], the next card describes the input option for the resonance data of the resonance absorber and may be either:

TAPE n,RESNUC if resonance parameters are read off tape,
or CARD if they are supplied on cards,

in format (A1, 3XI1, 1XA6), where n = (tape unit number (0 to 4 on IBM 7040), and RESNUC is the nuclide label which identifies the required resonance parameter file on tape, and must be identical to the label in columns 1 to 6 of the file heading (See Section 7.4.1).

The rest of the card deck is identical to items I(iii) to I(viii) of the LUBRA 2 input specifications (Section 4.2.1).

For tape input, one complete LUBRA 2 output file is required on the tape specified by LTIN for the evaluation of the Doppler coefficient at temperature T, and two complete LUBRA 2 output files (same formula option, different temperatures) for the calculation of the average Doppler coefficient over a range ΔT for each job.

When running a series of LUBRA 3 jobs the order of the LUBRA 3 problems must always correspond to the order of the LUBRA 2 output files on tape to prevent any input errors.

However, if the order of LUBRA 2 output files on the LUBRA 3 input tape is known, files may be skipped (either forward or backward) and the LUBRA 3 jobs run in any order desired without causing data input errors, provided, of course, the SKIP facility is used correctly.

Exit to the monitor is again achieved by an END card (E in column 1). However, the code may be restarted in one of the following ways:

- (1) A CONTINUE card (C in column 1) will repeat the preceding problem for a different formula option ICODE or J-function routine (denoted by JFUN), allowing for a different option INFO and/or input device LIN. Any one or all of ICODE, JFUN, INFO, LIN may be changed from the previous run. The CONTINUE card must be followed by:

- (i) a title card,
- (ii) the option card containing ICODE, INFO, JFUN, LIN, LTIN in format (2(I1, 1X), 2(A1, 1X), I1) separated by commas, where LTIN is the tape unit number and need not be specified if LIN=C or the same input tape is used for successive jobs.

LIN need not be specified if the entire series of jobs (or any two successive problems) obtains the data from a single input device [either cards or tape for the entire run]. However, LIN must be specified for each change in input device.

- (iii) the appropriate input must be the next file (or files) on the specified input tape, if LIN=T.

If the SKIP facility is used in conjunction with the "CONTINUE control return" (see below), the same input tape is used and both the LIN and LTIN fields may be left blank.

- (2) A TEMP card (T in column 1) must be used if:

- (i) the preceding problem is to be recalculated for a different temperature T, or
- (ii) the option ITP is changed from R to T or vice versa, or
- (iii) the input device is changed from cards to tape or vice versa. In each case this card must be followed by:

- (a) a title card, and
- (b) the card containing the required values of ITP, TEMP, LIN, LTIN in format (A1, 1XE10.3, 1XA1, 1XI1), where LTIN need only be specified if a new input tape is introduced and LIN must be specified if the input device for the current problem differs from that of the preceding job, and
- (c) the appropriate LUBRA 2 output file (or files) must be next on the input tape LTIN if required.

If ITP is set to R and the input tape remains the same as for preceding problems, the rest of this card may be left blank, since LIN is automatically set to T and the value of TEMP is provided on the input tape which must contain the appropriate 2 LUBRA 2 outputs as the next 2 files.

If ITP = R, and a new input tape is provided, LIN and LTIN must be specified as required.

If input has been from tape and either:

- (a) ITP is changed from R to T, or
- (b) stays at T but requires a new temperature value, and if the calculation of the Doppler coefficient at the temperature specified by TEMP does not read further input from tape, LIN must be set to C. If then the next problem in the series, still evaluating D_c at a temperature (ITP=T), again needs tape input, the ITP field must be reset to T, but LTIN may be left blank if the same tape is used.

If input is always from cards, D_c can be calculated at a particular temperature only. Hence only the value of TEMP may be changed each time and both the ITP and LIN fields may be left blank.

If the SKIP facility is used with the "TEMP control return", the same input tape is used as for the preceding problem and LIN, LTIN should be left blank.

- (3) A NEXT card (N in column 1) returns control to the very beginning of the programme and a whole new set of data [items I(i) to I(viii)] is necessary to continue execution of LUBRA 3. This return must be used if a new set of resonance parameters is to be read in.

THE REWIND/SKIP facility

The input tape may be rewound at any stage after completion of a problem by using a REWIND card (columns 1 to 6) in place of a NEXT card. Files may be skipped by the use of the skipping option which is indicated by the card SKIP $\pm n$, M (S in column 1), where n (in column 6) is the number of files to be skipped (1 digit only) and M (starting in column 8) is either CONTINUE, TEMP, or NEXT depending on the section of the input to which control is to be returned (equivalent to (1), (2), (3) above respectively). SKIP + n means forward skipping of n files, while SKIP - n is effectively a backward skip and is equivalent to REWIND plus SKIP + (p-n-1) where p is the number of files which had been read up to that statement. This means that the tape will be reset at the beginning of the (n+1)th file preceding the file which is next on tape at the time of using the SKIP option.

5.2.2 Output Specifications

The LUBRA 3 output is very similar in style and format to the LUBRA 2 output, all results being clearly labelled for quick and easy recognition. Again the tape output contains special identifying records. For LUBRA 3 the entire output is preceded by the Hollerith record: STARTbOFbLUBRA3bOUTPUT and terminated by the record ENDbLUBRA3bJOBS, with individual jobs terminated by the ENDbOFbFILE message.

All tape records are 72 characters long.

5.2.3 Limitations

The limitations imposed on dimensioned variables in LUBRA 3 are identical to those in LUBRA 2. Again, only one formula option and one temperature can be handled per run.

The evaluation of the unresolved Doppler coefficient is even more time-consuming than the calculation of the unresolved resonance integral. This is because the numerical integration requires the value of $\partial J / \partial \theta$ at each step, the evaluation being a lengthy procedure involving interpolation between several J-functions. Since the contribution of the statistical region to the total Doppler coefficient is very small indeed compared to the resolved region, it is envisaged that the unresolved Doppler coefficient will not be calculated very often, thereby eliminating unnecessary waste of computing time.

The rare need for $T=0^\circ\text{K}$ calculations does not warrant the effort involved in finding an analytic expression for the unresolved Doppler coefficient at absolute zero temperature. However, since the expression derived in Appendix B.2 for non-zero temperatures cannot be used at $T=0^\circ\text{K}$, the code estimates a suitable value by setting $T=0.1^\circ\text{K}$.

Special care should be taken when using the SKIP $\pm n$, M facility since input errors can easily occur if the tape contents, in particular the order of LUBRA 2 output files, is not known exactly. Appendices E.2 and F.1 illustrate a typical series of dependent LUBRA 2 and 3 jobs, pointing out the various combinations that can possibly arise.

6. LUBRA 4 (EDITING AND CROSS SECTION GROUP AVERAGING CODE)

6.1 Theory

6.1.1 Evaluation of σ_{abs} , $\nu\sigma_{\text{nf}}$, η , (for fissile nuclides only)

LUBRA 4 requires the cross section data obtained from a LUBRA 0 run (or any other source) and a set of ν -values to evaluate:

$$\sigma_{\text{abs}} = \sigma_{\text{n}\gamma} + \sigma_{\text{nf}}$$

$$\nu \sigma_{\text{nf}} \text{ (using an interpolated value of } \nu \text{),}$$

and $\eta = \nu \sigma_{\text{nf}} / \sigma_{\text{abs}}$, for each lethargy point u_j or group k , whose lethargy boundaries are g_k and g_{k+1} ,

where σ_{abs} , σ_{nf} , ν , and η are defined in Section 8.

The ν -values may be given either as point data $\nu(u_j)$ not necessarily at the same lethargy points as the cross sections, or as group values $\bar{\nu}$ for groups either identical to the averaging groups or entirely different, or they may be calculated by the code from the formula given below.

- (a) For point values it is assumed that ν varies linearly with energy between any two successive data points and hence the code can find the ν -values at the cross section points by interpolation from:

$$\nu(E^*_j) = A + B E^*_j$$

$$\text{where } \left. \begin{aligned} A &= \frac{\nu_j E_{j+1} - E_j \nu_{j+1}}{E_{j+1} - E_j} \\ B &= \frac{\nu_{j+1} - \nu_j}{E_{j+1} - E_j} \end{aligned} \right\} E_j < E^*_j < E_{j+1}$$

- (b) The ν -values may be calculated for each cross section point during the group averaging process from the formula:

$$\nu_j = a + b E_j$$

where E_j is in MeV, a and b are constants characteristic of each nuclide and part of the input.

- (c) If the ν -groups are identical to the groups used in the averaging process, then the given $\bar{\nu}_k$ are constant over the corresponding groups (g_k to g_{k+1}).
- (d) If the two sets of group structure are not the same, the $\bar{\nu}$ -values for the groups (g_k to g_{k+1}) are found by interpolating between successive input group values of $\bar{\nu}$.

6.1.2 Fission Interference

In their treatment of fission interference effects Feshbach, Porter, and Weisskopf (1954) considered interference between two adjacent resonances only (one on either side of the resonance being considered) and arrived at a formula for the cross term between resonances i and k of the form:

$$\sigma_{ik} = 8\pi \chi g_j \sqrt{\chi_i \chi_k} \frac{y_{ni} y_{nk} y_{fi} y_{fk} \left[(E_j - E_{oi}) (E_j - E_{ok}) + \frac{\Gamma_i}{2} \frac{\Gamma_k}{2} \right]}{\left\{ (E_j - E_{oi})^2 + \left(\frac{\Gamma_i}{2} \right)^2 \right\} \left\{ (E_j - E_{ok})^2 + \left(\frac{\Gamma_k}{2} \right)^2 \right\}}$$

$$\text{where } y_n = \sqrt{\frac{\Gamma_n}{2}}$$

$$y_f = \sqrt{\frac{\Gamma_f}{2}}$$

$$\chi = \sqrt{\frac{6.52 \times 10^5}{\pi E_j}}$$

$$\chi_i = \sqrt{\frac{6.52 \times 10^5}{\pi E_{oi}}} , \quad \chi_k = \sqrt{\frac{6.52 \times 10^5}{\pi E_{ok}}}$$

E_{oi} , E_{ok} are the resonance energies of resonances i and k respectively.

With $8\pi\chi g_j \sqrt{\chi_i \chi_k}$ now defined by:

$$5.216 \times 10^6 g_j E_j^{-\frac{1}{2}} E_{oi}^{-\frac{1}{4}} E_{ok}^{-\frac{1}{4}} ,$$

the above formula becomes:

$$\sigma_{ik} = 5.216 \times 10^6 g_j \frac{1}{\sqrt{E_j}} (E_{oi} E_{ok})^{-\frac{1}{4}} F ,$$

where $F = \frac{\gamma_{ni} \gamma_{nk} \gamma_{fi} \gamma_{fk} \left[(E_j - E_{oi})(E_j - E_{ok}) + \frac{\Gamma_i}{2} \frac{\Gamma_k}{2} \right]}{\left[(E_j - E_{oi})^2 + \left(\frac{\Gamma_i}{2} \right)^2 \right] \left[(E_j - E_{ok})^2 + \left(\frac{\Gamma_k}{2} \right)^2 \right]}$,

and hence the total fission cross section at energy E_j including the fission interference effect is given by:

$$\sigma_{nf}(E_j) = \sigma_{nf}^*(E_j) + \frac{1}{2} \sum_{\text{all resonances}} \left\{ \sigma_{i,i-1} + \sigma_{i,i+1} \right\} .$$

The factor $\frac{1}{2}$ occurs because $\sigma_{i,i-1} = \sigma_{i-1,i}$.

6.1.3 Group Averaged Cross Sections

Group cross sections may be obtained by averaging point cross sections over any type of point or group flux supplied by the code user or, if so desired, over a calculated flux supplied by the code itself.

◆ Flux Data

(a) Point flux (ϕ_j at point u_j):

The flux between any two adjacent data points is assumed to vary linearly with lethargy, so that the flux at a point u_k , where $u_j < u_k < u_{j+1}$, may be determined from:

$$\phi(u_k) = A u_k + B ,$$

$$\left. \begin{aligned} \text{with } A &= \frac{\phi_{j+1} - \phi_j}{u_{j+1} - u_j} \\ B &= \frac{u_{j+1} \phi_j - \phi_{j+1} u_j}{u_{j+1} - u_j} \end{aligned} \right\} 0 \leq u_j \leq 23 .$$

(b) Group flux [$\bar{\phi}_k$ for group (g_k to g_{k+1})] .

Group flux values may be supplied so that either:

- (i) the flux groups correspond to the averaging groups, in which case the flux $\bar{\phi}_k$ is constant for the group (g_k to g_{k+1}), or
- (ii) the 2 sets of groups do not correspond, so that the averaging process used for (i) must be suitably modified to allow for different group flux values within group (g_k to g_{k+1}).

(c) Calculated flux values.

Flux values may be calculated at the points used in the averaging process from the formula:

$$\phi(E_j) = E_j^{\delta-1}$$

which yields a $1/E$ flux for $\delta = 0$.

♦ Cross Section Data

For point cross section data the cross section is assumed to vary linearly with lethargy between any two adjacent points, so that the cross section at a point u_k is given by:

$$\begin{aligned} \sigma_k &= P u_k + Q \\ \text{where } P &= \frac{\sigma_{i+1} - \sigma_i}{u_{i+1} - u_i} \\ Q &= \frac{u_{i+1} \sigma_i - \sigma_{i+1} u_i}{u_{i+1} - u_i} \end{aligned} \left. \vphantom{\begin{aligned} \sigma_k \\ \text{where } P \\ Q \end{aligned}} \right\} \text{ with } u_i < u_k < u_{i+1}$$

♦ Averaging Process

The group cross section for group (g_k to g_{k+1}) is given by:

$$\bar{\sigma}_k = \frac{\int_{g_k}^{g_{k+1}} \sigma(u) \phi(u) du}{\int_{g_k}^{g_{k+1}} \phi(u) du}$$

where the $\sigma(u)$, $\phi(u)$ at the points of integration are found by the methods described above.

(a) For point fluxes and point cross sections

$$\begin{aligned} \bar{\sigma}_k &= \frac{\sum_{g_k}^{g_{k+1}} \int_{u_j}^{u_{j+1}} (Au+B)(Pu+Q) du}{\sum_{g_k}^{g_{k+1}} \int_{u_j}^{u_{j+1}} (Au+B) du} \\ &= \frac{\sum_{g_k}^{g_{k+1}} \left\{ \frac{AP}{3} (u_j^2 + u_j u_{j+1} + u_{j+1}^2) + \frac{1}{2} (u_j + u_{j+1}) (BP + QA) + BQ \right\}}{\sum_{g_k}^{g_{k+1}} \left\{ \frac{A}{2} (u_{j+1} + u_j) + B \right\}} \end{aligned}$$

where A, B, P, Q are found by interpolation, and the interval u_j to u_{j+1} is the portion of the curve for which both the cross sections and fluxes are linear.

(b) For group fluxes and point cross sections where the groups are in a 1:1 correspondence:

$$\bar{\sigma}_k = \frac{\int_{g_k}^{g_{k+1}} \bar{\phi}_k \sigma(u) du}{\int_{g_k}^{g_{k+1}} \bar{\phi}_k du}$$

$$= \frac{\sum_{g_k}^{g_{k+1}} \left\{ \frac{P}{2} (u_{j+1} + u_j) + Q \right\} (u_{j+1} - u_j)}{(g_{k+1} - g_k)}$$

(c) For group fluxes where the groups (q_h to q_{h+1}) do not correspond to the averaging groups, the above formula has been suitably modified in the code to yield the correct value for the average cross section in group (g_k to g_{k+1}).

(d) For fluxes calculated from $\phi(E) = E^{\delta-1}$ the formula reduces to:

$$\bar{\sigma}_k = \frac{\sum_{g_k}^{g_{k+1}} \left\{ E_i^\delta (Pu_i + Q) - E_{i+1}^\delta (Pu_{i+1} + Q) - \frac{P}{\delta} (E_{i+1}^\delta - E_i^\delta) \right\}}{(E_k^\delta - E_{k+1}^\delta)}$$

where the summation is performed over the input lethargy-cross section points. For a $1/E$ flux, the group cross section $\bar{\sigma}_k$ is given by the expression in (b) above.

6.1.4 'Residual-Resonance Removed' Cross Sections

When averaging the resonance removed cross sections obtained from LUBRA 0, the energy dependence is not predicted correctly because the symmetric part of the resonance wings is subtracted from non-resonance groups and added to the resonance groups. The new theory included in the GYMEA library group cross sections (Pollard and Robinson 1966) gives a more realistic energy dependence of cross sections yielding 'residual-resonance removed' cross sections in the groups containing resonances.

The formula used to calculate the group cross section for group k with lethargy boundaries g_k, g_{k+1} is:

$$\bar{\sigma}(k) = \frac{1}{\Delta u} \int_{g_k}^{g_{k+1}} \sigma(u) du - \frac{\pi}{2\Delta u} \sum_{\substack{\text{all} \\ \text{resonances} \\ \text{in group } k}} \left(\frac{\sigma_o \Gamma}{E_r} \right)_i r_i$$

where $\Delta u = g_{k+1} - g_k$

and r is $\frac{\Gamma_a}{\Gamma}, \frac{\Gamma_\gamma}{\Gamma}, \frac{\Gamma_f}{\Gamma}, 1$, for $\sigma_{abs}, \sigma_{n\gamma}, \sigma_{nf}, \sigma_{tot}$ respectively.

Assuming linearity of cross sections between each pair of input values (σ_j, σ_{j+1}) where the cross sections from LUBRA 0 must be 'asymmetric-included' (formula option 11, Section 2.1.1), the formula is reduced to :

$$\bar{\sigma}(k) = \frac{1}{\Delta u} \sum_{\text{all } j} \left\{ (u_{j+1} - u_j) \left[\frac{P}{2} (u_{j+1} + u_j) + Q \right] \right\} - \frac{\pi}{2\Delta u} \sum_{\substack{\text{all} \\ \text{resonances} \\ \text{in group } k}} \left(\frac{\sigma_o \Gamma}{E_r} r \right)_i$$

In the non-resonance groups, the averaging process remains as described in Section 6.1.3.

6.2 Operating Instructions

6.2.1 Input Specifications

Input of cross sections and flux data may be provided either on cards or tape. If cross section data have been obtained by some means other than LUBRA 0 they must be presented to the code in a format similar to a LUBRA 0 output. Flux data may be given as either point or group values in any format specified by the user but with the restriction that the point flux data are presented as $u, \phi(u)$ per card, and the group flux in a GYMEA type of input (that is, any number of group flux values per card), with a further option allowing input of a MULGA 1 point flux spectrum. All other information is on cards. The deck comprises the following:

- I(i) a title card containing up to 71 alphameric characters starting in column 2, and the nuclide label in columns 19 to 24 right adjusted (for example bbU233 or bTH232) for a GYMEA type output of cross sections only,
- I(ii) an option card containing ICODE, IXSEC, IFLUX, LOUT, ITXS, ITFL, LTOUT, ITO, in format.

(II, 2(IXA1),5(IXI1)) all separated by commas, where

ICODE takes the values 1 to 7 with:

$$\text{ICODE} = \begin{cases} 1 & \text{for calculation of } \sigma_{\text{abs}}, \nu\sigma_{\text{nf}}, \eta, \\ 2 & \text{for group averaging of cross sections } \sigma_{n\gamma}, \sigma_{\text{nf}}, \sigma_{\text{tot}}, \\ 4 & \text{for inclusion of fission interference.} \end{cases}$$

Any combination of these three options (3, 5, 6, 7) may be fed into the code, which will perform the calculations with the following proviso:

For any combination with option 4 (that is, 5, 6, 7) the fission interference term is calculated first and added onto the fission cross section at the appropriate lethargy before any of the other processes are carried out.

For ICODE = 4, there is a further option ITO with the following definition:

- ITO = 1 if the magnitude of the fission interference term only is required, in which case only the lethargy grid need be read into the code and should always have IXSEC = C (or blank).
- and ITO = 0 (more usually blank) if the effect of the fission interference is included in the fission cross section.

N.B. ITO is left blank for all other values of ICODE even if they are combinations of option 4.

For ICODE = 3, 7 a further option JBOA (see paragraph I(vii)) is required to inform the code whether group averaging is to be performed to $\sigma_{n\gamma}, \sigma_{\text{nf}}, \sigma_{\text{tot}}$ before calculating $\bar{\sigma}_{\text{abs}}, \bar{\nu}\bar{\sigma}_{\text{nf}}, \bar{\eta}$, or $\sigma_{\text{abs}}, \nu\sigma_{\text{nf}}, \eta$ are to be calculated first and then all six items group averaged.

IXSEC, IFLUX are the input options for the cross section and flux data respectively and are set to T for tape input and C (or blank) for card input.

LOUT is the output option for all results from LUBRA 4 and takes the values 1 to 7 with:

$$\text{LOUT} = \begin{cases} 1 & \text{- printer} \\ 2 & \text{- punch} \\ 4 & \text{- tape} \end{cases} \quad \text{output .}$$

ITXS, ITFL, LTOUT are the tape unit numbers (0 to 4 for IBM 7040) required for tape input/output (left blank for cards or printer).

I(iii) a card containing RESIDUALbRESONANCEbREMOVAL (R in column 1) if "residual-resonance removed" cross sections are to be calculated, followed by:

I(iv) a card stipulating the two energy limits (E_1 , E_2) denoting the resonance region in which the group averaging of cross sections includes the "residual-resonance removal" (lower energy limit E_1 first, in format 2E10.3),

I(v) a card specifying the input option for the resonance data, and containing either:

TAPE n, RESNUC for tape input

or CARD for card input

in format (A1,3XI1,1XA6), where n is the input tape unit and RESNUC the nuclide label (6 characters) required to identify the specified resonance parameter file on tape (Section 7.4.1), and

I(vi) the deck of cards (terminated by a blank), or tape file, containing the resonance data.

This information must not be included if these resonance parameters are already available in core.

If the "residual-resonance removal" calculation is not required, card I(iii) is a blank card, and I(iv) to I(vi) inclusive are not required.

I(vii) The next set of input contains the cross section data and optional formats used in the input/output routines. The layout of this deck depends entirely on the value of the input option IXSEC.

To simplify the instructions below, the format cards are identified by the following labels:

FMT1	=	format for $\sigma_{n\gamma}$	}	input formats.
FMT2	=	format for σ_{nf}		
FMT3	=	format for σ_{tot}		

FMT4 = format for the flux and must adhere to the following conditions:

- (a) for point fluxes, the code reads u, $\phi(u)$ per card and the format provided by the user must adhere to this requirement;
- (b) for group fluxes, the flux values must be provided in a format similar to the GYMEA flux data [for example: (6E11.3)] with the highest energy group flux first.

N.B. If this format card is blank the code will automatically read point fluxes under format (F7.3, 1PE11.3) and group fluxes under the GYMEA format defined in (b).

If FMT4 contains MULGA 1 in columns 1-6, the code requires a MULGA 1 output (i.e. 242 records) on cards or tape.

FMT5 = output format for the cross sections.

If this card is blank the input formats given for $\sigma_{n\gamma}$, σ_{nf} , and σ_{tot} and three further formats for σ_{abs} , $\nu\sigma_{nf}$, η defined below. are used by the code.

If a GYMEA type of output is required the format card must contain GYMEA in columns 1 to 5.

For any other format specification provided by the user, the code will output the lower and upper group boundaries and the corresponding group averaged cross section for each reaction. (A typical format would be (2F7.3, 1PE11.3)).

FMT6 = format for σ_{abs} ,	}	output formats if FMT5 is blank .
FMT7 = format for $\nu\sigma_{nf}$		
FMT8 = format for η		

Cross section data:

- (a) For tape input, a LUBRA 0 output file is required on the tape unit specified by ITXS. If the cross sections did not result from a LUBRA 0 run, the user must make sure that the tape input is identical to a LUBRA 0 output (Section 2.2.2), otherwise the code will skip to the next problem.

In addition the following format cards are required:

FMT4 is required for ICODE = 2, 3, 6, 7;

FMT5 for all values of ICODE except ICODE = 4, and

FMT6	}	if FMT5 is blank <u>and</u> ICODE = 1, 3, 5, 7.
FMT7		
FMT8		

N.B. For ICODE = 4 and ITO = 1, input is always from cards (see specifications below).

- (b) For card input, the cross section deck consists of the 3 input format cards FMT1, FMT2, FMT3 plus all or some of the other formats according to the requirements set out in (a) above, followed by the cross section deck which, for all ICODE except 4, is as follows:

- (1) A heading card for the total cross section containing a "T" in column 3, followed by the set of cards each containing (u, E, σ_{tot}) in format FMT3 and terminated by a blank card.

If there is no total cross section data to be read in, a single card containing NO TOTAL X-SECTION (N in column 1) must be inserted here instead of the σ_{tot} block.

- (2) A heading card for $\sigma_{n\gamma}$ containing a "C" in column 3 and the temperature T in column 31 → 40, followed by the set of cards (u, E, $\sigma_{n\gamma}$)_j in format FMT1. This is terminated by a blank card only if there is no total cross section data.

- (3) A heading card for σ_{nf} containing an "F" in column 3, followed by the block of cards containing (u, E, σ_{nf})_j in format FMT2.

If there is no fission cross section a "NO FISSION X-SECTION" card (N in column 1) must be inserted here to replace the σ_{nf} block.

For ICODE = 4 and card input there are 2 possible input layouts depending on the value of ITO.

ITO = 0 or blank requires a fission cross section deck (u, E, σ_{nf} per card in format FMT2) complete with a heading card containing an "F" in column 3 and the temperature in columns 31 → 40, and a blank end card.

ITO = 1, requires a card containing u_H , du , u_L in format (3E10.3), where u_H , u_L are the upper and lower lethargy limits of the lethargy grid and du is the lethargy step.

. . . . End of cross section input.

ν -information for ICODE = 1, 3, 5, 7 and fissile nuclides only.

For non-fissile nuclides paragraphs I(viii) to I(x) must be omitted.

I(viii) The next card contains NOUS, IUPOG, IUOE, ANU, BNU in format (I4, 2(IXA1), 1X2E10.3), where:

NOUS = the number of ν -values (either point or group) and is left blank if the ν -values are calculated by the code.

If NOUS = the number of cross section points, it is assumed that the ν -values are given at the same lethargy points as the cross sections.

IUPOG = $\left\{ \begin{array}{l} P \text{ (or blank) for point } \nu\text{-values,} \\ G \text{ for group values, } \bar{\nu}, \text{ where the groups do not coincide with} \\ \text{those used in the averaging process,} \\ X \text{ for group values, } \bar{\nu}, \text{ where the groups are identical to the} \\ \text{averaging groups,} \\ C \text{ for calculation of point } \nu\text{-values from the formula } \nu_j = a + b E_j. \end{array} \right.$

If the ν_j are point values their corresponding lethargies need not necessarily coincide with the lethargy values of the cross sections.

IUOE = $\left\{ \begin{array}{l} U \text{ (or blank) if the } \nu\text{-values are given at lethargy points,} \\ E \text{ if they are given at energy points.} \end{array} \right.$

N.B. (1) Both lethargy and energy grids are given in increasing order of magnitude and the ν -values must be arranged correspondingly. The energy grid values are given in units of MeV.

(2) If IUPOG = C or X, the IUOE field may be left blank.

ANU, BNU are the constants a , b which are required to calculate the ν -values from $\nu_j = a + b E_j$.

If IUPOG \neq C, these 2 fields remain blank.

. . . . This marks the end of the ν -information required for IUPOG = C.

For all other definitions of IUPOG the following additional information must be at hand:

I(ix) a card containing the NOUS values of ν or $\bar{\nu}$ in format (7E10.3), and

I(x) a card containing the NOUS lethargy or energy points corresponding to the NOUS point ν -values, or the (NOUS + 1) lethargy or energy boundaries of the NOUS group values $\bar{\nu}$. [in format (7E10.3)] .

This card is not required if:

(a) NOUS = 1, in which case ν is constant over the whole range,

(b) NOUS = NE, the number of cross section points, for the reason set out above,

- (c) IUPOG = X, which implies that the number of groups and group boundaries of the $\bar{\nu}$ -values are identical to those used in the averaging process.

. . . . End of information on ν .

Group structure (for ICODE = 2, 3, 6, 7 only).

- I(xi) The next set of information is required for group averaging of cross sections and consists of a card containing NG, JUOE, JBOA in format (I4, 2(1XA1)), where:

NG = number of groups to which the point cross sections are to be collapsed,

$$JUOE = \begin{cases} \text{U or blank, if the group boundaries are given in lethargy units} \\ \quad \text{(in increasing order of magnitude),} \\ \text{E if the group boundaries are given in energy units (again in increasing} \\ \quad \text{order of magnitude),} \end{cases}$$

JBOA need not be specified for ICODE = 2 or 6.

For ICODE = 3 and 7:

$$JBOA = \begin{cases} \text{B if group averaging of } \sigma_{n\gamma}, \sigma_{nf}, \sigma_{tot} \text{ is to be performed before} \\ \quad \text{evaluating } \bar{\sigma}_{abs}, \bar{\nu}\sigma_{nf}, \bar{\eta}, \\ \text{A or blank, if group averaging occurs after calculating } \sigma_{abs}, \nu\sigma_{nf}, \text{ and } \eta. \end{cases}$$

- I(xii) is a card containing the (NG + 1) lethargy or energy boundaries [in format (7E10.3)] according to option on JUOE. The energy boundaries must be given in units of MeV.

. . . . End group information.

Flux data for ICODE = 2, 3, 6, 7.

- I(xiii) The actual flux values are preceded by a card containing INOC, KPOG, DELTA, NGF in format (2(A1, 1X), E10.3, 1X14), where:

$$INOC = \begin{cases} \text{C, if flux is to be calculated at cross section lethargy points by} \\ \quad \text{the code,} \\ \text{blank, if the flux is read in from either cards or tape,} \end{cases}$$

$$KPOG = \begin{cases} \text{G, if group flux values are available,} \\ \text{P, if point flux values are available,} \\ \text{X, for group flux data, if flux groups are identical to averaging groups,} \end{cases}$$

$$DELTA = \text{the constant } \delta \text{ required to evaluate } \phi(E_j) = E_j^{\delta-1} \text{ when INOC = C only,} \\ \text{and is left blank otherwise.}$$

This field may also be left blank for $\delta = 0$.

NGF = number of flux groups, and requires specification only if KPOG = G.

- I(xiv) The layout of the flux input depends on the format specified by FMT4 and option KPOG.

If FMT4 = MULGA 1, a complete MULGA 1 output is required either on cards or as the leading file on tape ITFL. (242 records and END OF FILE record).

Point flux data, read under any other format, must have a heading record followed by the set of $u_j, \phi(u_j)$ in format FMT4 and terminated by a card or record containing 99.999 in field 1. Tape input must also have an ENDbOFbFILE record as the very last record of each flux file.

For group flux, the NGF values of the flux are read in under format FMT4. If $KPOG = G$, the code also requires the $(NGF + 1)$ lethargy boundaries (in increasing order of magnitude) corresponding to the flux groups. Again the flux data is preceded by a heading card or record.

. . . . End flux input.

I(xv) For ICODE = 4 only the last input item is the set of multilevel resonance parameter cards in the standard format (F7.3, 1PE11.3, 4E10.2, 5XI2, I3, I4) terminated by a blank card.

N.B. This option must not be used in conjunction with "residual-resonance removal" calculation.

Paragraphs I(i) to I(xv) describe the complete input to LUBRA 4 for a single run and an END card will cause exit to the LUBRA monitor. However, the code may be restarted in one of the following ways:

(1) A CONTINUE card (C in column 1) is required if the preceding problem is to be re-run with at least one of the following:

- (1) new cross section data (either on cards or tape),
- (2) a new flux spectrum (either on cards or tape),
- (3) a new group structure.

This card is followed by a title card and a card in format (3(I1,1X), 2(A1,1X), 2(I1,1X)) containing the options ISX, ISF, ISG which are set equal to 1 if the above conditions are fulfilled, and the input options IXSEC, IFLUX with their corresponding tape units ITXS, ITFL for cross section data and flux input, if new data are required.

If the tape units of 2 consecutive runs are the same, no rewind tapes occurs and the required input is the next file on the particular tape unit.

These 2 cards are followed by the REWIND/SKIP card if required, then the remaining data deck according to the values of ISX, ISF and ISG.

(2) A NEXT card (N in column 1) returns control to the beginning of the programme requiring a whole new set of input [paragraphs I(i) to I(xv)]. This return must be employed if the option ICODE is to be changed.

The REWIND and SKIP facilities

The REWIND and SKIP features are used only for tape input of cross sections and/or flux data and in conjunction with the CONTINUE option. The appropriate control card must be inserted immediately after the card containing ISX, ISF, ISG, IXSEC, IFLUX, ITXS, ITFL, where the IXSEC and/or IFLUX fields contain an "S" to designate that further input is required from the tapes already in use.

Each control card starts in column 1 and all "slashes" (/) and commas may be replaced by blanks.

The REWIND and SKIP facilities in LUBRA 4 differ from those employed in LUBRA 3 because of the possible existence of 2 input tapes (one for cross sections, one for flux data). Any one of the following control cards starting in column 1 may be employed

- (i) REWIND/X to rewind the cross section tape only,
- REWIND/F to rewind the flux tape only,
- REWIND to rewind both tapes at the same time.

- (ii) SKIP $\pm m, X$ to skip $\pm m$ (<10) files on the cross section tape,
- SKIP $\pm n, F$ to skip $\pm n$ (<10) files on the flux input tape,
- SKIP $\pm m$ to skip $\pm m$ files on both input tapes,
- SKIP $\pm m, X/\pm n, F$ } to skip $\pm m$ files on the cross
or SKIP $\pm n, F/\pm m, X$ } section tape and $\pm n$ files on
the flux tape.

SKIP $+m$ means forward skipping of m files from point of call, while SKIP $-m$ is effectively a backward skip and is equivalent to REWIND and SKIP $+(p-m-1)$ where p is the number of files which had been read up to that time. The tape will then be reset at the beginning of the $(n+1)$ th file preceding the point at which the SKIP $-m$ card is used.

The format of the SKIP card is SKIP in columns 1 to 4, $\pm m$ in columns 5 and 6, X or F in column 8.

6.2.2 Output Specifications

The output contains the input cross sections, calculated cross sections and flux data (if available) in any of the optional output formats already described in Section 6.2.1. Since explanatory headings and comments are dispersed throughout the output, the user should have no difficulty in reading the results. A sample output is provided in Appendix G.2.

6.2.3 Limitations

The dimensions specified in LUBRA 4 limit the number of energy points for each cross section to 1000, the number of resonance parameters, used in either the "residual-resonance-removal" or "fission interference" calculation, to 300 each, the number of point ν -values to 1000, the number of groups to 120, and the number of input flux values to 231. The number of calculated flux values following an energy dependence $E^{\delta-1}$ depends on the number of cross section points (which may be any number up to 1000), but these values are never stored, and consequently are not available as output data.

When using option ICODE=4, the maximum number of energy (or lethargy) points at which the fission interference term may be calculated is again 1000.

The options of "residual-resonance removal" and "fission interference" must not be employed simultaneously, since the single-level resonance parameters used in the "residual-resonance removal" and the multilevel parameters required for the calculation of "fission interference" are read into the same storage positions in the computer memory, each set of data overwriting the original contents at the point of input.

7. LUBRA TAPE MONITOR SYSTEM

7.1 Description of Monitor System

A single monitor system tape has been prepared to facilitate the use of the LUBRA codes. The monitor uses the chaining facility of the IBSYS System calling each chain into core as required. A series of LUBRA jobs is controlled by "CALL" cards which completely automate a monitor run, reducing operator intervention to the loading of specified tapes only.

7.2 Specification of Control Cards

7.2.1 Format of Control Cards

The two control cards manipulating the LUBRA monitor system are:

- (1) the "CALL" card which causes the monitor to call a particular LUBRA chain into core and perform its execution, and
- (2) the "CEASE" card which terminates the monitor run and exits to the IBSYS monitor system.

The standard format of the LUBRA call card is

Cols.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	'	C	A	L	L	b	L	U	B	R	A	n	'	*	(any	comment		

The important items for identification by the monitor are:

'CALLb in columns 1 to 6,

n in column 12,

* in column 14, and

(in column 15,

where n takes the values 0 to 4 corresponding to the LUBRA code required, and the symbols * and (are as explained below.

Columns 16 → 69 may contain any useful comment, which is reproduced on the printer before execution starts.

The above format was chosen to distinguish LUBRA call cards from other control cards in use at the A.A.E.C. Research Establishment and for the sake of uniformity throughout a monitor run. However, a card of the form:

Cols.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	b	C	A	L	L	b	b	b	b	b	n	b	*	(
													or	or				
													b	b				

where b stands for a blank. suffices for monitor recognition.

The CEASE card must only be used to terminate a monitor run since the LUBRA complex cannot be restarted without reloading once this card has been encountered. The format of this card must be:

1	2	3	4	5	6	7	8	-----
'	C	E	A	S	E	'		blank

7.2.2 The Meaning of the '*' in Column 14

If LUBRA 0 and 4 are executed consecutively during a monitor run with the input to LUBRA 4 not dependent on the LUBRA 0 output (that is the LUBRA 4 input is on cards or tape using an earlier run of LUBRA 0) then an asterisk (*) must be set in column 14. Since, for most runs, LUBRA 4 depends on LUBRA 0, whether information is stored in the computer memory or recorded on tape, this column usually remains blank.

Similarly, if consecutive runs of LUBRA 2 and 3 are completely independent, an '*' must occur in column 14, and appropriate input to LUBRA 3 must be furnished.

7.2.3 The Meaning of the '(' in Column 15

For a sequence of LUBRA jobs which treat a single absorber only, the set of resonance parameters read in by the first code remains constant throughout the monitor run. In order to prevent loss of time by repeated input of the same data, the monitor stores these parameters in a common area and subsequent input from cards must not contain the resonance parameter deck. For this condition column 15 is left blank.

However, if the resonance parameters required by the next LUBRA chain are different from the preceding ones, column 15 must contain a left bracket '(' and the required resonance data must be supplied for the subsequent input.

7.3 Error Traps

7.3.1 CALL Card Errors

The monitor rejects any LUBRA CALL card not in the form:

bCALLb or 'CALLb (Columns 1 to 6).

Diagnostic messages are printed and the monitor searches for the next CALL card. If this card calls on LUBRA 3 or 4 and does not contain an asterisk in column 14 (that is LUBRA 3 or 4 jobs are dependent on the output from preceding LUBRA 2 or 0 jobs respectively), the monitor bypasses these jobs also, skipping through the data deck until a correct independent CALL card is encountered.

If the LUBRA number, n , is greater than 4, the monitor again skips to the next CALL card, since LUBRA $n > 4$ is not available at the present state of the development of this complex.

7.3.2 Errors in the Input/Output Routines

The LUBRA monitor system uses a modified version of the IBSYS error routine XEM, which prevents exit to the IBSYS monitor and hence termination of the LUBRA monitor run. This modified error routine returns control to the LUBRA monitor on encountering input/output errors, which then prints diagnostic messages and searches for the next set of data.

Input data errors may be due to misinterpretation of the input format for each card or record on tape, or incorrect order of data. Similarly, errors may be detected in the output formats. In both cases the monitor exits from the particular chain in which errors were encountered and searches for the next problem.

In the case of input errors only a NEXT card, introducing an entirely new set of data, completely independent of any previous input, will cause re-entry into that chain. Otherwise the monitor will skip to the END card of this particular set of LUBRA jobs and continue with the next CALL. For output errors any of the continuation features for each LUBRA chain suffices to restart the chain, since all data have been read into the core previously.

If input/output errors occur in any LUBRA 0 or 2 jobs and output is written on tape, a file consisting of 3 records (title, error message, ENDbOFbFILE record) is created on the output tape for each incomplete problem. This precaution prevents input errors into dependent LUBRA 4 or 3 runs by allowing these latter codes to skip over problems in which LUBRA 0 or 2 has encountered input or output errors.

7.4 Tape Requirements

In order to reduce the number of input/output tapes to a minimum, the monitor has been provided with a facility which allows the use of a single output tape for all non-dependent LUBRA chains. Each LUBRA chain file begins with the Hollerith record STARTbOFbLUBRAnbOUTPUT and is terminated by the Hollerith record ENDbLUBRAnbJOBS. Hence the monitor can easily search through the output tape to find the last written record to set the write-head of the tape unit ready for the next LUBRA output, or through the input tape to find the particular LUBRA chain file required as input into the next LUBRA code.

For a monitor run involving dependent LUBRA codes, the minimum number of tapes is 2 (3 if a scratch tape is used on unit 1 for LUBRA 3), with the output from dependent LUBRA codes on separate tapes since the output tape of the one becomes the input tape to the dependent jobs. The output of any additional independent LUBRA chains may be written on either one of these output tapes. In addition LUBRA 4 may require an extra input tape for the flux data.

7.4.1 Resonance Data Tape

Each LUBRA code allows tape input of resonance information. This facility envisages the use of a resonance parameter library tape. Each resonance file on tape must consist of the following:

- (i) a heading record containing the nuclide label identifying the specific resonance data in the first 6 characters (for example *TH232),
- (ii) the set of resonance parameters for the resolved resonance region $[u, E_r, \Gamma_n, \Gamma_\gamma, \Gamma_f, g_J, ID, Z, A]$ in the standard format (F7.3, 1PE11.3, 4E10.2, 5X, I2, I3, I4),
- (iii) a blank record of 72 characters to terminate the resolved data, and
- (iv) the unresolved resonance parameters $[u_R, D, \langle \Gamma_n^0 \rangle, \overline{\Gamma}_\gamma, \langle \Gamma_f \rangle, g_J, ID, Z, A]$, in the standard format given in (ii) above, if required at any stage during the entire monitor run.

The order of the nuclide species on tape is arbitrary; however, the user must provide the exact nuclide label for the resonance absorber required when specifying RESNUC in the input.

7.4.2 Dependent Chains

Two LUBRA chains are classified as dependent if the output of one is part of (or the whole) input to the other. At the present stage LUBRA 0 and 4, and LUBRA 2 and 3, are the only pairs of dependent chains in the LUBRA complex of codes.

♦ The Dependent Pair LUBRA 0-4

For dependent runs of LUBRA 0 and 4 the following two situations are possible:

- (a) If LUBRA 0 is run for a single problem only, the cross sections are stored in the computer's memory and are directly available to LUBRA 4. Hence, neither the LUBRA 0 output tape unit nor the input option, IXSEC, and input unit, ITXS, for LUBRA 4 need be specified. However, the output option for LUBRA 0 must specify tape output (LOUT \geq 4) and LUBRA 4 must be called immediately after LUBRA 0.
- (b) If several problems are run consecutively by LUBRA 0, followed by LUBRA 4 jobs in the same sequence, the LUBRA 0 output tape contains the required cross section data for LUBRA 4 and the monitor automatically sets the LUBRA 4 tape input unit equal to the LUBRA 0 output unit. Hence, the IXSEC, ITXS fields of the option card of the LUBRA 4 input may be left blank.

N.B. It is advisable always to execute dependent runs of LUBRA 0 and 4 consecutively.

♦ The Dependent Pair LUBRA 2-3

For dependent runs of LUBRA 2 and 3 which must always be executed consecutively, the following situations may occur:

- (a) If the results of all LUBRA 2 runs are on a single output tape, the input tape unit for LUBRA 3 is automatically set equal to the LUBRA 2 output unit. Hence LIN, LTIN for LUBRA 3 need not be specified. The sequence of problems run by LUBRA 2 and 3 must be identical.
- (b) If the input to LUBRA 3 is from cards and if the initial data [items I(iii) to I(ix) of LUBRA 3 input] are identical to the LUBRA 2 data then, provided LUBRA 2 treated a single resonance absorber at one temperature only, these data are directly available from core and must not be read in again. In this case cards I(i) and I(ii) only are required as input to LUBRA 3.

7.5 Timing Facility

The LUBRA monitor system incorporates the timing subroutines:

- (i) CLOCK and SCLOCK to determine the time elapsed between entry into and exit from each LUBRA chain. This facility yields a rough estimate of the overall execution time (including input/output) of each LUBRA code.
- (ii) The subroutine INTVAL is included to time each individual problem in a series of jobs for any one particular LUBRA chain. This exact timing of individual jobs is an optional facility, initiated by the use of a TIME card (TIME in columns 1 to 4) immediately following the CALL card for a particular LUBRA chain. This card must be omitted if the timing facility is not required.

8. NOTATION

- E_r energy of a resonance peak
- u lethargy corresponding to the resonance energy E_r
- Γ_n neutron scattering width of that resonance
- Γ_γ neutron radiative capture width of resonance
- Γ_f neutron fission width of resonance
- g_J statistical spin factor of resonance with spin J
- $\Gamma_a = \Gamma_\gamma + \Gamma_f$
- Γ total neutron width = $\Gamma_n + \Gamma_\gamma + \Gamma_f$
- E_R energy of highest resolved resonance
- u_R lethargy of highest resolved resonance
- ℓ orbital angular momentum number of incident neutron
- $\langle \Gamma_n^0 \rangle$ average reduced neutron scattering width in unresolved resonance region
- $\langle \Gamma_f \rangle$ average neutron fission width in unresolved resonance region
- $\bar{\Gamma}_\gamma$ average neutron radiative capture width in unresolved resonance region
- D average level spacing between resonances in statistical region
- A mass number of absorber nucleus
- Z atomic number of absorber nucleus
- k Boltzmann's constant = 8.61×10^{-5}
- T temperature of system in degrees Kelvin
- $\sigma_{n\gamma_j}$ capture cross section at energy E_j
- σ_{nf_j} fission cross section at energy E_j
- σ_{tot_j} total cross section at energy E_j
- σ_{abs_j} absorption cross section at energy $E_j = \sigma_{n\gamma_j} + \sigma_{nf_j}$

- ν average number of neutrons per fission
 $\nu \sigma_{nfj}$ fission rate x fission cross section at energy E_j
 σ_b potential scattering cross section of absorber nuclide
 θ_ℓ^{-2} penetration probability of a neutron with orbital angular momentum ℓ
 d particle diameter in microns

Derived Quantities

$$\theta = \frac{\Gamma}{2} \sqrt{\frac{A}{kTE_r}}$$

$$\begin{aligned} \sigma_M &= \text{potential scattering cross section of moderator per absorber nucleus,} \\ &= \sum_{\text{all moderators}} \frac{N_i \sigma_{b_i}}{N_{\text{abs}}} \end{aligned}$$

- where N_i = atomic density ($\times 10^{-24}$) of the i^{th} moderator in the system,
 σ_{b_i} = the corresponding potential scattering cross section, and
 N_{abs} = atomic density of the resonance absorber.

$$\sigma_o = \text{peak height of resonance at energy } E_r = 2.608 \times 10^6 \frac{g_j \Gamma_n}{\Gamma E_r}$$

$$\begin{aligned} \xi_i &= \text{average logarithmic energy loss per collision with the } i^{\text{th}} \text{ nuclear species in the system,} \\ &= 1 + \frac{\alpha_i}{1 - \alpha_i} \ln \alpha_i \end{aligned}$$

$$\text{where } \alpha_i = \left(\frac{A_i - 1}{A_i + 1} \right)^2$$

A_i = atomic mass number of the i^{th} nuclear species.

$$\begin{aligned} \bar{\xi} &= \text{average energy loss for the system,} \\ &= \frac{\sum_{\text{all nuclides in system}} \left(\frac{\xi_i \sigma_{b_i} N_i}{N_{\text{abs}}} \right)}{\sum_{\text{all nuclides in system}} \left(\frac{N_i \sigma_{b_i}}{N_{\text{abs}}} \right)} \end{aligned}$$

9. ACKNOWLEDGEMENTS

The material content of this report relies heavily on previous work carried out by various members of the Theoretical Physics Section of the A.A.E.C. The author would like to express due thanks for the many valuable discussions with these people. Professor A. Keane's supervision of the project and advice on material content and presentation of the report are greatly appreciated.

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APPENDIX A

A.1 Generation of Line Shape Function $\psi(x, \theta)$ by Means of Subroutine PSICHI

For any given θ and x the subroutine PSICHI will calculate the Doppler-broadened line shape function $\psi(x, \theta)$ which is defined as:

$$\psi(x, \theta) = \frac{\theta}{2\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\frac{1}{4}\theta^2(x-y)^2} \frac{dy}{1+y^2},$$

$$\text{where } \theta = \frac{\Gamma}{2} \sqrt{\frac{A}{kTE_r}}.$$

For $0 \leq |x| \leq 10/\theta$, when $\theta < 7$, the subroutine evaluates $\psi(x, \theta)$ from the differential equation:

$$\psi''(x, \theta) = \frac{\theta^4}{4} - \theta^2 x \psi'(x, \theta) - \frac{\theta^2}{4} [2 + \theta^2(1+x^2)] \psi(x, \theta),$$

and the Taylor's expansions for $\psi'(x + \delta x, \theta)$, $\psi(x + \delta x, \theta)$,

that is,

$$\psi'(x + \delta x, \theta) = \psi'(x, \theta) + \delta x \psi''(x, \theta) + \frac{(\delta x)^2}{2!} \psi'''(x, \theta),$$

$$\psi(x + \delta x, \theta) = \psi(x, \theta) + \delta x \psi'(x, \theta) + \frac{(\delta x)^2}{2!} \psi''(x, \theta) + \frac{(\delta x)^3}{3!} \psi'''(x, \theta),$$

where $\delta x = \frac{0.1}{\theta}$, and $\psi'''(x, \theta)$ is obtained by differentiating the equation for $\psi''(x, \theta)$ given above.

For $\frac{10}{\theta} \leq |x| \leq \frac{11}{\theta}$, $\psi(x, \theta)$ is evaluated from the 3-term asymptotic expansion:

$$\psi(x, \theta) = \frac{1}{1+x^2} \left[1 + \frac{6x^2-2}{\theta^2(1+x^2)^2} + \frac{12(1-10x^2+5x^4)}{\theta^4(1+x^2)^4} \right].$$

For $\frac{11}{\theta} \leq |x| \leq \frac{35}{\theta}$, the 2-term expansion is used, while for $x > \frac{35}{\theta}$, $\psi(x, \theta) = \frac{1}{1+x^2}$

is satisfactory.

For $\theta > 7$, the 3-term asymptotic expansion suffices for the whole range.

For $\theta = \infty$ (that is, $T = 0^\circ\text{K}$), $\psi(x, \theta) = \frac{1}{1+x^2}$ always.

To economize on computing time, the lengthy process of solving the differential equations in the range $0 \leq |x| \leq \frac{10}{\theta}$, for every x sent into the subroutine, is performed only once on first entering PSICHI and the values of ψ , ψ' , ψ'' , ψ''' at each x ($\delta x = \frac{0.1}{\theta}$) are stored in dimensioned variables. The procedure is initiated by using the condition $\psi(0, \theta) = \theta \operatorname{erfc}\left(\frac{\theta}{2}\right)$,

(continued)

APPENDIX A (continued)

where $\operatorname{erfc} x = e^{-x^2} \int_x^\infty e^{-t^2} dt$, and is evaluated by a procedure derived from an

approximation to the error function given by Hastings (1955, p.169). This mesh is assumed fine enough to allow interpolation between adjacent points for any subsequent x entering the subroutine, provided $0 \leq |x| \leq \frac{10}{\theta}$, using Taylor's expansions about these points.

A.2 Evaluation of $J(\theta, \beta)$

The J-function defined as:

$$J(\theta, \beta) = \int_0^\infty \frac{\psi(x, \theta)}{\psi(x, \theta) + \beta} dx,$$

may be evaluated by one of two subroutines:

The slow but accurate subroutine BBPJN is a 7040 version of the routine "JFNCTN" written by Bell, Buckler, and Pull (1963). This subroutine takes between 4.5 and 12 seconds, depending on the values of β and θ , for each value of $J(\theta, \beta)$.

The alternative subroutine RESJ, following Doherty (1964 c), is faster but less accurate. The evaluation of each J-function takes $\sim 1.7 \times 10^{-2}$ seconds, but the range of validity covers all $\theta > 0.05$, $\beta < 335$ only.

APPENDIX B

B.1 The Resonance Integral in the Statistical Region

The unresolved resonance integral for the $\ell = 0$ orbital angular momentum state using the N.R. model is given by:

$$\begin{aligned}
 I_U &= (\sigma_M + \sigma_b) \int_{E_1}^{E_2} \frac{\sigma_a}{\sigma + \sigma_M} \frac{dE}{E} , \\
 &= (\sigma_M + \sigma_b) \sum_{\text{resonances}} \int_{\text{res}} \frac{\sigma_a}{\sigma + \sigma_M} \frac{dE}{E} , \\
 &= (\sigma_M + \sigma_b) \sum_{\text{resonances}} \frac{\bar{\Gamma}_a}{E_r} J(\theta, \beta) , \\
 &= \frac{(\sigma_M + \sigma_b) \bar{\Gamma}_a}{D} \int_{E_1}^{E_2} J(\theta, \beta) \frac{dE}{E} , \\
 &\quad \text{where } \bar{\Gamma}_a = \bar{\Gamma}_\gamma + \langle \Gamma_f \rangle .
 \end{aligned}$$

Allowing for the statistical distributions of Γ_n^0 and Γ_f , assuming $\bar{\Gamma}_\gamma$ and D are constant over the entire unresolved resonance region, the integral may be written as :

$$I_U|_{\ell=0} = \frac{(\sigma_M + \sigma_b) \bar{\Gamma}_a}{D} \int_0^\infty P(\Gamma_n^0) d\Gamma_n^0 \int_0^\infty P(\Gamma_f) d\Gamma_f \int_{E_1}^{E_2} \langle J(\theta, \beta) \rangle_{\ell=0} \frac{dE}{E} .$$

The statistical distributions of Γ_n^0 and Γ_f , as proposed by Porter and Thomas (1956), follow the chi-squared distributions with one and three degrees of freedom respectively:

$$\begin{aligned}
 P_1(\Gamma_n^0) &= \frac{1}{2\sqrt{\pi} \langle \Gamma_n^0 \rangle} \left(\frac{\Gamma_n^0}{2\langle \Gamma_n^0 \rangle} \right)^{-\frac{1}{2}} \exp \left\{ - \left(\frac{\Gamma_n^0}{2\langle \Gamma_n^0 \rangle} \right) \right\} , \\
 \text{and } P_3(\Gamma_f) &= \frac{3}{\sqrt{\pi} \langle \Gamma_f \rangle} \left(\frac{3\Gamma_f}{2\langle \Gamma_f \rangle} \right)^{+\frac{1}{2}} \exp \left\{ - \left(\frac{3\Gamma_f}{2\langle \Gamma_f \rangle} \right) \right\} ,
 \end{aligned}$$

where $\langle \Gamma_n^0 \rangle$ is the average reduced neutron width for $\ell = 0$ state,

and $\langle \Gamma_f \rangle$ is the average fission width for $\ell = 0$ state.

Following the method of Grebler and Goldman (1962), the area under the P_1 versus Γ_n^0 curve, and the area under the P_3 versus Γ_f curve, were partitioned into ten and four equal parts respectively. Ten values of Γ_n^0 used to represent the Γ_n^0 -distribution and four values of Γ_f for the Γ_f -distribution are then obtained from the relations:

$$\begin{aligned}
 \Gamma_{ni}^0 &= \langle \Gamma_n^0 \rangle X_i , & 1 \leq i \leq 10 , \\
 \text{and } \Gamma_{fj} &= \langle \Gamma_f \rangle Y_j , & 1 \leq j \leq 4 ,
 \end{aligned}$$

(continued)

APPENDIX B (continued)

$$\text{where } X_i = \frac{\int_{Z_{i-1}}^{Z_i} \Gamma_n^0 P_1(\Gamma_n^0) d\Gamma_n^0}{\int_{Z_{i-1}}^{Z_i} P_1(\Gamma_n^0) d\Gamma_n^0}$$

the Z_i values being chosen to make the denominator equal to $\frac{1}{10}$;

$$\text{and } Y_j = \frac{\int_{W_{j-1}}^{W_j} \Gamma_f P_3(\Gamma_f) d\Gamma_f}{\int_{W_{j-1}}^{W_j} P_3(\Gamma_f) d\Gamma_f}$$

the W_j values being obtained by setting the denominator equal to $\frac{1}{4}$.

The unresolved resonance integral for the $\ell=0$ momentum state may then be evaluated from:

$$I_U|_{\ell=0} = \frac{\sigma_M + \sigma_b}{40D} \sum_{j=1}^4 \sum_{i=1}^{10} (\bar{\Gamma}_\gamma + \Gamma_{fj}) \int_{E_1}^{E_2} \langle J(\theta, \beta) \rangle_{\ell=0} \frac{dE_r}{E_r}$$

The integral $\int_{E_1}^{E_2} \langle J(\theta, \beta) \rangle_{\ell=0} \frac{dE_r}{E_r}$ is evaluated numerically by the computer between

the energy limits $E_1 = E_R + \frac{D}{2}$ and $E_2 = 10 \text{ MeV}$, where $E_R =$ highest resolved resonance energy.

B.2 The Doppler Coefficient in the Statistical Region

The Doppler coefficient in the unresolved resonance region for the $\ell=0$ orbital angular momentum state based on the N.R. model for the effective resonance integral is given by:

$$\begin{aligned} D_c|_{\ell=0} &= - \frac{1}{\xi(\sigma_M + \sigma_b)} \frac{\partial I_U|_{\ell=0}}{\partial T} , \\ &= - \frac{1}{\xi(\sigma_M + \sigma_b)} \frac{\partial}{\partial T} \left\{ \frac{\sigma_M + \sigma_b}{40D} \sum_{j=1}^4 \sum_{i=1}^{10} \bar{\Gamma}_a \int_{E_1}^{E_2} \langle J(\theta, \beta) \rangle_{\ell=0} \frac{dE_r}{E_r} \right\} \end{aligned}$$

$$\text{Now } \frac{\partial I_U|_{\ell=0}}{\partial T} = \frac{\sigma_M + \sigma_b}{40D} \sum_{j=1}^4 \sum_{i=1}^{10} (\bar{\Gamma}_\gamma + \Gamma_{fj}) \int_{E_1}^{E_2} \left\langle \frac{\partial J}{\partial \theta} \cdot \frac{\partial \theta}{\partial T} \right\rangle_{\ell=0} \frac{dE_r}{E_r}$$

$$\text{and } \frac{\partial J}{\partial \theta} \cdot \frac{\partial \theta}{\partial T} = - \frac{\theta}{2T} \frac{\partial J}{\partial \theta}$$

$$\text{Hence } D_c|_{\ell=0} = \frac{1}{80 \xi DT} \sum_{j=1}^4 \sum_{i=1}^{10} (\bar{\Gamma}_\gamma + \Gamma_{fj}) \int_{E_1}^{E_2} \left\langle \theta \frac{\partial J}{\partial \theta} \right\rangle_{\ell=0} \frac{dE_r}{E_r}$$

(continued)

APPENDIX B (continued)

The integral $\int_{E_1}^{E_2} \left\langle \theta \frac{\partial J}{\partial \theta} \right\rangle_{\ell=0} \frac{dE_r}{E_r}$ is evaluated numerically (for $T > 0^\circ\text{K}$ only) between the energy limits $E_1 = E_R + \frac{D}{2}$ and $E_2 = 10 \text{ MeV}$, where $E_R =$ highest resolved resonance energy.

APPENDIX C

C.1 SAMPLE INPUT TO LUBRAO

THE SAMPLE INPUT TO LUBRAO ILLUSTRATED BELOW CONSISTS OF THE FOLLOWING 3 PROBLEMS-

- 1) CALCULATION OF ASYMMETRIC RESONANCE-INCLUDED POINT CROSS SECTIONS FOR U233 AT 300 DEGREES KELVIN FOR THE LETHARGY RANGE 12.0 TO 23.0 IN STEPS OF 0.05, USING A SINGLE FORMULA OPTION FOR THE WHOLE RANGE WITH DOPPLER BROADENING OF ALL RESONANCES,
- 2) CALCULATION OF SYMMETRIC POINT CROSS SECTIONS FOR U233 FOR THE SAME TEMPERATURE AND ENERGY RANGE AS ABOVE THIS ILLUSTRATES THE USE OF THE 'CONTINUE' CARD,
- 3) CALCULATION OF ASYMMETRIC CROSS SECTIONS FOR THE 1.054EV RESONANCE OF PU240 AT 300.DEG.K TRACING THE CONTOUR OF THE RESONANCE BETWEEN ER-10*GAMMA/2 AND ER+10*GAMMA/2 THIS ILLUSTRATES THE USE OF THE 'NEXT' RETURN.

ALL INPUT IS READ FROM CARDS, ALL OUTPUT IS OBTAINED ON THE PRINTER, PUNCH AND TAPE, AND THE OPTIONAL TIMING FACILITY IS USED.

END OF COMMENTS

BEGINNING OF INPUT

```
*CALL LUBRAO*
TIME
ASYMMETRIC POINT CROSS-SECTIONS FOR U233 AT T=300.DEG.K
CARD INPUT OF RESONANCE PARAMETERS
18.421 0.100E+00 1.63E-05 1.04E-01 9.46E-01 0.500E+00 17 92 233RRP U233
15.642 1.610E+00 2.55E-04 5.80E-02 7.03E-01 0.500E+00 17 92 233RRP U233
15.558 1.750E+00 2.45E-04 1.20E-02 2.31E-01 0.500E+00 17 92 233RRP U233
15.400 2.050E+00 3.08E-05 1.00E-06 3.00E-01 1.000E+00 17 92 233RRP U233
15.282 2.307E+00 1.43E-04 4.10E-02 5.00E-02 0.500E+00 17 92 233RRP U233
14.826 3.640E+00 1.87E-04 5.40E-02 2.06E-01 0.500E+00 17 92 233RRP U233
14.549 4.800E+00 3.31E-04 8.60E-02 6.98E-01 0.500E+00 17 92 233RRP U233
14.352 5.850E+00 1.20E-04 5.00E-02 3.20E-01 0.500E+00 17 92 233RRP U233
14.286 6.250E+00 0.68E-04 1.00E-06 3.50E-01 1.000E+00 17 92 233RRP U233
14.200 6.810E+00 7.47E-04 5.00E-02 0.98E-01 0.500E+00 17 92 233RRP U233
14.094 7.570E+00 3.50E-05 4.50E-02 9.00E-02 0.500E+00 17 92 233RRP U233
13.946 8.780E+00 1.99E-04 4.50E-02 7.00E-01 0.500E+00 17 92 233RRP U233
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13.888 9.300E+00 1.23E+04 4.50E-02 1.95E-01 0.500E+00 17 92 233RRP U233
13.783 1.033E+01 1.74E+03 5.80E-02 2.70E-01 0.500E+00 17 92 233RRP U233
13.677 1.148E+01 1.02E+04 4.50E-02 1.75E-01 5.83E-01 17 92 233RRP U233
13.562 1.288E+01 1.23E+03 4.50E-02 2.50E-01 5.83E-01 17 92 233RRP U233
13.487 1.389E+01 3.99E+04 4.50E-02 3.00E-01 5.83E-01 17 92 233RRP U233
13.380 1.546E+01 8.93E+04 4.50E-02 1.90E-01 5.83E-01 17 92 233RRP U233
13.326 1.632E+01 8.69E+04 4.50E-02 4.50E-01 5.83E-01 17 92 233RRP U233
13.304 1.667E+01 4.41E+04 4.50E-02 1.40E-01 5.83E-01 17 92 233RRP U233
13.222 1.810E+01 2.77E+04 4.50E-02 1.50E-01 5.83E-01 17 92 233RRP U233
13.195 1.860E+01 1.63E+04 4.50E-02 1.15E-01 5.83E-01 17 92 233RRP U233
13.169 1.909E+01 1.67E+04 4.50E-02 2.40E-01 5.83E-01 17 92 233RRP U233
13.085 2.076E+01 1.04E+04 4.50E-02 4.70E-01 5.83E-01 17 92 233RRP U233
13.027 2.200E+01 1.01E+04 4.50E-02 2.05E-01 5.83E-01 17 92 233RRP U233
13.005 2.250E+01 2.77E+04 4.50E-02 3.90E-01 5.83E-01 17 92 233RRP U233
12.944 2.390E+01 1.64E+03 4.50E-02 9.00E-01 4.16E-01 17 92 233RRP U233
12.880 2.548E+01 9.95E+04 4.50E-02 2.90E-01 5.83E-01 17 92 233RRP U233
C,7, ,2,2, ,1, 10.5
300.
11,
23, 0.05 12.
(F7.3,IP2E11.3,35X16H8 92 233NG U 233)
(F7.3,IP2E11.3,35X16H7 92 233NF U 233)
(F7.3,IP2E11.3,35X16H1 92 233NTOU 233)
CONTINUE
SYMMETRIC CROSS SECTIONS FOR U233 AT T=300 DEG.K
SAME OPTIONS FOR INPUT/OUTPUT, ENERGY GRID
300.
21,
SAME FORMATS AS FOR PREVIOUS PROBLEM
NEXT.
PU243 ASYMMETRIC X-SECTIONS ALONG CONTOUR OF 1 EV RES. AT T=300.
CARD
16.066 1.054E+00 2.36E-03 3.40E-02 0.0 1.00E+00 17 94 240RRPPU240
C,3, , ,3, ,1, 10.0
300.
11,
10, 1,
CARD 33
CARD 34
CARD 35
CARD 36
CARD 37
CARD 38
CARD 39
CARD 40
CARD 41
CARD 42
CARD 43
CARD 44
CARD 45
CARD 46
CARD 47
CARD 48
CARD 49
CARD 51
CARD 52
CARD 53
CARD 54
CARD 55

```

(F7.3.1P2E11.3.35X16H8 92 240NG PU240)
(F7.3.1P2E11.3.35X16H8 92 240NTOPU240)
END
↑CEASE↑

CARD 56
CARD 57
CARD 58
CARD 59

APPENDIX C (continued)

C.2 SAMPLE OUTPUT FROM LUBRAO

MONITOR HAS ENTERED LUBRAO

LUBRAO OUTPUT STARTS AT BEGINNING OF TAPE

ASYMMETRIC POINT CROSS-SECTIONS FOR U233 AT T=300.DEG.K

RESOLVED SINGLE-LEVEL RESONANCE PARAMETERS --

18.421	1.000E+01	1.63E+05	1.04E-01	9.46E-01	5.00E-01	92	233
15.642	1.610E+00	2.55E+04	5.80E-02	7.03E-01	5.00E-01	92	233
15.558	1.750E+00	2.45E+04	1.20E-02	2.31E-01	5.00E-01	92	233
15.400	2.050E+00	3.08E+05	1.00E-06	3.00E-01	1.00E+00	92	233
15.282	2.307E+00	1.43E+04	4.10E-02	5.00E-02	5.00E-01	92	233
14.826	3.640E+00	1.87E+04	5.40E-02	2.06E-01	5.00E-01	92	233
14.549	4.800E+00	3.31E+04	8.60E-02	6.98E-01	5.00E-01	92	233
14.352	5.850E+00	1.20E+04	5.00E-02	3.20E-01	5.00E-01	92	233
14.286	6.250E+00	6.80E+05	1.00E-06	3.50E-01	1.00E+00	92	233
14.200	6.810E+00	7.47E+04	5.00E-02	9.80E-02	5.00E-01	92	233
14.094	7.570E+00	3.50E+05	4.50E-02	9.00E-02	5.00E-01	92	233
13.946	8.780E+00	1.99E+04	4.50E-02	7.00E-01	5.00E-01	92	233
13.888	9.300E+00	1.23E+04	4.50E-02	1.95E-01	5.00E-01	92	233
13.783	1.033E+01	1.74E+03	5.80E-02	2.70E-01	5.00E-01	92	233
13.677	1.148E+01	1.02E+04	4.50E-02	1.75E-01	5.83E-01	92	233
13.562	1.288E+01	1.23E+03	4.50E-02	2.50E-01	5.83E-01	92	233
13.487	1.389E+01	3.99E+04	4.50E-02	3.00E-01	5.83E-01	92	233
13.380	1.546E+01	8.93E+04	4.50E-02	1.90E-01	5.83E-01	92	233
13.326	1.632E+01	8.69E+04	4.50E-02	4.50E-01	5.83E-01	92	233
13.304	1.667E+01	4.41E+04	4.50E-02	1.40E-01	5.83E-01	92	233
13.222	1.810E+01	2.77E+04	4.50E-02	1.50E-01	5.83E-01	92	233
13.195	1.860E+01	1.63E+04	4.50E-02	1.15E-01	5.83E-01	92	233
13.169	1.909E+01	1.67E+04	4.50E-02	2.40E-01	5.83E-01	92	233
13.085	2.076E+01	1.04E+04	4.50E-02	4.70E-01	5.83E-01	92	233
13.027	2.200E+01	1.01E+04	4.50E-02	2.05E-01	5.83E-01	92	233
13.005	2.250E+01	2.77E+04	4.50E-02	3.90E-01	5.83E-01	92	233
12.944	2.390E+01	1.64E+03	4.50E-02	9.00E-01	4.16E-01	92	233
12.880	2.548E+01	9.95E+04	4.50E-02	2.90E-01	5.83E-01	92	233

TOTAL CROSS-SECTIONS AT T = 3.000E+02

12.000	6.144E+05	1.074E+01	1 92	233NTOU	233
12.050	5.845E+05	1.075E+01	1 92	233NTOU	233
12.100	5.560E+05	1.078E+01	1 92	233NTOU	233
12.150	5.289E+05	1.080E+01	1 92	233NTOU	233
12.200	5.031E+05	1.083E+01	1 92	233NTOU	233
12.250	4.785E+05	1.087E+01	1 92	233NTOU	233
12.300	4.552E+05	1.091E+01	1 92	233NTOU	233
12.350	4.330E+05	1.095E+01	1 92	233NTOU	233
12.400	4.119E+05	1.100E+01	1 92	233NTOU	233
12.450	3.918E+05	1.107E+01	1 92	233NTOU	233
12.500	3.727E+05	1.115E+01	1 92	233NTOU	233
12.550	3.545E+05	1.126E+01	1 92	233NTOU	233
12.600	3.372E+05	1.141E+01	1 92	233NTOU	233
12.650	3.208E+05	1.162E+01	1 92	233NTOU	233
12.700	3.051E+05	1.196E+01	1 92	233NTOU	233
12.750	2.902E+05	1.259E+01	1 92	233NTOU	233
12.800	2.761E+05	1.416E+01	1 92	233NTOU	233
12.850	2.626E+05	2.350E+01	1 92	233NTOU	233
12.900	2.498E+05	4.320E+01	1 92	233NTOU	233
12.950	2.376E+05	8.613E+01	1 92	233NTOU	233
13.000	2.260E+05	5.739E+01	1 92	233NTOU	233

E.T.C.

22.500	1.692E+09	2.221E+03	1 92	233NTOU	233
22.550	1.609E+09	2.277E+03	1 92	233NTOU	233
22.600	1.531E+09	2.334E+03	1 92	233NTOU	233
22.650	1.456E+09	2.393E+03	1 92	233NTOU	233
22.700	1.385E+09	2.453E+03	1 92	233NTOU	233
22.750	1.318E+09	2.515E+03	1 92	233NTOU	233
22.800	1.253E+09	2.578E+03	1 92	233NTOU	233
22.850	1.192E+09	2.643E+03	1 92	233NTOU	233
22.900	1.134E+09	2.709E+03	1 92	233NTOU	233
22.950	1.079E+09	2.778E+03	1 92	233NTOU	233
23.000	1.026E+09	2.848E+03	1 92	233NTOU	233

CAPTURE CROSS-SECTIONS AT T= 3.000E+02

12.000	6.144E-05	3.312E-03	8 92	233NG	U	233
12.050	5.845E-05	3.888E-03	8 92	233NG	U	233
12.100	5.560E-05	4.579E-03	8 92	233NG	U	233
12.150	5.289E-05	5.414E-03	8 92	233NG	U	233
12.200	5.031E-05	6.429E-03	8 92	233NG	U	233
12.250	4.785E-05	7.763E-03	8 92	233NG	U	233
12.300	4.552E-05	9.319E-03	8 92	233NG	U	233
12.350	4.330E-05	1.127E-02	8 92	233NG	U	233
12.400	4.119E-05	1.376E-02	8 92	233NG	U	233
12.450	3.918E-05	1.699E-02	8 92	233NG	U	233
12.500	3.727E-05	2.130E-02	8 92	233NG	U	233
12.550	3.545E-05	2.724E-02	8 92	233NG	U	233
12.600	3.372E-05	3.581E-02	8 92	233NG	U	233
12.650	3.208E-05	4.904E-02	8 92	233NG	U	233
12.700	3.051E-05	7.166E-02	8 92	233NG	U	233
12.750	2.902E-05	1.176E-01	8 92	233NG	U	233
12.800	2.761E-05	2.480E-01	8 92	233NG	U	233
12.850	2.626E-05	1.264E+00	8 92	233NG	U	233
12.900	2.498E-05	3.280E+00	8 92	233NG	U	233
12.950	2.376E-05	3.889E+00	8 92	233NG	U	233
13.000	2.260E-05	4.404E+00	8 92	233NG	U	233

E.T.C.

22.500	1.692E-09	2.104E+02	8 92	233NG	U	233
22.550	1.609E-09	2.157E+02	8 92	233NG	U	233
22.600	1.531E-09	2.211E+02	8 92	233NG	U	233
22.650	1.456E-09	2.267E+02	8 92	233NG	U	233
22.700	1.385E-09	2.324E+02	8 92	233NG	U	233
22.750	1.318E-09	2.383E+02	8 92	233NG	U	233
22.800	1.253E-09	2.443E+02	8 92	233NG	U	233
22.850	1.192E-09	2.505E+02	8 92	233NG	U	233
22.900	1.134E-09	2.568E+02	8 92	233NG	U	233
22.950	1.079E-09	2.633E+02	8 92	233NG	U	233
23.000	1.026E-09	2.700E+02	8 92	233NG	U	233

FISSION CROSS-SECTIONS AT T= 3.000E+02

12.000	6.144E-05	2.604E-02	7 92	233NF	U	233
12.050	5.845E-05	3.073E-02	7 92	233NF	U	233
12.100	5.560E-05	3.641E-02	7 92	233NF	U	233
12.150	5.289E-05	4.333E-02	7 92	233NF	U	233
12.200	5.031E-05	5.186E-02	7 92	233NF	U	233
12.250	4.785E-05	6.256E-02	7 92	233NF	U	233
12.300	4.552E-05	7.590E-02	7 92	233NF	U	233
12.350	4.330E-05	9.292E-02	7 92	233NF	U	233
12.400	4.119E-05	1.150E-01	7 92	233NF	U	233
12.450	3.918E-05	1.443E-01	7 92	233NF	U	233
12.500	3.727E-05	1.843E-01	7 92	233NF	U	233
12.550	3.545E-05	2.407E-01	7 92	233NF	U	233
12.600	3.372E-05	3.241E-01	7 92	233NF	U	233
12.650	3.208E-05	4.555E-01	7 92	233NF	U	233
12.700	3.051E-05	6.828E-01	7 92	233NF	U	233
12.750	2.902E-05	1.138E+00	7 92	233NF	U	233
12.800	2.761E-05	2.346E+00	7 92	233NF	U	233
12.850	2.626E-05	1.001E+01	7 92	233NF	U	233
12.900	2.498E-05	2.920E+01	7 92	233NF	U	233
12.950	2.376E-05	7.146E+01	7 92	233NF	U	233
13.000	2.260E-05	4.193E+01	7 92	233NF	U	233

E.T.C.

22.550	1.609E-09	2.052E+03	7 92	233NF	U	233
22.600	1.531E-09	2.103E+03	7 92	233NF	U	233
22.650	1.456E-09	2.156E+03	7 92	233NF	U	233
22.700	1.385E-09	2.211E+03	7 92	233NF	U	233
22.750	1.318E-09	2.267E+03	7 92	233NF	U	233
22.800	1.253E-09	2.324E+03	7 92	233NF	U	233
22.850	1.192E-09	2.383E+03	7 92	233NF	U	233
22.900	1.134E-09	2.443E+03	7 92	233NF	U	233
22.950	1.079E-09	2.505E+03	7 92	233NF	U	233
23.000	1.026E-09	2.568E+03	7 92	233NF	U	233

EXECUTION TIME OF PROBLEM 1 IS 7 MINUTES, 5.00 SECS.

SYMMETRIC CROSS SECTIONS FOR U233 AT T=300 DEG.K

CAPTURE CROSS-SECTIONS AT T= 3.000E+02

12.000	6.144E-05	1.255E-02	8 92	233NG	U 233
12.050	5.845E-05	1.435E-02	8 92	233NG	U 233
12.100	5.560E-05	1.645E-02	8 92	233NG	U 233
12.150	5.289E-05	1.893E-02	8 92	233NG	U 233
12.200	5.031E-05	2.187E-02	8 92	233NG	U 233
12.250	4.785E-05	2.586E-02	8 92	233NG	U 233
12.300	4.552E-05	3.015E-02	8 92	233NG	U 233
12.350	4.330E-05	3.537E-02	8 92	233NG	U 233
12.400	4.119E-05	4.185E-02	8 92	233NG	U 233
12.450	3.918E-05	5.002E-02	8 92	233NG	U 233
12.500	3.727E-05	6.058E-02	8 92	233NG	U 233
12.550	3.545E-05	7.471E-02	8 92	233NG	U 233
12.600	3.372E-05	9.448E-02	8 92	233NG	U 233
12.650	3.208E-05	1.241E-01	8 92	233NG	U 233
12.700	3.051E-05	1.732E-01	8 92	233NG	U 233
12.750	2.902E-05	2.700E-01	8 92	233NG	U 233
12.800	2.761E-05	5.383E-01	8 92	233NG	U 233
12.850	2.626E-05	2.588E+00	8 92	233NG	U 233
12.900	2.498E-05	6.590E+00	8 92	233NG	U 233
12.950	2.376E-05	7.811E+00	8 92	233NG	U 233
13.000	2.260E-05	8.854E+00	8 92	233NG	U 233

E.T.C.

22.600	1.531E-09	2.422E+02	8 92	233NG	U 233
22.650	1.456E-09	2.478E+02	8 92	233NG	U 233
22.700	1.385E-09	2.535E+02	8 92	233NG	U 233
22.750	1.318E-09	2.594E+02	8 92	233NG	U 233
22.800	1.253E-09	2.654E+02	8 92	233NG	U 233
22.850	1.192E-09	2.716E+02	8 92	233NG	U 233
22.900	1.134E-09	2.779E+02	8 92	233NG	U 233
22.950	1.079E-09	2.844E+02	8 92	233NG	U 233
23.000	1.026E-09	2.910E+02	8 92	233NG	U 233

FISSION CROSS-SECTIONS AT T= 3.000E+02

12.000	6.144E-05	1.008E-01	7 92	233NF	U	233
12.050	5.845E-05	1.155E-01	7 92	233NF	U	233
12.100	5.560E-05	1.328E-01	7 92	233NF	U	233
12.150	5.289E-05	1.533E-01	7 92	233NF	U	233
12.200	5.031E-05	1.778E-01	7 92	233NF	U	233
12.250	4.785E-05	2.080E-01	7 92	233NF	U	233
12.300	4.552E-05	2.442E-01	7 92	233NF	U	233
12.350	4.330E-05	2.890E-01	7 92	233NF	U	233
12.400	4.119E-05	3.454E-01	7 92	233NF	U	233
12.450	3.918E-05	4.179E-01	7 92	233NF	U	233
12.500	3.727E-05	5.139E-01	7 92	233NF	U	233
12.550	3.545E-05	6.454E-01	7 92	233NF	U	233
12.600	3.372E-05	8.343E-01	7 92	233NF	U	233
12.650	3.208E-05	1.124E+00	7 92	233NF	U	233
12.700	3.051E-05	1.612E+00	7 92	233NF	U	233
12.750	2.902E-05	2.568E+00	7 92	233NF	U	233
12.800	2.761E-05	5.051E+00	7 92	233NF	U	233
12.850	2.626E-05	2.053E+01	7 92	233NF	U	233
12.900	2.498E-05	5.882E+01	7 92	233NF	U	233
12.950	2.376E-05	1.430E+02	7 92	233NF	U	233
13.000	2.260E-05	8.403E+01	7 92	233NF	U	233

E.T.C.

22.550	1.609E-09	2.247E+03	7 92	233NF	U	233
22.600	1.531E-09	2.299E+03	7 92	233NF	U	233
22.650	1.456E-09	2.352E+03	7 92	233NF	U	233
22.700	1.385E-09	2.406E+03	7 92	233NF	U	233
22.750	1.318E-09	2.462E+03	7 92	233NF	U	233
22.800	1.253E-09	2.519E+03	7 92	233NF	U	233
22.850	1.192E-09	2.578E+03	7 92	233NF	U	233
22.900	1.134E-09	2.638E+03	7 92	233NF	U	233
22.950	1.079E-09	2.700E+03	7 92	233NF	U	233
23.000	1.026E-09	2.763E+03	7 92	233NF	U	233

EXECUTION TIME OF PROBLEM 2 IS 3 MINUTES, 38.00 SECS.

PU240 ASYMMETRIC X-SECTIONS ALONG CONTOUR OF 1 EV RES. AT T=300.

RESOLVED SINGLE-LEVEL RESONANCE PARAMETERS -

16.066	1.054E+00	2.36E-03	3.40E-02	0.	1.00E+00	94	240
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TOTAL CROSS-SECTIONS AT T = 3.000E+02

15.906	1.236E-06	1.573E+03				8	92	240	TOPU240
15.921	1.218E-06	1.951E+03				8	92	240	TOPU240
15.936	1.199E-06	2.482E+03				8	92	240	TOPU240
15.952	1.181E-06	3.265E+03				8	92	240	TOPU240
15.967	1.163E-06	4.489E+03				8	92	240	TOPU240
15.983	1.145E-06	6.572E+03				8	92	240	TOPU240
15.999	1.127E-06	1.054E+04				8	92	240	TOPU240
16.015	1.109E-06	1.949E+04				8	92	240	TOPU240
16.032	1.090E-06	4.202E+04				8	92	240	TOPU240
16.048	1.072E-06	8.540E+04				8	92	240	TOPU240
16.066	1.054E-06	1.145E+05				8	92	240	TOPU240
16.083	1.036E-06	8.616E+04				8	92	240	TOPU240
16.101	1.018E-06	4.279E+04				8	92	240	TOPU240
16.119	9.995E-07	2.003E+04				8	92	240	TOPU240
16.137	9.813E-07	1.094E+04				8	92	240	TOPU240
16.156	9.631E-07	6.883E+03				8	92	240	TOPU240
16.175	9.449E-07	4.746E+03				8	92	240	TOPU240
16.194	9.267E-07	3.485E+03				8	92	240	TOPU240
16.214	9.086E-07	2.674E+03				8	92	240	TOPU240
16.234	8.904E-07	2.122E+03				8	92	240	TOPU240
16.255	8.722E-07	1.728E+03				8	92	240	TOPU240

CAPTURE CROSS-SECTIONS AT T= 3.000E+02

15.906	1.236E-06	1.402E+03	8 92	240NG	PU240
15.921	1.218E-06	1.748E+03	8 92	240NG	PU240
15.936	1.199E-06	2.236E+03	8 92	240NG	PU240
15.952	1.181E-06	2.958E+03	8 92	240NG	PU240
15.967	1.163E-06	4.089E+03	8 92	240NG	PU240
15.983	1.145E-06	6.017E+03	8 92	240NG	PU240
15.999	1.127E-06	9.703E+03	8 92	240NG	PU240
16.015	1.109E-06	1.803E+04	8 92	240NG	PU240
16.032	1.090E-06	3.905E+04	8 92	240NG	PU240
16.048	1.072E-06	7.963E+04	8 92	240NG	PU240
16.066	1.054E-06	1.070E+05	8 92	240NG	PU240
16.083	1.036E-06	8.102E+04	8 92	240NG	PU240
16.101	1.018E-06	4.042E+04	8 92	240NG	PU240
16.119	9.995E-07	1.898E+04	8 92	240NG	PU240
16.137	9.813E-07	1.040E+04	8 92	240NG	PU240
16.156	9.631E-07	6.561E+03	8 92	240NG	PU240
16.175	9.449E-07	4.537E+03	8 92	240NG	PU240
16.194	9.267E-07	3.340E+03	8 92	240NG	PU240
16.214	9.086E-07	2.570E+03	8 92	240NG	PU240
16.234	8.904E-07	2.044E+03	8 92	240NG	PU240
16.255	8.722E-07	1.669E+03	8 92	240NG	PU240

EXECUTION TIME OF PROBLEM 3 IS 0 MINUTES, 18.90 SECS.

EXECUTION TIME = 11.0 MINUTES 1.97 SECS.
 LUBRAO JOB(S) COMPLETED

D.2 SAMPLE OUTPUT FROM LUBRA1

MONITOR HAS ENTERED LUBRA1

LUBRA1 INFINITELY DILUTE RESONANCE INTEGRAL FOR TH232 IN AN 1/E-FLUX

13.034	2.184E+01	1.78E-03	2.15E-02	0.	1.00E+00	90 232
12.962	2.348E+01	3.20E-03	2.50E-02	0.	1.00E+00	90 232
12.031	5.955E+01	4.60E-03	2.08E-02	0.	1.00E+00	90 232
11.881	6.920E+01	4.24E-02	1.84E-02	0.	1.00E+00	90 232
11.392	1.129E+02	1.20E-02	1.50E-02	0.	1.00E+00	90 232
11.325	1.207E+02	1.85E-02	2.00E-02	0.	1.00E+00	90 232
11.258	1.291E+02	3.41E-03	2.00E-02	0.	1.00E+00	90 232
11.135	1.459E+02	3.60E-05	2.00E-02	0.	1.00E+00	90 232
11.079	1.543E+02	1.24E-04	2.00E-02	0.	1.00E+00	90 232
10.980	1.704E+02	5.80E-02	2.00E-02	0.	1.00E+00	90 232
10.857	1.926E+02	1.40E-02	2.00E-02	0.	1.00E+00	90 232
10.840	1.960E+02	3.51E-02	2.00E-02	0.	1.00E+00	90 232
10.824	1.992E+02	1.10E-02	2.00E-02	0.	1.00E+00	90 232
10.720	2.210E+02	3.13E-02	1.60E-02	0.	1.00E+00	90 232
10.591	2.513E+02	3.17E-02	2.20E-02	0.	1.00E+00	90 232
10.545	2.632E+02	1.90E-02	2.20E-02	0.	1.00E+00	90 232
10.464	2.856E+02	2.80E-02	1.70E-02	0.	1.00E+00	90 232
10.397	3.053E+02	2.62E-02	1.60E-02	0.	1.00E+00	90 232
10.323	3.288E+02	6.89E-02	2.00E-02	0.	1.00E+00	90 232
10.284	3.419E+02	3.61E-02	2.00E-02	0.	1.00E+00	90 232
10.218	3.651E+02	2.79E-02	2.20E-02	0.	1.00E+00	90 232
10.206	3.693E+02	2.79E-02	2.50E-02	0.	1.00E+00	90 232
10.125	4.008E+02	1.00E-02	2.50E-02	0.	1.00E+00	90 232
UNRESOLVED AVERAGE PARAMETERS READ IN						
	2.030E+01	1.20E-03	3.67E-02	0.	1.00E+00	90 232

E1= 4.000E-01 LAST RES.E = 4.008E+02 DELTA= 0.

TOTAL RESOLVED I(N,G),I(N,F),I(TOTAL)
 6.67311E+01 0. 6.67311E+01

FIRST UNRES.E= 4.109E+02 E2= 1.000E+07
 CONTRIBUTION OF EACH L-STATE TO UNRESOLVED R.I.
 I(N,G) I(N,F) I(TOT) L
 6.43194E+00 0. 6.43194E+00 0
 9.66644E+01 0. 9.66644E+01 1
 1.66802E+01 0. 1.66802E+01 2
 6.97934E+02 0. 6.97934E+02 3
 3.82881E+02 0. 3.82881E+02 4

UNRESOLVED I(N,G),I(N,F),I(TOTAL)
 7.67347E+00 0. 7.67347E+00

TOTAL RESONANCE INTEGRALS FROM E1 TO E2 ARE
 7.44046E+01 0. 7.44046E+01

LUBRA1 INFINITELY DILUTE RESONANCE INTEGRAL FOR TH232 IN A NON 1/E-FLUX

E1= 4.000E-01 LAST RES.E = 4.008E+02 DELTA= 5.000E-02

TOTAL RESOLVED I(N,G),I(N,F),I(TOTAL)
 8.10748E+01 0. 8.10748E+01
 FIRST UNRES.E= 4.109E+02 E2= 1.000E+07
 CONTRIBUTION OF EACH L-STATE TO UNRESOLVED R.I.
 I(N,G) I(N,F) I(TOT) L
 8.99670E+00 0. 8.99670E+00 0
 1.35210E+00 0. 1.35210E+00 1
 2.33314E+01 0. 2.33314E+01 2
 9.76237E+02 0. 9.76237E+02 3
 5.35556E+02 0. 5.35556E+02 4

UNRESOLVED I(N,G),I(N,F),I(TOTAL)
 1.07333E+01 0. 1.07333E+01

TOTAL RESONANCE INTEGRALS FROM E1 TO E2 ARE
 9.18081E+01 0. 9.18081E+01

LUBRAI INF. DILUTE RES. INT. FOR TH232 IN A NON 1/E-FLUX,NEG.RES. CALC
 NEGATIVE ENERGY RESONANCE PARAMETERS-
 -99.999 -5.400E+00 1.03E-02 3.67E-02 1.02E-06 1.00E+00 90 232

E1= 4.000E-01 LAST RES.E = 4.008E+02 DELTA= 5.000E-02

TOTAL RESOLVED I(N,G),I(N,F),I(TOTAL)
 8.73635E+01 1.74228E-04 8.73636E+01

FIRST UNRES.E= 4.109E+02 E2= 1.000E+07
 CONTRIBUTION OF EACH L-STATE TO UNRESOLVED R.I.

I(N,G)	I(N,F)	I(TOT)	L
8.99670E+00	0.	8.99670E+00	0
1.35210E+00	0.	1.35210E+00	1
2.33314E-01	0.	2.33314E-01	2
9.76237E-02	0.	9.76237E-02	3
5.35556E-02	0.	5.35556E-02	4

UNRESOLVED I(N,G),I(N,F),I(TOTAL)
 1.07333E+01 0. 1.07333E+01

TOTAL RESONANCE INTEGRALS FROM E1 TO E2 ARE
 9.80968E+01 1.74228E-04 9.80969E+01

EXECUTION TIME = 1.0 MINUTES 6.57 SECS.
 LUBRAI JOB(S) COMPLETED

APPENDIX E

E.1 SAMPLE INPUT TO LUBRA2

THE FIRST 9 PROBLEMS PROVIDED AS SAMPLE INPUT TO LUBRA2
EVALUATE THE EFFECTIVE RESONANCE INTEGRAL FOR THE 1.054EV
RESONANCE OF PU240 FOR THE FOLLOWING TEMPERATURES AND MODELS
THEREBY ILLUSTRATING THE USE OF THE 'TEMP' AND 'CONTINUE' CARDS

- 1) N.R. MODEL AT T=0 DEG.K,
- 2) N.R. MODEL AT T=300 DEG.K,
- 3) N.R. MODEL AT T=600 DEG.K,
- 4) N.R.I.A. MODEL AT T=600 DEG.K,
- 5) N.R.I.A. MODEL AT T=300 DEG.K,
- 6) N.R.I.A. MODEL AT T=0 DEG.K,
- 7) I.R.(3) MODEL AT T=0 DEG.K,
- 8) I.R.(3) MODEL AT T=300 DEG.K,
- 9) I.R.(3) MODEL AT T=600 DEG.K.

THE OUTPUT OF THE ABOVE PROBLEMS IS OBTAINED ON THE PRINTER,
PUNCH AND TAPE.

10) THE LAST PROBLEM GIVEN TO ILLUSTRATE THE USE OF 'NEXT',
CALCULATES THE TOTAL EFFECTIVE RESONANCE INTEGRAL (RESOLVED+
UNRESOLVED) FOR TH232 AT T=300 DEG.K. OUTPUT FOR THIS JOB
IS OBTAINED ON THE PRINTER AND PUNCH.

END OF COMMENTS

BEGINNING OF INPUT

```
'CALL LUBRA2',
E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=0 DEG.K, NR MODEL
1,C,7, ,4,1,B,R,
  1 1 1 2 1
BE 9 4.123 E-02 6.0
PU240 10.0
2.4738E-05
0.0
16.066 1.054E+00 2.36E-03 3.40E-02 0.0 1.00E+00 17 94 240RRPPU240
TEMP
E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=300 DEG.K, NR MODEL
300.
TEMP
E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=600 DEG.K, NR MODEL
600.
CARD 1
CARD 2
CARD 3
CARD 4
CARD 5
CARD 6
CARD 7
CARD 8
CARD 240RRPPU240
CARD 10
CARD 11
CARD 12
CARD 13
CARD 14
CARD 15
```


10.720	2.210E+02	3.13E-02	1.60E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.591	2.513E+02	3.17E-02	2.20E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.545	2.632E+02	1.90E-02	2.20E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.463	2.856E+02	2.80E-02	1.70E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.397	3.053E+02	2.62E-02	1.60E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.323	3.288E+02	6.89E-02	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.283	3.419E+02	3.61E-02	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.218	3.651E+02	2.79E-02	2.20E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.207	3.693E+02	2.79E-02	2.50E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.125	4.008E+02	1.00E-02	2.50E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.125	2.030E+01	1.20E-03	3.67E-02	0.0	1.0	18 90	232URRPTH232

END

'CFASE'

CARD 66

APPENDIX E (continued)

E.2 SAMPLE OUTPUT FROM LUBRA2

MONITOR HAS ENTERED LUBRA2

LUBRA2 OUTPUT STARTS AT BEGINNING OF TAPE

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=0 DEG.K, NR MODEL

1	1	2	1+0.	-0.		
BE	9	4.12300E+02	6.00000E+00	-0.		
PU240	-0.		1.00000E+01	-0.		
2.474E-05						
0.						
16.066	1.054E+00	2.360E-03	3.400E-02	0.	1.000E+00	17 94 240

FORMULA OPTION 1

TEMPERATURE= 0.
SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.00000E+04
E RES.INT.
1.05400E+00 1.97117E+03 3.85175E-01

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=300 DEG.K, NR MODEL

FORMULA OPTION 1

TEMPERATURE= 300.0 XIBAR= 2.06403E-01
SIGMA= 1.00000E+04 PARTICLE SIGMA= 1.00000E+04
PART.SIZE= 0 MICRONS
E RES.INT.
1.05400E+00 2.02956E+03 3.74443E-01

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=600 DEG.K, NR MODEL

FORMULA OPTION 1

TEMPERATURE= 600.0 XIBAR= 2.06403E-01
 SIGMA= 1.00000E+04
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.00000E+04
 E RES.INT. P
 1.05400E+00 2.08143E+03 3.65159E-01

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=600 DEG.K, NR1A MODEL

FORMULA OPTION 2

TEMPERATURE= 600.0 XIBAR= 2.06601E-01
 SIGMA= 1.00000E+04
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.00000E+04
 E RES.INT. P
 1.05400E+00 2.15112E+03 3.53399E-01

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=300 DEG.K, NR1A MODEL

FORMULA OPTION 2

TEMPERATURE= 300.0 XIBAR= 2.06601E-01
 SIGMA= 1.00000E+04
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.00000E+04
 E RES.INT. P
 1.05400E+00 2.09589E+03 3.62964E-01

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=0 DEG.K, NR1A MODEL

FORMULA OPTION 2

TEMPERATURE= 0.
 SIGMA= 1.00000E+04 XIBAR= 2.06601E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.00000E+04
 E RES.INT. P
 1.05400E+00 2.03334E+03 3.74110E-01

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=0 DEG.K, IR(3) MODEL

FORMULA OPTION 5

TEMPERATURE= 0.
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.00000E+04

LAMBDA (MODERATOR-ABSORBER)

6.30119E-01 1.14553E-02
 BETA= 4.19252E-02 SPLT= 6.30131E+03

RES.INT.	P	2/(1+P)
1.63242E+03	4.53798E+01	1.37571E+00
2.24574E+03	3.37244E+01	1.49561E+00
E	RES.INT.	P
1.05400E+00	2.24574E+03	3.37244E-01

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=300 DEG.K, IR(3) MODEL

FORMULA OPTION 5

TEMPERATURE= 300.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.00000E+04

LAMBDA (MODERATOR=ABSORBER)

6.30119E-01 1.14553E-02
 BETA= 4.19252E-02 SPLT= 6.30131E+03

RES.INT.	P	2/(1+P)
1.67022E+03	4.45572E+01	1.38354E+00
2.31081E+03	3.26787E+01	1.50740E+00
E	RES.INT.	P
1.05400E+00	2.31081E+03	3.26787E+01

E.R.I. FOR THE 1.054EV RESONANCE OF PU240 AT T=600 DEG.K, IR(3) MODEL

FORMULA OPTION 5

TEMPERATURE= 600.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.00000E+04

LAMBDA (MODERATOR=ABSORBER)

6.30119E-01 1.14553E-02
 BETA= 4.19252E-02 SPLT= 6.30131E+03

RES.INT.	P	2/(1+P)
1.70491E+03	4.38152E+01	1.39067E+00
2.37098E+03	3.17408E+01	1.51813E+00
E	RES.INT.	P
1.05400E+00	2.37098E+03	3.17408E+01

E	RES. INT.	P
2.18400E+01	7.22042E+00	9.65673E+01
2.34800E+01	8.77094E+00	9.58456E+01
5.95500E+01	2.69305E+00	9.87056E+01
6.92000E+01	2.81623E+00	9.86468E+01
1.12900E+02	1.31155E+00	9.93675E+01
1.20700E+02	1.47846E+00	9.92873E+01
1.29100E+02	6.17103E+01	9.97019E+01
1.45900E+02	6.90559E+03	9.99967E+01
1.54300E+02	2.11065E+02	9.99898E+01
1.70400E+02	9.09386E+01	9.95610E+01
1.92600E+02	6.75640E+01	9.96737E+01
1.96000E+02	7.75300E+01	9.96256E+01
1.99200E+02	5.79521E+01	9.97200E+01
2.21000E+02	5.58253E+01	9.97303E+01
2.51300E+02	5.63222E+01	9.97279E+01
2.63200E+02	4.65443E+01	9.97751E+01
2.85600E+02	3.85427E+01	9.98137E+01
3.05300E+02	3.29275E+01	9.98408E+01
3.28800E+02	3.53530E+01	9.98291E+01
3.41900E+02	3.29797E+01	9.98406E+01
3.65100E+02	2.98660E+01	9.98556E+01
3.69300E+02	3.14316E+01	9.98481E+01
4.00800E+02	1.67421E+01	9.99190E+01
RESOLVED RESONANCE INTEGRAL = 3.16409E+01		

6.83735E+00

UNRESOLVED RESONANCE INTEGRAL UP TO E=1.E+07 EV IS
 TOTAL RES. INT.OVER RESOLVED+UNRES. REGIONS= 3.84783E+01

EXECUTION TIME = 6.0 MINUTES 57.73 SECS.
 LUBRA2 JOB(S) COMPLETED

APPENDIX F

F.1 SAMPLE INPUT TO LUBRA3

ALL PROBLEMS (EXCEPT THE LAST) IN THE SAMPLE LUBRA3
RUN ILLUSTRATED BELOW READ THE REQUIRED INPUT DATA FROM THE
TAPE CREATED BY THE PRECEDING LUBRA2 SAMPLE RUN. THE FIRST
9 PROBLEMS ILLUSTRATE THE USE THE 'TEMP' AND 'CONTINUE'
RETURNS. THE NEXT 9 PROBLEMS ARE CALCULATIONS OF AVERAGE
DOPPLER COEFFICIENTS WHICH ILLUSTRATE THE USE OF THE 'REWIND'
AND 'SKIP' OPTIONS, AND REQUIRE A SCRATCH TAPE ON UNIT 1.
THE LAST JOB CALCULATES THE TOTAL RESOLVED DOPPLER COEFFICIENT
FOR TH232 AT T=300 DEG.K FOR MODERATOR SCATTERING OF 1000 B
USING INPUT FROM CARDS.

ALL OUTPUT IS OBTAINED ON THE PRINTER AND PUNCH.

END OF COMMENTS

BEGINNING OF INPUT

'CALL LUBRA3'	CARD	1
DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=0, NR	CARD	2
1, T, 3, 4, , T, B, R	CARD	3
TEMP	CARD	4
DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=300, NR	CARD	5
T, 300.	CARD	6
TEMP	CARD	7
DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=600, NR	CARD	8
T, 600.	CARD	9
CONTINUE	CARD	10
DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=600. NR1A	CARD	11
2.	CARD	12
TEMP	CARD	13
DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=300. NR1A	CARD	14
T, 300.	CARD	15
TEMP	CARD	16
DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T= 0. NR1A	CARD	17
T, 0.	CARD	18
CONTINUE	CARD	19
DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T= 0 IR(3)	CARD	20
5, B,	CARD	21
TEMP	CARD	22
DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=300. IR(3)	CARD	23

11.079	1.543E+02	1.24E-04	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.980	1.704E+02	5.80E-02	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.857	1.926E+02	1.40E-02	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.840	1.960E+02	3.51E-02	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.824	1.992E+02	1.10E-02	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.720	2.210E+02	3.13E-02	1.60E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.591	2.513E+02	3.17E-02	2.20E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.545	2.632E+02	1.90E-02	2.20E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.463	2.856E+02	2.80E-02	1.70E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.397	3.053E+02	2.62E-02	1.60E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.323	3.288E+02	6.89E-02	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.283	3.419E+02	3.61E-02	2.00E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.218	3.651E+02	2.79E-02	2.20E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.207	3.693E+02	2.79E-02	2.50E-02	0.0	1.00E+00	17 90	232RRRPTH232
10.125	4.008E+02	1.00E-02	2.50E-02	0.0	1.00E+00	17 90	232RRRPTH232

END
↑CEASE↑
CARD 78
CARD 79

APPENDIX F (continued)

F.2 SAMPLE OUTPUT FROM LUBRA3

MONITOR HAS ENTERED LUBRA3

LUBRA2 OUTPUT STARTS AT BEGINNING OF TAPE

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=0, NR

1	1	1	2	1=0.	=0.	
BE	9	4	12300E-02	6.00000E+00	-0.	
PU240	-0.		1.00000E+01	-0.		
2.474E-05						
0.						
16.066	1.054E+00	2.36E-03	3.40E-02	0.	1.00E+00	17 94 240

FORMULA OPTION 1

TEMPERATURE= 0.
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.000E+04

ER	THETA	BETA	D.C.
1.05400E+00	1.00000E+09	6.23274E-02	-1.01959E-04

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=300, NR

FORMULA OPTION 1

TEMPERATURE= 300.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.000E+04

ER	THETA	BETA	DJ/D(THETA)	D.C.
1.05400E+00	1.70694E+00	6.23274E-02	-1.98322E-01	-8.81778E-05

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=600, NR

FORMULA OPTION 1

TEMPERATURE= 600.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.000E+04

ER	THETA	BETA	DJ/D(THETA)	D.C.
1.05400E+00	1.20699E+00	6.23274E-02	-5.07056E-01	-7.97074E-05

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=600. NRIA

FORMULA OPTION 2

TEMPERATURE= 600.0
 SIGMA= 1.00000E+04 XIBAR= 2.06601E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.000E+04

ER	THETA	BETA	DJ/D(THETA)	D.C.
1.05400E+00	1.20699E+00	6.65871E-02	-5.04140E-01	-8.45841E-05

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=300. NRIA

FORMULA OPTION 2

TEMPERATURE= 300.0
 SIGMA= 1.00000E+04 XIBAR= 2.06601E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.000E+04

ER	THETA	BETA	DJ/D(THETA)	D.C.
1.05400E+00	1.70694E+00	6.65871E-02	-1.98159E-01	-9.40364E-05

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T= 0 . NR1A

FORMULA OPTION 2

TEMPERATURE= 0.
 SIGMA= 1.00000E+04 XIBAR= 2.06601E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.000E+04

ER THETA BETA D.C.
 1.05400E+00 1.00000E+09 6.65871E-02 -1.09589E-04

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T= 0 IR(3)

FORMULA OPTION 5

TEMPERATURE= 0.
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.000E+04

ER THETA BETA D.C.
 1.05400E+00 1.00000E+09 4.19252E-02 -1.33023E-04

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=300. IR(3)

FORMULA OPTION 5

TEMPERATURE= 300.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.000E+04

ER THETA BETA D.C.
 1.05400E+00 1.70694E+00 4.19252E-02 -1.94478E-01 -1.21012E-04

DOPPLER COEFFICIENT FOR 1.054EV RESONANCE OF PU240 AT T=600 IR(3)

FORMULA OPTION 5

TEMPERATURE= 600.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.0000E+04
 ER THETA BETA DJ/D(THETA) D.C.
 1.05400E+00 1.20699E+00 4.19252E-02 -5.10711E-01 -1.13312E-04

AVERAGE D.C. (0-300DEG.K) FOR 1.054EV RESONANCE OF PU240 NR MODEL

1	1	1	2	1-0.	-0.		
BE	9.4	12300E-02	6.00000E+00-0.	-0.			
PU240-0.			1.00000E+01-0.	-0.			
2.474E-05							
0.							
16.066	1.054E+00	2.36E-03	3.40E-02	0.	1.00E+00	17	94 240

FORMULA OPTION 1

DOPPLER COEFFT.OVER RANGE T= 0. TO T= 300.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.0000E+04

ER D.C.
 1.05400E+00 -9.42035E-05

AVERAGE D.C. (0-300DEG.K) FOR 1.054EV RESONANCE OF PU240 NR1A MODEL

FORMULA OPTION 2

DOPPLER COEFFT.OVER RANGE T= 0. TO T= 300.0
 SIGMA= 1.00000E+04 XIBAR= 2.06601E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.0000E+04

ER D.C.
 1.05400E+00 -1.00818E-04

AVERAGE D.C. (0-300DEG.K) FOR 1.054EV RESONANCE OF PU240 IR(3) MODEL

FORMULA OPTION 5

DOPPLER COEFFT.OVER RANGE T= 0. TO T= 300.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.0000E+04

ER D.C.
 1.05400E+00 -1.04985E-04

AVERAGE D.C. (300-600DEG.K) FOR 1.054EV RESONANCE OF PU240 NR MODEL

FORMULA OPTION 1

DOPPLER COEFFT.OVER RANGE T= 300.0 TO T= 600.0
 SIGMA= 1.00000E+04 XIBAR= 2.06403E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.0000E+04

ER D.C.
 1.05400E+00 -8.36845E-05

AVERAGE D.C. (300-600DEG.K) FOR 1.054EV RESONANCE OF PU240 NR1A

FORMULA OPTION 2

DOPPLER COEFFT.OVER RANGE T= 300.0 TO T= 600.0
 SIGMA= 1.00000E+04 XIBAR= 2.06601E-01
 PART.SIZE= 0 MICRONS PARTICLE SIGMA= 1.0000E+04

10.323	3.288E+02	6.89E-02	2.00E-02	0.	1.00E+00	17 90	232
10.284	3.419E+02	3.61E-02	2.00E-02	0.	1.00E+00	17 90	232
10.218	3.651E+02	2.79E-02	2.20E-02	0.	1.00E+00	17 90	232
10.206	3.693E+02	2.79E-02	2.50E-02	0.	1.00E+00	17 90	232
10.125	4.008E+02	1.00E-02	2.50E-02	0.	1.00E+00	17 90	232

FORMULA OPTION 1

TEMPERATURE= 300.0 XIBAR= 2.04137E-01
 SIGMA= 1.00000E+03 0 MICRONS PARTICLE SIGMA= 1.000E+03
 PART.SIZE= 0 MICRONS

ER	THETA	BETA	DJ/D(THETA)	D.C.
2.18400E+01	2.36052E-01	1.10904E-01	-1.04772E+01	-1.98777E-05
2.34800E+01	2.75773E-01	8.03392E-02	-1.08000E+01	-2.58908E-05
5.95500E+01	1.55971E-01	1.27670E-01	-1.48491E+01	-6.60471E-06
6.92000E+01	3.46340E-01	3.85278E-02	-1.04266E+01	-7.83940E-06
1.12900E+02	1.20412E-01	9.86295E-02	-2.59739E+01	-3.39258E-06
1.20700E+02	1.66058E-01	9.75274E-02	-1.84978E+01	-4.15556E-06
1.29100E+02	9.76315E-02	3.44115E-01	-5.00705E+00	-6.18306E-07
1.45900E+02	7.86023E-02	3.15278E+01	-8.31768E-04	-7.31711E-11
1.54300E+02	7.67685E-02	9.72274E+00	-9.11809E-03	-7.40761E-10
1.70400E+02	2.83147E-01	8.89747E-02	-9.63010E+00	-2.61294E-06
1.92600E+02	1.16092E-01	1.81609E-01	-1.22422E+01	-1.20493E-06
1.96000E+02	1.86499E-01	1.19462E-01	-1.31130E+01	-2.03742E-06
1.99200E+02	1.04080E-01	2.17966E-01	-1.00735E+01	-8.59442E-07
2.21000E+02	1.50771E-01	1.29670E-01	-1.50977E+01	-1.34549E-06
2.51300E+02	1.60520E-01	1.65287E-01	-1.05873E+01	-1.21470E-06
2.63200E+02	1.19755E-01	2.20519E-01	-9.04031E+00	-7.38822E-07
2.85600E+02	1.26178E-01	1.78214E-01	-1.18003E+01	-7.23593E-07
3.05300E+02	1.14446E-01	1.90927E-01	-1.15122E+01	-5.63743E-07
3.28800E+02	2.32321E-01	1.64719E-01	-7.19562E+00	-8.30197E-07
3.41900E+02	1.43769E-01	2.06293E-01	-8.69537E+00	-5.97051E-07
3.65100E+02	1.23750E-01	2.53535E-01	-7.17654E+00	-4.36918E-07
3.69300E+02	1.30442E-01	2.71870E-01	-6.23691E+00	-4.49651E-07
4.00800E+02	8.28430E-02	5.44661E-01	-2.38724E+00	-1.00714E-07

TOTAL RESOLVED DOPPLER COEFFT.=-8.20955E-05

LUBRA3 JOB(S) COMPLETED
 EXECUTION TIME = 12.0 MINUTES 7.38 SECS.

APPENDIX G

G.1 SAMPLE INPUT TO LUBRA4

THE PROBLEMS GIVEN AS A SAMPLE RUN FOR LUBRA4 ILLUSTRATE SOME OF THE INPUT FEATURES DESCRIBED IN SECTION 6.2.1. ALL INPUT CROSS SECTION DATA OBTAINED FROM THE LUBRAO RUN PROVIDED AS SAMPLE IN C.1,C.2, ARE READ FROM TAPE., ALL OUTPUT IS PRODUCED ON THE PRINTER AND PUNCH. THE 3 PROBLEMS ALL CALCULATE 10-GROUP CROSS SECTIONS AVERAGED OVER A 1/E-SPECTRUM FOR U233 AT T=300 DEG.K, USING THE LUBRAO OUTPUT ON TAPE, IN THE FOLLOWING SEQUENCE-

- 1) RESIDUAL-RESONANCE REMOVED; CROSS SECTIONS USING THE FIRST LUBRAO OUTPUT,
- 2) ASYMMETRIC CROSS SECTIONS ALSO USING THE FIRST LUBRAO OUTPUT FILE,
- 3) SYMMETRIC CROSS SECTIONS FROM THE SECOND LUBRAO OUTPUT OUTPUT ON PRINTER AND PUNCH WITH TIMING FACILITY USED

END OF COMMENTS

BEGINNING OF INPUT

CARD	1	2	3	4	5	6	7	CARD
'CALL LUBRA4'								
TIME								
GROUP X-SECS. FOR U233 AT T=300. 1/E FLUX, RESIDUAL RES.REMOVED								
3,T, ,3,2								
RESIDUAL RESONANCE REMOVAL								
0.1								
25.48								
CARD								
18.421	0.100E+00	1.63E-05	1.04E-01	9.46E-01	0.500E+00	17	92	233RRP U233
15.642	1.610E+00	2.55E-04	5.80E-02	7.03E-01	0.500E+00	17	92	233RRP U233
15.558	1.750E+00	2.45E-04	1.20E-02	2.31E-01	0.500E+00	17	92	233RRP U233
15.400	2.050E+00	3.08E-05	1.00E-06	3.00E-01	1.000E+00	17	92	233RRP U233
15.282	2.307E+00	1.43E-04	4.10E-02	5.00E-02	0.500E+00	17	92	233RRP U233
14.826	3.640E+00	1.87E-04	5.40E-02	2.06E-01	0.500E+00	17	92	233RRP U233
14.549	4.800E+00	3.31E-04	8.60E-02	6.98E-01	0.500E+00	17	92	233RRP U233
14.352	5.850E+00	1.20E-04	5.00E-02	3.20E-01	0.500E+00	17	92	233RRP U233
14.286	6.250E+00	0.68E-04	1.00E-06	3.50E-01	1.000E+00	17	92	233RRP U233
14.200	6.810E+00	7.47E-04	5.00E-02	0.98E-01	0.500E+00	17	92	233RRP U233
14.094	7.570E+00	3.50E-05	4.50E-02	9.00E-02	0.500E+00	17	92	233RRP U233
13.946	8.780E+00	1.99E-04	4.50E-02	7.00E-01	0.500E+00	17	92	233RRP U233
13.888	9.300E+00	1.23E-04	4.50E-02	1.95E-01	0.500E+00	17	92	233RRP U233

13.783	1.033E+01	1.74E+03	5.80E-02	2.70E-01	0.500E+00	17 92	233RRP	U233
13.677	1.148E+01	1.02E-04	4.50E-02	1.75E-01	5.83E-01	17 92	233RRP	U233
13.562	1.288E+01	1.23E-03	4.50E-02	2.50E-01	5.83E-01	17 92	233RRP	U233
13.487	1.389E+01	3.99E-04	4.50E-02	3.00E-01	5.83E-01	17 92	233RRP	U233
13.380	1.546E+01	8.93E-04	4.50E-02	1.90E-01	5.83E-01	17 92	233RRP	U233
13.326	1.632E+01	8.69E-04	4.50E-02	4.50E-01	5.83E-01	17 92	233RRP	U233
13.304	1.667E+01	4.41E-04	4.50E-02	1.40E-01	5.83E-01	17 92	233RRP	U233
13.222	1.810E+01	2.77E-04	4.50E-02	1.50E-01	5.83E-01	17 92	233RRP	U233
13.195	1.860E+01	1.63E-04	4.50E-02	1.15E-01	5.83E-01	17 92	233RRP	U233
13.169	1.909E+01	1.67E-04	4.50E-02	2.40E-01	5.83E-01	17 92	233RRP	U233
13.085	2.076E+01	1.04E-04	4.50E-02	4.70E-01	5.83E-01	17 92	233RRP	U233
13.027	2.200E+01	1.01E-04	4.50E-02	2.05E-01	5.83E-01	17 92	233RRP	U233
13.005	2.250E+01	2.77E-04	4.50E-02	3.90E-01	5.83E-01	17 92	233RRP	U233
12.944	2.390E+01	1.64E-03	4.50E-02	9.00E-01	4.16E-01	17 92	233RRP	U233
12.880	2.548E+01	9.95E-04	4.50E-02	2.90E-01	5.83E-01	17 92	233RRP	U233

NO FLUX OUTPUT							CARD	36
GYMEA							CARD	37
1							CARD	38
2.5							CARD	39
10.							CARD	40
12.	13.75	14.6	15.5	16.3	17.1	17.9	CARD	41
18.7	19.5	20.25	23.				CARD	42

G,
CONTINUE
GROUP X-SECS. FOR U233 AT T=300. 1/E FLUX, ASYMMETRIC

CONTINUE
GROUP X-SECS. FOR U233 AT T=300. 1/E FLUX, SYMMETRIC

1, , , S
NO REWIND/NFXT FILE
NO FLUX OUTPUT
GYMEA
1
2.5
END
'CEASE'

6.2 SAMPLE OUTPUT FROM LUBRA4

MONITOR HAS ENTERED LUBRA4

LUBRAO OUTPUT STARTS AT BEGINNING OF TAPE

GROUP X-SECS. FOR U233 AT T=300. 1/E FLUX, RESIDUAL RES.REMOVED

POINT CROSS-SECTIONS

* GYMEA LIBRARY CROSS-SECTIONS FOR U233 AT T= 300.0

X(N,G)=	U233,233,0	U233	AT T=	300.0	
3.312E+03	3.888E-03	4.579E-03	5.414E+03	6.429E+03	7.763E-03
9.319E+03	1.127E-02	1.376E-02	1.699E-02	2.130E-02	2.724E-02
3.581E-02	4.904E-02	7.166E-02	1.176E-01	2.480E-01	1.264E+00
3.280E+00	3.889E+00	4.404E+00	1.049E+00	1.096E+00	1.819E+00
1.401E+01	2.774E+00	3.684E+01	1.016E+01	1.169E+01	3.884E+00
1.151E+01	3.741E+01	8.406E+00	4.687E+00	6.990E+00	2.312E+01
5.943E+01	9.439E+00	1.205E+01	5.236E+00	3.338E+00	3.568E+00
1.454E+01	1.604E+01	2.709E+02	1.836E+01	8.575E+00	1.365E+01
7.626E+00	7.358E+00	1.104E+01	1.456E+01	1.174E+01	8.539E+00
8.121E+00	1.261E+01	3.758E+01	4.084E+01	1.445E+01	8.250E+00
6.636E+00	6.647E+00	8.030E+00	1.196E+01	2.532E+01	1.248E+02
2.422E+02	4.660E+01	2.751E+01	2.861E+01	4.040E+01	5.719E+01
5.173E+01	3.948E+01	3.213E+01	2.712E+01	2.320E+01	2.007E+01
1.760E+01	1.568E+01	1.419E+01	1.306E+01	1.219E+01	1.154E+01
1.105E+01	1.071E+01	1.048E+01	1.034E+01	1.029E+01	1.031E+01
1.039E+01	1.052E+01	1.070E+01	1.093E+01	1.119E+01	1.149E+01
1.182E+01	1.217E+01	1.255E+01	1.295E+01	1.337E+01	1.381E+01
1.426E+01	1.472E+01	1.519E+01	1.567E+01	1.616E+01	1.665E+01
1.716E+01	1.766E+01	1.817E+01	1.869E+01	1.921E+01	1.973E+01
2.026E+01	2.080E+01	2.134E+01	2.189E+01	2.245E+01	2.301E+01
2.359E+01	2.417E+01	2.476E+01	2.536E+01	2.597E+01	2.660E+01
2.724E+01	2.789E+01	2.855E+01	2.923E+01	2.992E+01	3.063E+01
3.136E+01	3.210E+01	3.286E+01	3.364E+01	3.444E+01	3.526E+01
3.610E+01	3.696E+01	3.784E+01	3.874E+01	3.967E+01	4.062E+01
4.159E+01	4.259E+01	4.362E+01	4.467E+01	4.575E+01	4.685E+01
4.799E+01	4.915E+01	5.035E+01	5.158E+01	5.283E+01	5.412E+01
5.545E+01	5.681E+01	5.820E+01	5.963E+01	6.109E+01	6.260E+01
6.414E+01	6.572E+01	6.735E+01	6.901E+01	7.072E+01	7.247E+01

7.427E+01	7.801E+01	7.995E+01	8.194E+01	8.398E+01
8.607E+01	9.042E+01	9.268E+01	9.500E+01	9.737E+01
9.981E+01	1.049E+02	1.075E+02	1.102E+02	1.130E+02
1.158E+02	1.217E+02	1.247E+02	1.279E+02	1.311E+02
1.344E+02	1.412E+02	1.448E+02	1.484E+02	1.522E+02
1.560E+02	1.640E+02	1.681E+02	1.723E+02	1.767E+02
1.812E+02	1.904E+02	1.952E+02	2.001E+02	2.052E+02
2.104E+02	2.211E+02	2.267E+02	2.324E+02	2.383E+02
2.443E+02	2.568E+02	2.633E+02	2.700E+02	
X(N,FISS) =				
2.604E-02	3.641E-02	4.333E-02	5.186E-02	6.256E-02
7.590E-02	1.150E-01	1.443E-01	1.843E-01	2.407E-01
3.241E-01	6.828E-01	1.138E+00	2.346E+00	1.001E+01
2.920E+01	4.193E+01	8.994E+00	9.924E+00	1.016E+01
4.108E+01	1.428E+02	6.848E+01	5.453E+01	2.314E+01
7.322E+01	4.647E+01	2.309E+01	3.254E+01	1.091E+02
2.788E+02	6.558E+01	4.978E+01	2.543E+01	1.773E+01
3.772E+01	5.456E+02	7.691E+01	1.009E+02	9.470E+01
5.282E+01	8.480E+01	1.133E+02	8.951E+01	6.093E+01
5.058E+01	1.568E+02	1.686E+02	6.817E+01	4.538E+01
4.064E+01	4.926E+01	6.278E+01	9.315E+01	2.378E+02
4.229E+02	3.426E+02	4.223E+02	6.313E+02	9.334E+02
8.129E+02	5.719E+02	3.540E+02	2.950E+02	2.503E+02
2.159E+02	1.896E+02	1.538E+02	1.418E+02	1.326E+02
1.256E+02	1.203E+02	1.164E+02	1.119E+02	1.110E+02
1.108E+02	1.112E+02	1.137E+02	1.156E+02	1.179E+02
1.205E+02	1.234E+02	1.300E+02	1.336E+02	1.374E+02
1.413E+02	1.454E+02	1.539E+02	1.583E+02	1.627E+02
1.673E+02	1.719E+02	1.812E+02	1.860E+02	1.908E+02
1.957E+02	2.007E+02	2.108E+02	2.160E+02	2.212E+02
2.266E+02	2.320E+02	2.432E+02	2.489E+02	2.548E+02
2.608E+02	2.669E+02	2.795E+02	2.861E+02	2.928E+02
2.996E+02	3.066E+02	3.212E+02	3.287E+02	3.365E+02
3.444E+02	3.525E+02	3.694E+02	3.782E+02	3.872E+02
3.965E+02	4.059E+02	4.256E+02	4.359E+02	4.464E+02
4.572E+02	4.682E+02	4.912E+02	5.031E+02	5.154E+02
5.280E+02	5.409E+02	5.677E+02	5.816E+02	5.959E+02
6.106E+02	6.256E+02	6.569E+02	6.731E+02	6.897E+02
7.068E+02	7.244E+02	7.608E+02	7.797E+02	7.991E+02

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8.190E+02  8.394E+02  8.603E+02  8.818E+02  9.038E+02  9.264E+02
9.496E+02  9.734E+02  9.977E+02  1.023E+03  1.048E+03  1.075E+03
1.102E+03  1.129E+03  1.158E+03  1.187E+03  1.216E+03  1.247E+03
1.278E+03  1.311E+03  1.344E+03  1.377E+03  1.412E+03  1.448E+03
1.484E+03  1.521E+03  1.560E+03  1.599E+03  1.639E+03  1.681E+03
1.723E+03  1.767E+03  1.811E+03  1.857E+03  1.904E+03  1.952E+03
2.001E+03  2.052E+03  2.103E+03  2.156E+03  2.211E+03  2.267E+03
2.324E+03  2.383E+03  2.443E+03  2.505E+03  2.568E+03
X(N,TWO-N) = 221*0.
*****

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GROUP CROSS-SECTIONS

RESIDUAL RESONANCE GROUP CROSS-SECTIONS BETWEEN 1.000E-01 AND 2.548E+01 EV

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* GYMEA LIBRARY CROSS-SECTIONS FOR U233 AT T= 300.0
U233,233,2

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X(N,G) =
-7.091E-02  2.603E+00  3.868E+00  -5.397E+00  1.157E+01  1.823E+01
-3.860E+02  3.992E+01  5.783E+01  1.470E+02
X(N,FISS) =
-1.444E+00  -8.783E+00  7.167E+01  -9.732E+01  1.199E+02  1.772E+02
-3.498E+03  3.807E+02  5.507E+02  1.399E+03
X(N,ABS) =
-1.515E+00  -6.180E+00  7.554E+01  -1.027E+02  1.315E+02  1.954E+02
-3.884E+03  4.206E+02  6.085E+02  1.546E+03
X(N,NU-FISS) =
-3.610E+00  -2.196E+01  1.792E+02  -2.433E+02  2.997E+02  4.430E+02
-8.745E+03  9.516E+02  1.377E+03  3.497E+03
X(N,TR) =
 9.531E+00  3.441E+00  8.595E+01  -9.482E+01  1.402E+02  2.044E+02
-3.875E+03  4.296E+02  6.175E+02  1.555E+03
X(N,TWO-N) = 10*0.
*****

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*RESONANCE DATA FOLLOWS-

```

12.880  2.548E+01  9.95E-04  4.50E-02  2.90E-01  5.83E-01  17 92 233
12.944  2.390E+01  1.64E-03  4.50E-02  9.00E-01  4.16E-01  17 92 233
13.005  2.250E+01  2.77E-04  4.50E-02  3.90E-01  5.83E-01  17 92 233
13.027  2.200E+01  1.01E-04  4.50E-02  2.05E-01  5.83E-01  17 92 233
13.085  2.076E+01  1.04E-04  4.50E-02  4.70E-01  5.83E-01  17 92 233
13.169  1.909E+01  1.67E-04  4.50E-02  2.40E-01  5.83E-01  17 92 233

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13.195	1.860E+01	1.63E+04	4.50E-02	1.15E-01	5.83E-01	17	92	233
13.222	1.810E+01	2.77E+04	4.50E-02	1.50E-01	5.83E-01	17	92	233
13.304	1.667E+01	4.41E+04	4.50E-02	1.40E-01	5.83E-01	17	92	233
13.326	1.632E+01	8.69E+04	4.50E-02	4.50E-01	5.83E-01	17	92	233
13.380	1.546E+01	8.93E+04	4.50E-02	1.90E-01	5.83E-01	17	92	233
13.487	1.389E+01	3.99E+04	4.50E-02	3.00E-01	5.83E-01	17	92	233
13.562	1.288E+01	1.23E+03	4.50E-02	2.50E-01	5.83E-01	17	92	233
13.677	1.148E+01	1.02E+04	4.50E-02	1.75E-01	5.83E-01	17	92	233
13.783	1.033E+01	1.74E+03	5.80E-02	2.70E-01	5.00E-01	17	92	233
13.888	9.300E+00	1.23E+04	4.50E-02	1.95E-01	5.00E-01	17	92	233
13.946	8.780E+00	1.99E+04	4.50E-02	7.00E-01	5.00E-01	17	92	233
14.094	7.570E+00	3.50E+05	4.50E-02	9.00E-02	5.00E-01	17	92	233
14.200	6.810E+00	7.47E+04	5.00E-02	9.80E-02	5.00E-01	17	92	233
14.286	6.250E+00	6.80E+05	1.00E+06	3.50E-01	1.00E+00	17	92	233
14.352	5.850E+00	1.20E+04	5.00E-02	3.20E-01	5.00E-01	17	92	233
14.549	4.800E+00	3.31E+04	8.60E-02	6.98E-01	5.00E-01	17	92	233
14.826	3.640E+00	1.87E+04	5.40E-02	2.06E-01	5.00E-01	17	92	233
15.282	2.307E+00	1.43E+04	4.10E-02	5.00E-02	5.00E-01	17	92	233
15.400	2.050E+00	3.08E+05	1.00E-06	3.00E-01	1.00E+00	17	92	233
15.558	1.750E+00	2.45E-04	1.20E-02	2.31E-01	5.00E-01	17	92	233
15.642	1.610E+00	2.55E-04	5.80E-02	7.03E-01	5.00E-01	17	92	233
18.421	1.000E-01	1.63E-05	1.04E-01	9.46E-01	5.00E-01	17	92	233

6*0.

EXECUTION TIME OF PROBLEM 1 IS 2 MINUTES, 26.20 SECS.

GROUP X-SECS. FOR U233 AT T=300. 1/E FLUX, ASYMMETRIC

GROUP CROSS-SECTIONS

* GYMEA LIBRARY CROSS-SECTIONS FOR U233 AT T= 300.0
 U233,233,0
 X(N,G)=
 5.068E+00 2.901E+01 3.804E+01 2.390E+01 1.157E+01 1.823E+01
 2.738E+01 3.992E+01 5.783E+01 1.470E+02
 X(N,FISS)=
 2.771E+01 1.051E+02 1.640E+02 3.298E+02 1.199E+02 1.772E+02
 2.622E+02 3.807E+02 5.507E+02 1.399E+03

```

X(N,ABS)=
  3.278E+01  1.341E+02  2.020E+02  3.537E+02  1.315E+02  1.954E+02
  2.895E+02  4.206E+02  6.085E+02  1.546E+03
X(N,NU-FISS)=
  6.928E+01  2.627E+02  4.100E+02  8.245E+02  2.997E+02  4.430E+02
  6.554E+02  9.516E+02  1.377E+03  3.497E+03
X(N,TR)=
  4.392E+01  1.441E+02  2.126E+02  3.619E+02  1.402E+02  2.044E+02
  2.985E+02  4.296E+02  6.175E+02  1.555E+03
X(N,TWO-N)= 10*0.
*****

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EXECUTION TIME OF PROBLEM 2 IS 0 MINUTES, 55.00 SECS.

GROUP X-SECS. FOR U233 AT T=300. 1/E FLUX, SYMMETRIC

GROUP CROSS-SECTIONS

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* GYMEA LIBRARY CROSS-SECTIONS FOR U233 AT T= 300.0
U233,233,0
X(N,G)=
  1.255E-02  1.435E-02  1.645E-02  1.893E-02  2.187E-02  2.586E-02
  3.015E-02  3.537E-02  4.185E-02  5.002E-02  6.058E-02  7.471E-02
  9.448E-02  1.241E-01  1.732E-01  2.700E-01  5.383E-01  2.588E+00
  6.590E+00  7.811E+00  8.854E+00  2.142E+00  2.248E+00  3.723E+00
  2.809E+01  5.641E+00  7.389E+01  2.041E+01  2.336E+01  7.872E+00
  2.311E+01  7.511E+01  1.681E+01  9.497E+00  1.416E+01  4.668E+01
  1.185E+02  1.880E+01  2.407E+01  1.051E+01  6.767E+00  7.312E+00
  2.933E+01  3.257E+01  5.419E+02  3.656E+01  1.726E+01  2.748E+01
  1.546E+01  1.506E+01  2.250E+01  2.938E+01  2.359E+01  1.724E+01
  1.656E+01  2.575E+01  7.592E+01  8.162E+01  2.901E+01  1.684E+01
  1.383E+01  1.406E+01  1.708E+01  2.527E+01  5.251E+01  2.528E+02
  4.837E+02  9.371E+01  5.627E+01  5.892E+01  8.273E+01  1.158E+02
  1.040E+02  7.903E+01  6.408E+01  5.392E+01  4.605E+01  3.986E+01
  3.505E+01  3.140E+01  2.862E+01  2.658E+01  2.508E+01  2.402E+01
  2.331E+01  2.288E+01  2.267E+01  2.266E+01  2.281E+01  2.309E+01
  2.349E+01  2.399E+01  2.457E+01  2.523E+01  2.594E+01  2.670E+01
  2.749E+01  2.832E+01  2.917E+01  3.002E+01  3.089E+01  3.175E+01
  3.261E+01  3.346E+01  3.429E+01  3.511E+01  3.591E+01  3.669E+01

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3.745E+01
 4.165E+01
 4.543E+01
 4.918E+01
 5.323E+01
 5.785E+01
 6.320E+01
 6.948E+01
 7.683E+01
 8.544E+01
 9.551E+01
 1.073E+02
 1.210E+02
 1.369E+02
 1.555E+02
 1.771E+02
 2.022E+02
 2.314E+02
 2.654E+02
 X(N,FISS) =
 1.008E-01
 2.442E-01
 8.343E-01
 5.882E+01
 8.265E+01
 1.470E+02
 5.564E+02
 7.710E+01
 1.086E+02
 1.045E+02
 8.932E+01
 8.651E+02
 1.628E+03
 4.246E+02
 2.572E+02
 2.417E+02
 2.714E+02
 3.149E+02
 3.575E+02
 3.9553E+02
 3.820E+01
 4.230E+01
 4.605E+01
 4.983E+01
 5.396E+01
 5.868E+01
 6.418E+01
 7.063E+01
 7.818E+01
 8.702E+01
 9.735E+01
 1.094E+02
 1.235E+02
 1.398E+02
 1.589E+02
 1.810E+02
 2.068E+02
 2.368E+02
 2.716E+02
 3.892E+01
 4.294E+01
 4.666E+01
 5.048E+01
 5.470E+01
 5.954E+01
 6.519E+01
 7.180E+01
 7.956E+01
 8.863E+01
 9.923E+01
 1.116E+02
 1.260E+02
 1.428E+02
 1.623E+02
 1.851E+02
 2.115E+02
 2.422E+02
 2.779E+02
 3.963E+01
 4.357E+01
 4.728E+01
 5.115E+01
 5.546E+01
 6.042E+01
 6.622E+01
 7.301E+01
 8.097E+01
 9.028E+01
 1.012E+02
 1.139E+02
 1.286E+02
 1.459E+02
 1.659E+02
 1.892E+02
 2.163E+02
 2.478E+02
 2.844E+02
 4.032E+01
 4.419E+01
 4.791E+01
 5.183E+01
 5.623E+01
 6.132E+01
 6.728E+01
 7.425E+01
 8.242E+01
 9.198E+01
 1.031E+02
 1.162E+02
 1.313E+02
 1.490E+02
 1.695E+02
 1.934E+02
 2.212E+02
 2.535E+02
 2.910E+02
 4.099E+01
 4.481E+01
 4.854E+01
 5.253E+01
 5.703E+01
 6.225E+01
 6.836E+01
 7.553E+01
 8.391E+01
 9.372E+01
 1.052E+02
 1.185E+02
 1.341E+02
 1.522E+02
 1.733E+02
 1.978E+02
 2.263E+02
 2.594E+02

2.080E-01
 6.454E-01
 2.053E+01
 2.080E+01
 4.703E+01
 2.207E+02
 3.669E+01
 1.920E+02
 1.241E+02
 9.720E+01
 4.965E+02
 1.886E+03
 4.921E+02
 2.689E+02
 2.399E+02
 2.649E+02
 3.074E+02
 3.508E+02
 3.893E+02
 4.242E+02
 1.778E-01
 5.139E-01
 5.051E+00
 2.014E+01
 1.091E+02
 6.630E+01
 5.160E+01
 2.041E+02
 1.809E+02
 1.412E+02
 2.030E+02
 1.292E+03
 5.809E+02
 2.849E+02
 2.394E+02
 2.589E+02
 3.000E+02
 3.438E+02
 3.832E+02
 4.185E+02
 1.533E-01
 4.179E-01
 2.568E+00
 1.820E+01
 1.373E+02
 4.702E+01
 1.003E+02
 1.561E+02
 2.298E+02
 3.408E+02
 1.394E+02
 8.724E+02
 6.994E+02
 3.066E+02
 2.406E+02
 2.535E+02
 2.926E+02
 3.368E+02
 3.770E+02
 4.128E+02
 1.328E-01
 3.454E-01
 1.612E+00
 8.403E+01
 2.869E+02
 9.307E+01
 1.318E+02
 1.093E+03
 1.740E+02
 3.197E+02
 1.102E+02
 7.111E+02
 8.662E+02
 3.354E+02
 2.436E+02
 2.487E+02
 2.853E+02
 3.296E+02
 3.707E+02
 4.070E+02

4.299E+02	4.356E+02	4.413E+02	4.471E+02	4.529E+02	4.588E+02
4.647E+02	4.708E+02	4.769E+02	4.832E+02	4.896E+02	4.961E+02
5.028E+02	5.096E+02	5.166E+02	5.237E+02	5.311E+02	5.386E+02
5.463E+02	5.542E+02	5.623E+02	5.706E+02	5.792E+02	5.880E+02
5.970E+02	6.063E+02	6.158E+02	6.256E+02	6.356E+02	6.459E+02
6.565E+02	6.674E+02	6.786E+02	6.900E+02	7.018E+02	7.139E+02
7.263E+02	7.391E+02	7.522E+02	7.656E+02	7.794E+02	7.936E+02
8.081E+02	8.231E+02	8.384E+02	8.541E+02	8.703E+02	8.868E+02
9.038E+02	9.213E+02	9.391E+02	9.575E+02	9.763E+02	9.957E+02
1.016E+03	1.036E+03	1.057E+03	1.078E+03	1.100E+03	1.123E+03
1.146E+03	1.169E+03	1.194E+03	1.219E+03	1.244E+03	1.271E+03
1.297E+03	1.325E+03	1.353E+03	1.382E+03	1.412E+03	1.443E+03
1.474E+03	1.506E+03	1.539E+03	1.573E+03	1.608E+03	1.643E+03
1.680E+03	1.717E+03	1.755E+03	1.795E+03	1.835E+03	1.876E+03
1.918E+03	1.962E+03	2.006E+03	2.052E+03	2.099E+03	2.147E+03
2.196E+03	2.247E+03	2.299E+03	2.352E+03	2.406E+03	2.462E+03
2.519E+03	2.578E+03	2.638E+03	2.700E+03	2.763E+03	
X(N,ABS) =					
1.133E-01	1.299E-01	1.492E-01	1.722E-01	1.997E-01	2.339E-01
2.744E-01	3.244E-01	3.873E-01	4.679E-01	5.745E-01	7.201E-01
9.288E-01	1.248E+00	1.785E+00	2.838E+00	5.589E+00	2.312E+01
6.541E+01	1.508E+02	9.288E+01	2.034E+01	2.239E+01	2.452E+01
1.107E+02	3.386E+01	3.608E+02	1.577E+02	1.325E+02	5.490E+01
1.701E+02	4.939E+02	1.099E+02	5.652E+01	8.046E+01	2.674E+02
6.749E+02	1.146E+02	1.559E+02	1.108E+02	5.837E+01	4.400E+01
1.064E+02	1.173E+02	1.635E+03	1.927E+02	2.214E+02	2.195E+02
1.241E+02	1.270E+02	1.965E+02	2.592E+02	2.045E+02	1.413E+02
1.211E+02	1.574E+02	3.956E+02	4.224E+02	1.702E+02	1.140E+02
1.031E+02	1.087E+02	1.273E+02	1.647E+02	2.555E+02	7.493E+02
1.349E+03	6.451E+02	7.674E+02	9.313E+02	1.375E+03	2.002E+03
1.732E+03	1.219E+03	9.303E+02	7.533E+02	6.269E+02	5.320E+02
4.596E+02	4.054E+02	3.640E+02	3.332E+02	3.100E+02	2.929E+02
2.805E+02	2.719E+02	2.663E+02	2.633E+02	2.622E+02	2.630E+02
2.652E+02	2.687E+02	2.733E+02	2.787E+02	2.848E+02	2.916E+02
2.989E+02	3.065E+02	3.145E+02	3.226E+02	3.309E+02	3.392E+02
3.475E+02	3.557E+02	3.639E+02	3.719E+02	3.797E+02	3.875E+02
3.949E+02	4.024E+02	4.096E+02	4.166E+02	4.235E+02	4.303E+02
4.369E+02	4.435E+02	4.499E+02	4.564E+02	4.627E+02	4.690E+02
4.753E+02	4.816E+02	4.880E+02	4.944E+02	5.008E+02	5.073E+02
5.139E+02	5.206E+02	5.274E+02	5.344E+02	5.414E+02	5.486E+02

5.560E+02 5.636E+02 5.713E+02 5.792E+02 5.873E+02 5.956E+02
 6.042E+02 6.129E+02 6.218E+02 6.310E+02 6.405E+02 6.503E+02
 6.602E+02 6.705E+02 6.810E+02 6.918E+02 7.029E+02 7.143E+02
 7.260E+02 7.380E+02 7.504E+02 7.630E+02 7.761E+02 7.894E+02
 8.031E+02 8.173E+02 8.318E+02 8.466E+02 8.618E+02 8.775E+02
 8.935E+02 9.101E+02 9.270E+02 9.444E+02 9.623E+02 9.805E+02
 9.993E+02 1.019E+03 1.038E+03 1.059E+03 1.079E+03 1.101E+03
 1.123E+03 1.145E+03 1.169E+03 1.192E+03 1.216E+03 1.241E+03
 1.267E+03 1.292E+03 1.320E+03 1.348E+03 1.375E+03 1.405E+03
 1.434E+03 1.465E+03 1.496E+03 1.528E+03 1.561E+03 1.595E+03
 1.630E+03 1.665E+03 1.701E+03 1.739E+03 1.778E+03 1.816E+03
 1.857E+03 1.898E+03 1.940E+03 1.984E+03 2.028E+03 2.074E+03
 2.120E+03 2.169E+03 2.218E+03 2.268E+03 2.320E+03 2.373E+03
 2.427E+03 2.484E+03 2.541E+03 2.600E+03 2.660E+03 2.721E+03
 2.784E+03 2.850E+03 2.916E+03 2.984E+03 3.054E+03

X(N,NU-FISS)

2.520E-01 2.888E-01 3.320E-01 3.833E-01 4.445E-01 5.200E-01
 6.105E-01 7.225E-01 8.635E-01 1.045E+00 1.285E+00 1.613E+00
 2.086E+00 2.810E+00 4.030E+00 6.420E+00 1.263E+01 5.133E+01
 1.470E+02 3.575E+02 2.101E+02 4.550E+01 5.035E+01 5.200E+01
 2.066E+02 7.055E+01 7.172E+02 3.432E+02 2.728E+02 1.176E+02
 3.675E+02 1.047E+03 2.327E+02 1.175E+02 1.657E+02 5.517E+02
 1.391E+03 2.396E+02 2.396E+02 3.295E+02 2.507E+02 1.290E+02
 1.927E+02 2.119E+02 2.733E+03 3.903E+02 5.103E+02 4.800E+02
 2.715E+02 2.797E+02 4.350E+02 5.745E+02 4.522E+02 3.103E+02
 2.613E+02 3.290E+02 2.367E+02 8.520E+02 3.530E+02 2.430E+02
 2.233E+02 2.367E+02 2.755E+02 3.485E+02 5.075E+02 1.241E+03
 2.163E+03 1.378E+03 1.778E+03 2.181E+03 3.230E+03 4.715E+03
 4.070E+03 2.850E+03 2.166E+03 1.748E+03 1.452E+03 1.230E+03
 1.061E+03 9.350E+02 8.385E+02 7.665E+02 7.123E+02 6.723E+02
 6.430E+02 6.225E+02 6.090E+02 6.015E+02 5.985E+02 5.997E+02
 6.042E+02 6.117E+02 6.217E+02 6.337E+02 6.472E+02 6.622E+02
 6.785E+02 6.955E+02 7.132E+02 7.315E+02 7.500E+02 7.685E+02
 7.872E+02 8.055E+02 8.240E+02 8.420E+02 8.595E+02 8.770E+02
 8.937E+02 9.105E+02 9.267E+02 9.425E+02 9.580E+02 9.732E+02
 9.882E+02 1.003E+03 1.017E+03 1.032E+03 1.046E+03 1.060E+03
 1.075E+03 1.089E+03 1.103E+03 1.118E+03 1.132E+03 1.147E+03
 1.162E+03 1.177E+03 1.192E+03 1.208E+03 1.224E+03 1.240E+03
 1.257E+03 1.274E+03 1.291E+03 1.309E+03 1.328E+03 1.346E+03
 1.366E+03 1.385E+03 1.406E+03 1.426E+03 1.448E+03 1.470E+03

1.492E+03	1.516E+03	1.539E+03	1.564E+03	1.589E+03	1.615E+03
1.641E+03	1.668E+03	1.696E+03	1.725E+03	1.755E+03	1.785E+03
1.816E+03	1.848E+03	1.880E+03	1.914E+03	1.948E+03	1.984E+03
2.020E+03	2.058E+03	2.096E+03	2.135E+03	2.176E+03	2.217E+03
2.260E+03	2.303E+03	2.348E+03	2.394E+03	2.441E+03	2.489E+03
2.540E+03	2.590E+03	2.643E+03	2.695E+03	2.750E+03	2.808E+03
2.865E+03	2.923E+03	2.985E+03	3.048E+03	3.110E+03	3.178E+03
3.243E+03	3.313E+03	3.383E+03	3.455E+03	3.530E+03	3.608E+03
3.685E+03	3.765E+03	3.848E+03	3.933E+03	4.020E+03	4.108E+03
4.200E+03	4.293E+03	4.388E+03	4.488E+03	4.588E+03	4.690E+03
4.795E+03	4.905E+03	5.015E+03	5.130E+03	5.248E+03	5.368E+03
5.490E+03	5.618E+03	5.747E+03	5.880E+03	6.015E+03	6.155E+03
6.297E+03	6.445E+03	6.595E+03	6.750E+03	6.908E+03	
X(N,TR) =	221*0.				
X(N,TWO-N) =	221*0.				

GROUP CROSS-SECTIONS

* GYMEA LIBRARY CROSS-SECTIONS FOR	U233	AT T=	300.0		
U233,233,0					
X(N,G) =					
1.020E+01	5.815E+01	7.690E+01	4.827E+01	2.648E+01	3.874E+01
4.927E+01	6.158E+01	7.920E+01	1.682E+02		
X(N,FISS) =					
5.582E+01	2.120E+02	3.405E+02	6.601E+02	2.654E+02	3.693E+02
4.657E+02	5.817E+02	7.489E+02	1.595E+03		
X(N,ABS) =					
6.602E+01	2.702E+02	4.174E+02	7.083E+02	2.919E+02	4.080E+02
5.150E+02	6.433E+02	8.281E+02	1.763E+03		
X(N,NU_FISS) =					
1.396E+02	5.301E+02	8.512E+02	1.650E+03	6.635E+02	9.231E+02
1.164E+03	1.454E+03	1.872E+03	3.987E+03		
X(N,TR) =	10*0.				
X(N,TWO-N) =	10*0.				

EXECUTION TIME OF PROBLEM 3 IS 1 MINUTES, 27.50 SECS.

EXECUTION TIME = 4.0 MINUTES 51.78 SECS.
LUBRA4 JOB(S) COMPLETED

APPENDIX H

H SAMPLE MONITOR INPUT DECK

THIS APPENDIX ILLUSTRATES THE DATA REQUIREMENTS FOR A TYPICAL LUBRA MONITOR RUN, WHICH MAY CONSIST OF THE FOLLOWING JOBS -

- 1) THE FIRST TWO LUBRA0 JOBS GIVEN IN APPENDIX C.1,
- 2) THE THREE LUBRA4 JOBS OF APPENDIX G.1, USING THE CROSS SECTION DATA PREPARED ON TAPE BY THE PRECEDING LUBRA0 PROBLEMS,
- 3) EVALUATION OF THE INFINITELY DILUTE RESONANCE INTEGRAL FOR U233 USING THE RESOLVED PARAMETERS ALREADY IN CORE, (THE UNRESOLVED PARAMETERS ARE CALCULATED BY THE CODE), FOLLOWED BY THE FIRST PROBLEM OF THE LUBRA1 INPUT GIVEN IN APPENDIX D.1. (USE OF 'NEXT' REQUIRES INPUT OF RESONANCE DATA DECK).
- 4) SIX LUBRA2 JOBS CALCULATING THE E.R.I. OF THE 1 EV RESONANCE OF PU240 FOR THE N.R. AND IR(3) MODELS AT T=0, 300,600 DEG.K, (N.B. SINCE NEW RESONANCE PARAMETERS ARE READ IN, COLUMN 15 OF THE CALL CARD MUST CONTAIN A '((')
- 5) FOURTEEN LUBRA3 JOBS USING THE TAPE OUTPUT OF THE PRECEDING LUBRA2 JOBS., THE FIRST TEN PROBLEMS CALCULATE THE DOPPLER COEFFICIENT AT TEMPERATURES 0(150)600 DEG.K FOR BOTH THE N.R. AND IR(3) MODELS, THE LAST FOUR CALCULATE THE AVERAGE D.C. FOR 300 DEGREE RANGES.
A MINIMUM NUMBER OF TAPES IS USED -
A TAPE ON UNIT 4 FOR THE OUTPUT FROM LUBRAS 0 AND 2,
A TAPE ON UNIT 3 FOR THE OUTPUT FROM LUBRAS 4,3,AND 1,
AND A SCRATCH TAPE ON UNIT 1 FOR LUBRA 3.

END OF COMMENTS

BEGINNING OF INPUT

'CALL LUBRA0,	CROSS SECTION DATA FOR U233 AT T=300.	CARD	1
ASYMMETRIC POINT	CROSS SECTIONS FOR U233 AT T=300.DEG.K	CARD	2
CARD INPUT OF RESONANCE DATA		CARD	3
18.421	0.100E+00 1.63E-05 1.04E-01 9.46E-01 0.500E+00	17 92	233RRP U233
15.642	1.610E+00 2.55E-04 5.80E-02 7.03E-01 0.500E+00	17 92	233RRP U233
15.558	1.750E+00 2.45E-04 1.20E-02 2.31E-01 0.500E+00	17 92	233RRP U233
15.400	2.050E+00 3.08E-05 1.00E-06 3.00E-01 1.000E+00	17 92	233RRP U233

15.282	2.307E+00	1.43E-04	4.10E-02	5.00E-02	0.500E+00	17 92	233RRP	U233
14.826	3.640E+00	1.87E-04	5.40E-02	2.06E-01	0.500E+00	17 92	233RRP	U233
14.549	4.800E+00	3.31E-04	8.60E-02	6.98E-01	0.500E+00	17 92	233RRP	U233
14.352	5.850E+00	1.20E-04	5.00E-02	3.20E-01	0.500E+00	17 92	233RRP	U233
14.286	6.250E+00	0.68E-04	1.00E-06	3.50E-01	1.000E+00	17 92	233RRP	U233
14.200	6.810E+00	7.47E-04	5.00E-02	0.98E-01	0.500E+00	17 92	233RRP	U233
14.094	7.570E+00	3.50E-05	4.50E-02	9.00E-02	0.500E+00	17 92	233RRP	U233
13.946	8.780E+00	1.99E-04	4.50E-02	7.00E-01	0.500E+00	17 92	233RRP	U233
13.888	9.300E+00	1.23E-04	4.50E-02	1.95E-01	0.500E+00	17 92	233RRP	U233
13.783	1.033E+01	1.74E-03	5.80E-02	2.70E-01	0.500E+00	17 92	233RRP	U233
13.677	1.148E+01	1.02E-04	4.50E-02	1.75E-01	5.83E-01	17 92	233RRP	U233
13.562	1.288E+01	1.23E-03	4.50E-02	2.50E-01	5.83E-01	17 92	233RRP	U233
13.487	1.389E+01	3.99E-04	4.50E-02	3.00E-01	5.83E-01	17 92	233RRP	U233
13.380	1.546E+01	8.93E-04	4.50E-02	1.90E-01	5.83E-01	17 92	233RRP	U233
13.326	1.632E+01	8.69E-04	4.50E-02	4.50E-01	5.83E-01	17 92	233RRP	U233
13.304	1.667E+01	4.41E-04	4.50E-02	1.40E-01	5.83E-01	17 92	233RRP	U233
13.222	1.810E+01	2.77E-04	4.50E-02	1.50E-01	5.83E-01	17 92	233RRP	U233
13.195	1.860E+01	1.63E-04	4.50E-02	1.15E-01	5.83E-01	17 92	233RRP	U233
13.169	1.909E+01	1.67E-04	4.50E-02	2.40E-01	5.83E-01	17 92	233RRP	U233
13.085	2.076E+01	1.04E-04	4.50E-02	4.70E-01	5.83E-01	17 92	233RRP	U233
13.027	2.200E+01	1.01E-04	4.50E-02	2.05E-01	5.83E-01	17 92	233RRP	U233
13.005	2.250E+01	2.77E-04	4.50E-02	3.90E-01	5.83E-01	17 92	233RRP	U233
12.944	2.390E+01	1.64E-03	4.50E-02	9.00E-01	4.16E-01	17 92	233RRP	U233
12.880	2.548E+01	9.95E-04	4.50E-02	2.90E-01	5.83E-01	17 92	233RRP	U233

C,4, ,4,2, ,1, 10.5
300.

11,
23. 0.05 12.
(F7.3,1P2E11.3,35X16H8 90 232NG U 233)
(F7.3,1P2E11.3,35X16H8 90 232NF U 233)
(F7.3,1P2E11.3,35X16H8 90 232TOTU233)
CONTINUE

SYMMETRIC POINT CROSS SECTIONS FOR U233 AT T=300.DEG.K
SAME OPTIONS FOR INPUT/OUTPUT, ENERGY GRID
300.

21,
SAME FORMATS AS FOR PREVIOUS PROBLEM
END

CARD 32
CARD 33
CARD 34
CARD 35
CARD 36
CARD 37
CARD 38
CARD 39
CARD 40
CARD 41
CARD 42
CARD 43
CARD 44
CARD 45
CARD 46

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'CALL LUBRA4,
GROUP X-SECS. FOR U233 AT T=300., 1/E FLUX, RESIDUAL RES. REMOVED,
3,T, ,4, ,3,
RESIDUAL RESONANCE REMOVAL ( RESONANCE PARAMETERS ALREADY IN CORE)
0.1 25.48
NO FLUX OUTPUT
GYMEA OUTPUT OF CROSS SECTIONS
1
2.5
10
12. 13.75 14.6 15.5 16.3 17.1 17.9
18.7 19.5 20.25 23.
C,
CONTINUE
GROUP X-SECS. FOR U233 AT T=300. AVERAGED OVER A 1/E FLUX, ASYMMETRIC
CONTINUE
GROUP X-SECS. FOR U233 AT T=300. AVERAGED OVER A 1/E FLUX, SYMMETRIC
1, ,S
NO REWIND/NEXT FILE
NO FLUX OUTPUT
GYMEA OUTPUT OF X-SECTION DATA
1
2.5
END
'CALL LUBRA1,
INFINITELY DILUTE RESONANCE INTEGRAL FOR U233 IN A 1/E FLUX
C,4, ,3,
0. 0.4 1. E+07
NEXT
LUBRA1 INFINITELY DILUTE RESONANCE INTEGRAL FOR TH232 IN A 1/E FLUX
C,4, ,3,
1
0. 0.4 E+07
13.034 2.184E+01 1.78E-03 2.15E-02 0.0 1.00E+00 17 90 232RRRPTH232
12.962 2.348E+01 3.20E-03 2.50E-02 0.0 1.00E+00 17 90 232RRRPTH232
12.031 5.955E+01 4.60E-03 2.08E-02 0.0 1.00E+00 17 90 232RRRPTH232
11.881 6.920E+01 4.24E-02 1.84E-02 0.0 1.00E+00 17 90 232RRRPTH232
11.392 1.129E+02 1.20E-02 1.50E-02 0.0 1.00E+00 17 90 232RRRPTH232
11.325 1.207E+02 1.85E-02 2.00E-02 0.0 1.00E+00 17 90 232RRRPTH232
CARD 47
CARD 48
CARD 49
CARD 50
CARD 51
CARD 52
CARD 53
CARD 54
CARD 55
CARD 56
CARD 57
CARD 58
CARD 59
CARD 60
CARD 61
CARD 62
CARD 63
CARD 64
CARD 65
CARD 66
CARD 67
CARD 68
CARD 69
CARD 70
CARD 71
CARD 72
CARD 73
CARD 74
CARD 75
CARD 76
CARD 77
CARD 78
CARD 79

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11.257	1.291E+02	3.41E-03	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
11.135	1.459E+02	3.60E-05	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
11.079	1.543E+02	1.24E-04	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
10.980	1.704E+02	5.80E-02	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
10.857	1.926E+02	1.40E-02	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
10.840	1.960E+02	3.51E-02	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
10.824	1.992E+02	1.10E-02	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
10.720	2.210E+02	3.13E-02	1.60E-02	0.0	1.00E+00	17 90	232RRPTH232
10.591	2.513E+02	3.17E-02	2.20E-02	0.0	1.00E+00	17 90	232RRPTH232
10.545	2.632E+02	1.90E-02	2.20E-02	0.0	1.00E+00	17 90	232RRPTH232
10.463	2.856E+02	2.80E-02	1.70E-02	0.0	1.00E+00	17 90	232RRPTH232
10.397	3.053E+02	2.62E-02	1.60E-02	0.0	1.00E+00	17 90	232RRPTH232
10.323	3.288E+02	6.89E-02	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
10.283	3.419E+02	3.61E-02	2.00E-02	0.0	1.00E+00	17 90	232RRPTH232
10.218	3.651E+02	2.79E-02	2.20E-02	0.0	1.00E+00	17 90	232RRPTH232
10.207	3.693E+02	2.79E-02	2.50E-02	0.0	1.00E+00	17 90	232RRPTH232
10.125	4.008E+02	1.00E-02	2.50E-02	0.0	1.00E+00	17 90	232RRPTH232

2.030E+01	1.20E-03	3.67E-02	0.0	1.00E+00	18 90	232URPTH232
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END
 'CALL LUBRA2, (RESONANCE DATA FOR PU240 1 EV RES. MUST BE READ IN
 LUBRA2 E.R.I.FOR 1EV RESONANCE OF PU240 AT T=0 DEG.K, NR MODEL
 I,C,4, ,4,1,B,R,

1	1	1	2	1			
BE	9	4.123	E-02	6.0			
PU240				10.0			
4.9476E-06							

16.066	1.054E+00	2.36E-03	3.40E-02	0.0	1.00E+00	17 94	240RRPPU240
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TEMP
 LUBRA2 E.R.I.FOR 1EV RESONANCE OF PU240 AT T=300 DEG.K, NR MODEL
 300.

TEMP							
LUBRA2 E.R.I.FOR 1EV RESONANCE OF PU240 AT T=600 DEG.K, NR MODEL							
600.							

CONTINUE
 LUBRA2 E.R.I. FOR 1EV RESONANCE OF PU240 AT T=600 DEG.K, IR(3) MODEL
 5,1,B
 TEMP

CARD	103
CARD	105
CARD	106
CARD	107
CARD	108
CARD	109
CARD	110
CARD	111
CARD	112
CARD	113
CARD	115
CARD	116
CARD	117
CARD	118
CARD	119
CARD	120
CARD	121
CARD	122
CARD	123
CARD	124

LUBRA2 E.R.I. FOR 1EV RESONANCE OF PU240 AT T=300 DEG.K, IR(3) MODEL
 300.
 TEMP CARD 125
 LUBRA2 E.R.I. FOR 1EV RESONANCE OF PU240 AT T= 0 DEG.K, IR(3)MODEL
 0.
 END CARD 126
 'CALL LUBRA3,
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T= 0 DEG.K, NR MODEL
 1,T,4,4,3, ,T,B,R CARD 127
 TEMP CARD 128
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T=150 DEG.K, NR MODEL
 T, 150. ,C
 TEMP CARD 129
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T=300 DEG.K, NR MODEL
 T, 300. ,T,
 TEMP CARD 130
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T=450 DEG.K, NR MODEL
 T, 450. ,C
 TEMP CARD 131
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T=600 DEG.K, NR
 T, 600.
 CONTINUE CARD 132
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T=600 DEG.K, IR(3)
 5, ,B
 TEMP CARD 133
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T=450 DEG.K, IR(3)
 T, 450. ,C
 TEMP CARD 134
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T= 300 DEG.K, IR(3)
 T, 300. ,T
 TEMP CARD 135
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T=150 DEG.K, IR(3)
 T, 150. ,C
 TEMP CARD 136
 LUBRA3 D.C. FOR PU240 1EV RESONANCE AT T= 0 DEG.K, IR(3)
 T
 REWIND CARD 137
 LUBRA3 AVERAGE D.C. FOR PU240 1EV RESONANCE, 0-300 DEG. K, NR MODEL
 1,T,4, ,3, ,R,B,R CARD 138
 CARD 139
 CARD 140
 CARD 141
 CARD 142
 CARD 143
 CARD 144
 CARD 145
 CARD 146
 CARD 147
 CARD 148
 CARD 149
 CARD 150
 CARD 151
 CARD 152
 CARD 153
 CARD 154
 CARD 155
 CARD 156
 CARD 157
 CARD 158
 CARD 159
 CARD 160
 CARD 161
 CARD 162
 CARD 163

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SKIP+2,C  
LUBRA3 AVERAGE D.C. FOR PU240 1EV RESONANCE, 0-300 DEG. K, IR(3) MODEL  
5, 'B  
SKIP-4,C  
LUBRA3 AVERAGE D.C. FOR PU240 1EV RESONANCE, 300-600 DEG. K, NR MODEL  
1, 'B  
CONTINUE  
LUBRA3 AVERAGE D.C. FOR PU240 1EV RESONANCE, 300-600 DEG. K, IR(3)MODEL  
5, 'B  
END  
'CEASE'
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CARD	164
CARD	165
CARD	166
CARD	167
CARD	168
CARD	169
CARD	170
CARD	171
CARD	172
CARD	173
CARD	174