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ORNL-TM-461

NEUTRON THERMALIZATION PROGRAMS FOR THE IBM 7090

C. A. Preskitt
E. A. Nephew
M. E. Tsagaris

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Abstract

A system of six codes is described which permits the solution of a broad class of problems encountered in the study of neutron thermalization, average cross sections, and spectral models. These programs are all compatible with use on MONITOR for the IBM 7090. The following nomenclature has been adopted for the members of the code group:

1. GTP – Gas Transfer Probability. This code calculates the scattering transfer kernel according to the Wigner-Wilkins formulation in which the scattering medium is assumed to have the properties of a free gas. The transfer matrices generated by the GTP code are stored in binary form on a KERNEL LIBRARY TAPE.

2. THR – Tape Handling Routine. This code is designed to make the KERNEL LIBRARY TAPE generated by the GTP program accessible to modification or inspection.

3. IMS – Infinite Medium Spectrum. This code obtains a numerical solution to the space independent Boltzmann equation by means of a normalized extrapolated Gauss iteration scheme.

4. TKS – Transfer Kernel Sources. This code evaluates the source terms appearing in the space independent Boltzmann equation which arise due to integration over a finite energy interval.

5. ACS – Average Cross Sections. This code performs the numerical integrations encountered in the calculation of spectrum averaged cross sections.

6. DCØM – Flux Decomposition. This code decomposes the spectrum obtained from an IMS calculation into a Maxwellian component and a residue component by least squares analysis.

NEUTRON THERMALIZATION PROGRAMS FOR THE IBM 7090

C. A. Preskitt, E. A. Nephew, and M. E. Tsagaris

Introduction

A group of programs for the IBM 7090 has been written to facilitate the calculation of neutron spectra in infinite homogeneous media. These programs are all compatible with use on MONITOR and are interlocking in the sense that they may share common blocks of input data and that the output of one program may be used as input to another. Figure 1 shows the inter-relationship among the codes. The nomenclature of Fig. 1 is the following:

1. GTP – Gas Transfer Probability. This code calculates the scattering transfer kernel according to the Wigner-Wilkins[1,2] formulation which treats the moderator as a monatomic gas with a Maxwellian distribution of nuclear velocities. The transfer matrices generated by the GTP code are stored in binary form on a KERNEL LIBRARY TAPE.

2. THR – Tape Handling Routine. This code is designed to make the KERNEL LIBRARY TAPE accessible to modification or inspection.

3. IMS – Infinite Medium Spectrum. The IMS code obtains a numerical solution to the space independent Boltzmann equation by means of a normalized extrapolated Gauss iteration scheme.

4. TKS – Transfer Kernel Sources. This code evaluates the residue or source terms in the Boltzmann equation arising from limiting the integration range to a finite energy interval.

5. ACS – Average Cross Sections. The ACS code performs the numerical integrations encountered in the calculation of spectrum averaged cross sections.

6. DCØM – Flux Decomposition. This code decomposes the IMS spectra into a Maxwellian component and a residue component by the method of least squares.

It is noted that the above programs are constructed so that they may be used either separately or together in a chain-like sequence. As an example of the sequential operations depicted in Fig. 1, we consider the case where it is desired to obtain the neutron energy distribution for an infinite homogeneous region with a specific moderator temperature and mass number together with a given macroscopic absorption cross section $\Sigma_a(E)$ for the region. First, the kernel code GTP, or one based on an alternate

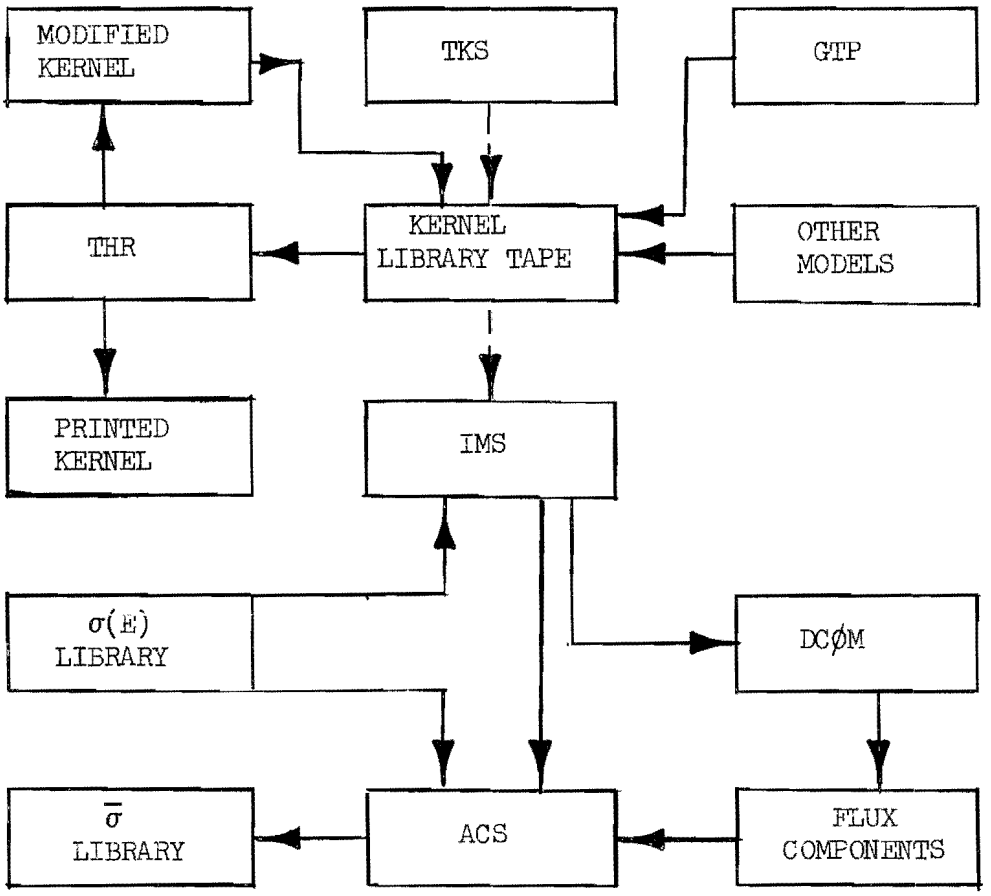

Fig. 1. Diagram Showing the Useful Data Transfers Between the Programs.

model, is used to generate a complete energy transfer matrix which together with its identification, energy mesh, and source data is stored on the KERNEL LIBRARY TAPE. The spectrum code IMS then uses the energy transfer matrix as input data together with decks from the cross section library $\sigma(E)$ in obtaining a numerical solution to the space independent Boltzmann equation. The output of the IMS code optionally may include a deck of cards specifying the converged flux values for each point of the energy mesh specified in the transfer kernel. This deck can then be used directly as input to either the ACS or DCØM codes. The various options and provisions for stacking cases will be described fully in the latter sections of the report describing the individual codes.

I. Mathematical Formulation of the Neutron Thermalization Problem

In an infinite homogeneous medium the neutron flux obeys the space independent Boltzmann equation which, in integral form, may be written as

$$\Sigma_a(E)\ \phi(E) + \phi(E) \int_0^\infty \Sigma(E \to E')\ dE' = \int_0^\infty \phi(E')\ \Sigma(E' \to E)\ dE' , \quad (1)$$

where $\Sigma_a(E)$ and $\phi(E)$ are the absorption cross section and flux per unit energy at the energy E, and $\Sigma(E \to E')$ is an energy transfer kernel. This kernel is defined in such a way that the product $\phi(E)\ \Sigma(E \to E')$ gives the number of neutrons (per cm^3/sec) per unit energy interval at energy E which are scattered into a unit energy interval at E′ (per cm^3/sec).

In order to reduce the problem to a finite energy interval, Eq. (1) is written as

$$\Sigma'(E)\ \phi(E) + \phi(E) \int_{E_1}^{E_2} \Sigma(E \to E')\ dE' = \int_{E_1}^{E_2} \phi(E')\ \Sigma(E' \to E)\ dE' + S'(E) , \quad (2)$$

where

$$S'(E) = \int_0^{E_1} \phi(E')\ \Sigma(E' \to E)\ dE' + \int_{E_2}^\infty \phi(E')\ \Sigma(E' \to E)\ dE'$$

and

$$\Sigma'(E) = \Sigma_a(E) + \int_0^{E_1} \Sigma(E \to E')\ dE' + \int_{E_2}^\infty \Sigma(E \to E')\ dE' .$$

Equation (2) can be solved numerically for $\phi(E)$ if the two functions $S'(E)$ and $\Sigma'(E)$ are provided. It is noted that only the function $S'(E)$ requires an assumption to be made concerning the flux and that only outside the energy interval $E_1 \leqslant E \leqslant E_2$. At the slight penalty of having to extend the energy over which an assumption must be made concerning the flux, we may combine the functions $S'(E)$ and $\Sigma'(E)$ into a single function $S(E)$, thus reducing the required amount of input data. The space independent Boltzmann equation becomes

$$\Sigma_a(E)\ \phi(E) + \phi(E) \int_{E_1}^{E_2} \Sigma(E \rightarrow E')\ dE' = \int_{E_1}^{E_2} \phi(E')\ \Sigma(E' \rightarrow E)\ dE' + S(E)\ , \tag{3}$$

where

$$S(E) = \int_{E_2}^{\infty} \phi(E')\ \Sigma(E' \rightarrow E)\ dE' - \phi(E) \int_{E_2}^{\infty} \Sigma(E \rightarrow E')\ dE'$$

$$+ \int_{0}^{E_1} \phi(E')\ \Sigma(E' \rightarrow E)\ dE' - \phi(E) \int_{0}^{E_1} \Sigma(E \rightarrow E')\ dE'\ . \tag{4}$$

It is seen that the first two terms of Eq. (4) represent the net number of neutrons (per cm^3/sec) entering the finite energy interval at E, $E_1 \leqslant E \leqslant E_2$, from above E_2 and the second two terms represent the corresponding net number entering the interval from below E_1. S(E) is, furthermore, a function of the flux within the energy interval. However if E_2 is chosen sufficiently large so as to be in the asymptotic flux region, the source term S(E) is relatively insensitive to the minor departure of the flux shape from 1/E.

The neutron thermalization programs described in this report obtain solutions to the space independent Boltzmann equation as represented by Eqs. (3) and (4). Program GTP provides the matrix $\Sigma(E \rightarrow E')$ appearing in both Eqs. (3) and (4), program TKS computes the source terms S(E) represented by Eq. (4), and program IMS obtains a numerical solution to Eq. (3) by an extrapolated normalized Gauss iteration method.

II. GTP – An IBM 7090 Program for the Calculation of Free-Gas Energy Transfer Kernels

Description of the Problem

Program GTP calculates the quantities $\Sigma(E \rightarrow E')$ appearing in Eqs. (3) and (4) for the case of scattering from free-gas atoms in thermal equilibrium and having no internal degrees of freedom. The further approximation is made that the free atom scattering cross section may be written in the following form:

$$\sigma_s(E) = \sum_i \sigma_i \, e^{-\gamma_i E} ,$$

where the sum over i includes as many terms as necessary to adequately represent the cross section, up to a maximum of five terms.

When the above conditions are satisfied, then we may write

$$\sigma(E \rightarrow E') = \sum_i \sigma_i \, P_i(E \rightarrow E') , \tag{5a}$$

where the probability $P_i(E \rightarrow E')$ is defined below. Note that the thermal motion of the scattering atoms results in a normalization of the cross section such that

$$\int_0^\infty \sigma(E \rightarrow E') \, dE' = \sigma_s(E) \frac{\bar{v}_r}{v_n} ,$$

where $\bar{v}_r$ is the average relative velocity between the two particles and v_n is the neutron velocity in the laboratory system. In the limits of large mass for the scattering atom or large incident neutron energy this ratio approaches unity.

The expression for $P_i(E_1 \rightarrow E_2)$ may be written[1] as

$$P_i(E_1 \to E_2) = \frac{\eta^2}{2E_1} \frac{\tau_i^3}{\lambda_i} \left\{ \exp\left[- \frac{\gamma_i \tau_i^2}{2\beta^2} X_1^2 \right] \left[\mathrm{erf}(\eta_i X_i - \rho_i X_2) \right.\right.$$

$$\left. \pm \mathrm{erf}(\eta_i X_1 + \rho_i X_2) \right] + \left[\mathrm{erf}(\eta_i X_2 - \rho_i X_1) \mp \mathrm{erf}(\eta_i X_2 + \rho_i X_1) \right] \times$$

$$\left. \left[\exp(X_1^2 - \lambda_i X_2^2 \right] \right\} , \tag{5b}$$

where

$$X_1^2 = \frac{E_1}{kT} , \qquad X_2^2 = \frac{E_2}{kT} , \qquad \beta = \frac{1}{2kT} ,$$

$$\tau_i = \frac{2M\beta^2}{2M\beta^2 + \gamma_i} , \qquad \lambda_i = 1 + M(1 - \tau_i^2) ,$$

$$\eta_i = \frac{M + 1}{2\tau_i \sqrt{M}} , \qquad \rho_i = \tau_i \sqrt{M} - \eta_i ,$$

and M is the ratio of the mass of the scatterer to the neutron mass. The upper signs apply in Eq. (5) when $E_1 > E_2$ and the lower signs when $E_1 \leqslant E_2$.

At each point in a mesh of neutron energies, program GTP uses Eqs. (5a) and (5b) to calculate the transfer probability to all lower energies and uses the condition of detailed balance to calculate the transfer probability to all higher energies. It is easy to see that the kernel must satisfy detailed balance by examining Eq. (1) for the case of zero absorption cross section. For this case the neutrons will come into thermal equilibrium with the moderator atoms and will assume a Maxwellian distribution. Equation (1) then becomes

$$M(E) \int_0^\infty \Sigma(E \to E') \, dE' = \int_0^\infty M(E') \, \Sigma(E' \to E) \, dE' , \tag{6}$$

where

$$M(E) = \frac{E}{(kT)^2} \exp(- \frac{E}{kT}).$$

The condition on $\Sigma(E' \rightarrow E)$ which is required in order that $M(E)$ be the solution to Eq. (6) is obviously

$$M(E)\ \Sigma(E \rightarrow E') = M(E')\ \Sigma(E' \rightarrow E)\ ,$$

which is the condition of detailed balance between energies E and E′.

Due to the fact that the error function approaches unity for large values of its argument, difficulty is encountered in obtaining accurate kernels for large initial or final energies. Even though the function itself may be known to one part in 10^6, the availability of only eight significant digits in a 7090 floating point number may result in complete loss of significance when the subtractions in Eq. (5) are made. To circumvent this difficulty the quantity $1 - \mathrm{erf}(x)$ is calculated to high accuracy by rational approximation,[3] and the relationship

$$\mathrm{erf}(y) - \mathrm{erf}(x) = 1 - \mathrm{erf}(x) - [1 - \mathrm{erf}(y)]$$

is used whenever a subtraction occurs.

Preparation of Input Data

The input data required to do a calculation consist of values for the moderator temperature and mass ratio, expansion constants for the free atom scattering cross section, and a specification of the energy at each point in the energy mesh. In addition, values of the function S(E) as defined by Eq. (4) are required for each point of the energy mesh. These source values, which are obtained either from the TKS code or approximated by hand calculation, are not used in calculating the kernel but must be available for transmission to the kernel library tape at execution time. It may be noted that a dummy set of sources can be used at the time of the kernel calculation since the tape handling routine, THR, provides a means of subsequently writing in the correct sources. All data are supplied on the Ten Digit Data Form and must be assembled in the following order.

1. Card 1. Column 1 must contain a 1-punch. Columns 2-66 may contain any alphabetic or numeric information which identifies the calculation. Columns 71-72 must contain the kernel number assigned to the calculated kernel. If no decimal point is specified in the kernel number

it is assumed to be to the immediate right of column 72. The contents of this card will appear at the top of each page of printed output.

2. Card 2.

Field 1. Moderator temperature in degrees Kelvin.

Field 2. Ratio of the moderator mass to the neutron mass.

Field 3. Number of points in the energy mesh. This must be an odd number less than or equal to 161 in order to be consistent with the requirements of the IMS code described later.

Field 4. Number of terms in the expansion of the free atom scattering cross section. This must be less than or equal to 5.

3. Cards 3. These cards contain up to three pairs of numbers per card giving values of σ_i and γ_i for the expansion of the free atom scattering cross section. The number of pairs is specified in field 4 of card 2. If this control number is set equal to zero, then the free atom cross section is assumed to be independent of energy and equal to unity.

4. Cards 4. These cards contain the energy, in electron volts, at each point of the mesh. The values are given in order with the lowest energy given first. The number zero may not be specified as the lowest energy. Seven numbers per card are punched, or less if required on the last card. The number of energies listed must equal the number punched in field 3 of card 2.

5. Cards 5. These cards contain the values of the sources for each point of the energy mesh. The values are given in exact correspondence to the energy values stipulated in cards 3 and are likewise written seven numbers to the card, or less if required on the last card.

6. Card 6. If a final data card containing a 00 in columns 71-72 is added for either a single kernel calculation or a series of calculations, an end of file mark will be put on logical tapes 2 and 3 following the last recorded kernel. Although not strictly necessary, such an end of file mark may be convenient in certain cases.

Considerable freedom is allowed in the format of the input numbers. All numbers must contain a decimal point even if they are integers. The most convenient form is that of a decimal fraction with 10 or less digits including the decimal point (1.34, 21.9, etc.), but an exponential notation may be used. If this is done, the exponent must be separated from

the characteristic by a plus or minus sign and must be written in the appropriate exponent field beginning in column 9, 19, etc. Both columns of the exponent field must be filled, with zero for the first column if necessary. The same liberty permitted in the format of the GTP program input numbers is applicable to each of the other codes of the system.

Output

Each transfer matrix calculated by the GTP code for a given moderator temperature and mass number is stored on three different tapes. Logical tapes 2 and 3 are permanent and constitute the KERNEL LIBRARY TAPE, with spare. Each kernel on the library tape consists of five records. The first record contains the kernel title and number in BCD form. Information on the remaining four records is stored in binary form. The second and third records contain, respectively, the size of the energy mesh and the points comprising the energy mesh in electron volts. The fourth record contains the source terms defined by Eq. (4), whereas the fifth record contains the energy transfer matrix calculated by the GTP code according to Eq. (5). It is emphasized that the KERNEL LIBRARY TAPE constitutes a more or less permanent compilation of all the kernels which have been calculated, each identifiable by a different kernel number. Newly calculated kernels are automatically added at the end of the tape. An exception to this is in storing the first kernel, in which case logical tapes 2 and 3 must first be initialized by option 1 of the THR code. This option writes the number -100 on logical tapes 2 and 3 at a position corresponding to the kernel number field of the title card and enables the GTP program to begin writing kernels at the beginning of the tapes.

In addition to the kernel library tapes (2 and 3) the results of a particular kernel calculation are stored in BCD form on logical tape 9. This tape may be listed to obtain a printed record of the calculated kernel.

The Fortran listing of the GTP code, input data form,and a sample problem data sheet are given in the following pages. Due to the large size of the sample problem kernel, only a few pages of output are included.

TEN DIGIT DATA FORM

PROBLEM	REQUEST
GTP	3325

CODER	DATE	PAGE
MET	10-26-62	1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 - GTP.- CØLUMNS-2-66-AVAILABLE-FØR-IDENTIFICATIØN.-KERNEL-NØ.-IN-CØLUMNS-71-72														KN	1
TEMP(°K)		MASS		N		NB									2
σ_1		γ_1		σ_2		γ_2									3
E_1(ev)		E_2		E_3		E_4		E_5		E_6		E_7			4
E_8								E_N							4
S_1		S_2		S_3		S_4		S_5		S_6		S_7			5
S_8								S_N							5
														00	6

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GTP INPUT DATA FORM

TEN DIGIT DATA FORM

PROBLEM: GTP

REQUEST: 3325

CODER: MET

DATE: 10-26-62

PAGE: 1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 ← FG-600K-A=12-MSH(.0001(161)				5.0)-S(APPRØX.)-(GTP-3)-									→	02	1
600.0		12.0		161.0		0.0									2
1.0	-4	1.8	-4	3.0	-4	5.0	-4	7.0	-4	1.0	-3	1.42	-3		3
2.1	-3	2.82	-3	3.7	-3	4.7	-3	5.8	-3	7.03	-3	8.4	-3		3
9.84	-3	1.15	-2	1.31	-2	1.69	-2	2.11	-2	2.58	-2	3.1	-2		3
3.67	-2	4.28	-2	4.94	-2	5.64	-2	6.4	-2	7.20	-2	8.05	-2		3
8.94	-2	9.89	-2	1.09	-1	1.19	-1	1.3	-1	1.41	-1	1.53	-1		3
1.65	-1	1.78	-1	1.91	-1	2.05	-1	2.19	-1	2.34	-1	2.49	-1		3
2.65	-1	2.75	-1	2.81	-1	2.90	-1	2.97	-1	3.07	-1	3.14	-1		3
3.25	-1	3.32	-1	3.40	-1	3.49	-1	3.6	-1	3.68	-1	3.87	-1		3
4.06	-1	4.26	-1	4.46	-1	4.67	-1	4.88	-1	5.10	-1	5.32	-1		3
5.55	-1	5.78	-1	6.02	-1	6.26	-1	6.5	-1	6.75	-1	7.01	-1		3
7.27	-1	7.53	-1	7.80	-1	8.08	-1	8.35	-1	8.64	-1	8.93	-1		3
9.22	-1	9.52	-1	9.82	-1	1.01		1.04		1.07		1.11			3
1.14		1.17		1.21		1.24		1.28		1.31		1.35			3
1.38		1.42		1.45		1.49		1.53		1.57		1.61			3
1.65		1.69		1.73		1.77		1.81		1.85		1.89			3
1.93		1.98		2.02		2.06		2.11		2.15		2.20			3
2.24		2.29		2.34		2.38		2.43		2.48		2.53			3
2.58		2.63		2.68		2.73		2.78		2.83		2.88			3
2.94		3.0		3.04		3.10		3.15		3.21		3.26			3
3.32		3.37		3.43		3.49		3.54		3.60		3.66			3
3.72		3.78		3.84		3.90		3.96		4.02		4.08			3
4.15		4.21		4.27		4.34		4.4		4.47		4.53			3
4.60		4.66		4.73		4.80		4.86		4.93		5.0			3

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SAMPLE PROBLEM INPUT

TEN DIGIT DATA FORM

PROBLEM: GTP | REQUEST: 3325

CODER: MET | DATE: 10-26-62 | PAGE: 2 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
0.0		0.0		0.0		0.0		0.0		0.0		0.0			4
															4
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															4
										0.0		0.0			4
0.0		0.0		0 0.0		0.0		0.0		.02492		.097690			4
.168112		.236299		.302354		.366378		.428461		.488691		.547150			4
.613215		.668093		.721430		.781792		.832002		.888878		.936228			4
.989909		1.03464		1.08539		1.13466		1.17576		1.22245		1.26783			4

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SAMPLE PROBLEM INPUT (contd.)

FG 600K A=12 MSM(.0001(161)5.0) S(APPROX.) (GTP-3) 2.

SIZE, 161

ENERGY	SOURCE	ENERGY	SOURCE	ENERGY	SOURCE	ENERGY	SOURCE	ENERGY	SOURCE
10.0000E-05	0.	1.4100E-01	0.	6.2600E-01	0.	1.6900E 00	0.	3.2600E 00	0.
1.8000E-04	0.	1.5300E-01	0.	6.5000E-01	0.	1.7300E 00	0.	3.3200E 00	0.
3.0000E-04	0.	1.6500E-01	0.	6.7500E-01	0.	1.7700E 00	0.	3.3700E 00	0.
5.0000E-04	0.	1.7800E-01	0.	7.0100E-01	0.	1.8100E 00	0.	3.4300E 00	0.
7.0000E-04	0.	1.9100E-01	0.	7.2700E-01	0.	1.8500E 00	0.	3.4900E 00	0.
10.0000E-04	0.	2.0500E-01	0.	7.5300E-01	0.	1.8900E 00	0.	3.5400E 00	0.
1.4200E-03	0.	2.1900E-01	0.	7.8000E-01	0.	1.9300E 00	0.	3.6000E 00	2.4920E-02
2.1000E-03	0.	2.3400E-01	0.	8.0800E-01	0.	1.9800E 00	0.	3.6600E 00	9.7690E-02
2.8200E-03	0.	2.4900E-01	0.	8.3500E-01	0.	2.0200E 00	0.	3.7200E 00	1.6811E-01
3.7000E-03	0.	2.6500E-01	0.	8.6400E-01	0.	2.0600E 00	0.	3.7800E 00	2.3630E-01
4.7000E-03	0.	2.7500E-01	0.	8.9300E-01	0.	2.1100E 00	0.	3.8400E 00	3.0235E-01
5.8000E-03	0.	2.8100E-01	0.	9.2200E-01	0.	2.1500E 00	0.	3.9000E 00	3.6638E-01
7.0300E-03	0.	2.9000E-01	0.	9.5200E-01	0.	2.2000E 00	0.	3.9600E 00	4.2846E-01
8.4000E-03	0.	2.9700E-01	0.	9.8200E-01	0.	2.2400E 00	0.	4.0200E 00	4.8869E-01
9.8400E-03	0.	3.0700E-01	0.	1.0100E 00	0.	2.2900E 00	0.	4.0800E 00	5.4715E-01
1.1500E-02	0.	3.1400E-01	0.	1.0400E 00	0.	2.3400E 00	0.	4.1500E 00	6.1321E-01
1.3100E-02	0.	3.2500E-01	0.	1.0700E 00	0.	2.3800E 00	0.	4.2100E 00	6.6809E-01
1.6900E-02	0.	3.3200E-01	0.	1.1100E 00	0.	2.4300E 00	0.	4.2700E 00	7.2143E-01
2.1100E-02	0.	3.4000E-01	0.	1.1400E 00	0.	2.4800E 00	0.	4.3400E 00	7.8179E-01
2.5800E-02	0.	3.4900E-01	0.	1.1700E 00	0.	2.5300E 00	0.	4.4000E 00	8.3200E-01
3.1000E-02	0.	3.6000E-01	0.	1.2100E 00	0.	2.5800E 00	0.	4.4700E 00	8.8888E-01
3.6700E-02	0.	3.6800E-01	0.	1.2400E 00	0.	2.6300E 00	0.	4.5300E 00	9.3623E-01
4.2800E-02	0.	3.8700E-01	0.	1.2800E 00	0.	2.6800E 00	0.	4.6000E 00	9.8991E-01
4.9400E-02	0.	4.0600E-01	0.	1.3100E 00	0.	2.7300E 00	0.	4.6600E 00	1.0346E 00
5.6400E-02	0.	4.2600E-01	0.	1.3500E 00	0.	2.7800E 00	0.	4.7300E 00	1.0854E 00
6.4000E-02	0.	4.4600E-01	0.	1.3800E 00	0.	2.8300E 00	0.	4.8000E 00	1.1347E 00
7.2000E-02	0.	4.6700E-01	0.	1.4200E 00	0.	2.8800E 00	0.	4.8600E 00	1.1758E 00
8.0500E-02	0.	4.8800E-01	0.	1.4500E 00	0.	2.9400E 00	0.	4.9300E 00	1.2224E 00
8.9400E-02	0.	5.1000E-01	0.	1.4900E 00	0.	3.0000E 00	0.	5.0000E 00	1.2678E 00
9.8900E-02	0.	5.3200E-01	0.	1.5300E 00	0.	3.0400E 00	0.	0.	0.
1.0900E-01	0.	5.5500E-01	0.	1.5700E 00	0.	3.1000E 00	0.	0.	0.
1.1900E-01	0.	5.7800E-01	0.	1.6100E 00	0.	3.1500E 00	0.	0.	0.
1.3000E-01	0.	6.0200E-01	0.	1.6500E 00	0.	3.2100E 00	0.	0.	0.

FG 600K A=12 MSH(.0001(161)5.0)S(APPROX.) (GTP-3) 2.

INITIAL ENERGY,10.00000E-05

FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY
10.00E-05	5.0439E 02	1.41E-01	3.5410E-02	6.26E-01	1.7807E-16	1.69E 00	0.	3.26E 00	0.
1.80E-04	5.0164E 02	1.53E-01	1.5681E-02	6.50E-01	3.4913E-17	1.73E 00	0.	3.32E 00	0.
3.00E-04	4.9754E 02	1.65E-01	6.9441E-03	6.75E-01	6.3958E-18	1.77E 00	0.	3.37E 00	0.
5.00E-04	4.9065E 02	1.78E-01	2.8733E-03	7.01E-01	1.0947E-18	1.81E 00	0.	3.43E 00	0.
7.00E-04	4.8422E 02	1.91E-01	1.1889E-03	7.27E-01	1.8738E-19	1.85E 00	0.	3.49E 00	0.
10.00E-04	4.7445E 02	2.05E-01	4.5964E-04	7.53E-01	3.2073E-20	1.89E 00	0.	3.54E 00	0.
1.42E-03	4.6112E 02	2.19E-01	1.7770E-04	7.80E-01	0.	1.93E 00	0.	3.60E 00	0.
2.10E-03	4.4032E 02	2.34E-01	6.4193E-05	8.08E-01	0.	1.98E 00	0.	3.66E 00	0.
2.82E-03	4.1932E 02	2.49E-01	2.3189E-05	8.35E-01	0.	2.02E 00	0.	3.72E 00	0.
3.70E-03	3.9501E 02	2.65E-01	7.8269E-06	8.64E-01	0.	2.06E 00	0.	3.78E 00	0.
4.70E-03	3.6909E 02	2.75E-01	3.9699E-06	8.93E-01	0.	2.11E 00	0.	3.84E 00	0.
5.80E-03	3.4253E 02	2.81E-01	2.6418E-06	9.22E-01	0.	2.15E 00	0.	3.90E 00	0.
7.03E-03	3.1510E 02	2.90E-01	1.4341E-06	9.52E-01	0.	2.20E 00	0.	3.96E 00	0.
8.40E-03	2.8714E 02	2.97E-01	6.9167E-07	9.82E-01	0.	2.24E 00	0.	4.02E 00	0.
9.84E-03	2.6036E 02	3.07E-01	4.5227E-07	1.01E 00	0.	2.29E 00	0.	4.08E 00	0.
1.15E-02	2.3265E 02	3.14E-01	2.8121E-07	1.04E 00	0.	2.34E 00	0.	4.15E 00	0.
1.31E-02	2.0809E 02	3.25E-01	1.3327E-07	1.07E 00	0.	2.38E 00	0.	4.21E 00	0.
1.69E-02	1.6124E 02	3.32E-01	8.2865E-08	1.11E 00	0.	2.43E 00	0.	4.27E 00	0.
2.11E-02	1.2125E 02	3.40E-01	4.8142E-08	1.14E 00	0.	2.48E 00	0.	4.34E 00	0.
2.58E-02	8.6132E 01	3.49E-01	2.6133E-08	1.17E 00	0.	2.53E 00	0.	4.40E 00	0.
3.10E-02	6.1923E 01	3.60E-01	1.2385E-08	1.21E 00	0.	2.58E 00	0.	4.47E 00	0.
3.67E-02	4.2055E 01	3.68E-01	7.1952E-09	1.24E 00	0.	2.63E 00	0.	4.53E 00	0.
4.28E-02	2.7797E 01	3.87E-01	1.9311E-09	1.28E 00	0.	2.68E 00	0.	4.60E 00	0.
4.94E-02	1.7759E 01	4.06E-01	5.4544E-10	1.31E 00	0.	2.73E 00	0.	4.66E 00	0.
5.64E-02	1.1042E 01	4.26E-01	1.4032E-10	1.35E 00	0.	2.78E 00	0.	4.73E 00	0.
6.40E-02	6.5922E 00	4.46E-01	3.6097E-11	1.38E 00	0.	2.83E 00	0.	4.80E 00	0.
7.20E-02	3.8300E 00	4.67E-01	8.6765E-12	1.42E 00	0.	2.88E 00	0.	4.86E 00	0.
8.05E-02	2.1510E 00	4.88E-01	2.0855E-12	1.45E 00	0.	2.94E 00	0.	4.93E 00	0.
8.94E-02	1.1796E 00	5.10E-01	4.6839E-13	1.49E 00	0.	3.00E 00	0.	5.00E 00	0.
9.89E-02	6.1690E-01	5.32E-01	1.0519E-13	1.53E 00	0.	3.04E 00	0.	0.	1.7219E-40
1.09E-01	3.1079E-01	5.55E-01	2.2074E-14	1.57E 00	0.	3.10E 00	0.	0.	0.0574E-40
1.19E-01	1.5704E-01	5.78E-01	4.6321E-15	1.61E 00	0.	3.15E 00	0.	0.	-1.2931E-26
1.30E-01	7.4714E-02	6.02E-01	9.0821E-16	1.65E 00	0.	3.21E 00	0.	0.	1.8845E-37

FE 600K A=12 MSM(.0001(161)5.0)S(APPROX.) (GTP-3) 2.

INITIAL ENERGY, 1.80000E-04

FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY
10.00E-05	2.7911E 02	1.41E-01	2.7186E-02	6.26E-01	1.4775E-16	1.69E 00	0.	3.26E 00	0.
1.80E-04	3.7590E 02	1.53E-01	1.2063E-02	6.50E-01	2.9074E-17	1.73E 00	0.	3.32E 00	0.
3.00E-04	3.7266E 02	1.65E-01	5.3528E-03	6.75E-01	5.3463E-18	1.77E 00	0.	3.37E 00	0.
5.00E-04	3.6764E 02	1.78E-01	2.2197E-03	7.01E-01	9.1870E-19	1.81E 00	0.	3.43E 00	0.
7.00E-04	3.6290E 02	1.91E-01	9.2045E-04	7.27E-01	1.5786E-19	1.85E 00	0.	3.49E 00	0.
10.00E-04	3.5560E 02	2.05E-01	3.5669E-04	7.53E-01	2.7125E-20	1.89E 00	0.	3.54E 00	0.
1.42E-03	3.4553E 02	2.19E-01	1.3822E-04	7.80E-01	0.	1.93E 00	0.	3.60E 00	0.
2.10E-03	3.3006E 02	2.34E-01	5.0056E-05	8.08E-01	0.	1.98E 00	0.	3.66E 00	0.
2.82E-03	3.1456E 02	2.49E-01	1.8127E-05	8.35E-01	0.	2.02E 00	0.	3.72E 00	0.
3.70E-03	2.9620E 02	2.65E-01	6.1345E-06	8.64E-01	0.	2.06E 00	0.	3.78E 00	0.
4.70E-03	2.7661E 02	2.75E-01	3.1166E-06	8.93E-01	0.	2.11E 00	0.	3.84E 00	0.
5.80E-03	2.5694E 02	2.81E-01	2.0760E-06	9.22E-01	0.	2.15E 00	0.	3.90E 00	0.
7.03E-03	2.3641E 02	2.90E-01	1.1286E-06	9.52E-01	0.	2.20E 00	0.	3.96E 00	0.
8.40E-03	2.1547E 02	2.97E-01	7.0253E-07	9.82E-01	0.	2.24E 00	0.	4.02E 00	0.
9.84E-03	1.9545E 02	3.07E-01	3.5691E-07	1.01E 00	0.	2.29E 00	0.	4.08E 00	0.
1.15E-02	1.7466E 02	3.14E-01	2.2217E-07	1.04E 00	0.	2.34E 00	0.	4.15E 00	0.
1.31E-02	1.5674E 02	3.25E-01	1.0548E-07	1.07E 00	0.	2.38E 00	0.	4.21E 00	0.
1.69E-02	1.2119E 02	3.32E-01	6.5660E-08	1.11E 00	0.	2.43E 00	0.	4.27E 00	0.
2.11E-02	9.1155E 01	3.40E-01	3.8196E-08	1.14E 00	0.	2.48E 00	0.	4.34E 00	0.
2.58E-02	6.6340E 01	3.49E-01	2.0764E-08	1.17E 00	0.	2.53E 00	0.	4.40E 00	0.
3.10E-02	4.6655E 01	3.60E-01	9.8580E-09	1.21E 00	0.	2.58E 00	0.	4.47E 00	0.
3.67E-02	3.1717E 01	3.68E-01	5.7345E-09	1.24E 00	0.	2.63E 00	0.	4.53E 00	0.
4.28E-02	2.0966E 01	3.87E-01	1.5837E-09	1.28E 00	0.	2.68E 00	0.	4.60E 00	0.
4.94E-02	1.3423E 01	4.06E-01	4.3735E-10	1.31E 00	0.	2.73E 00	0.	4.66E 00	0.
5.64E-02	8.3561E 00	4.26E-01	1.1287E-10	1.35E 00	0.	2.78E 00	0.	4.73E 00	0.
6.40E-02	4.9950E 00	4.46E-01	2.9128E-11	1.38E 00	0.	2.83E 00	0.	4.80E 00	0.
7.20E-02	2.9061E 00	4.67E-01	7.0246E-12	1.42E 00	0.	2.88E 00	0.	4.86E 00	0.
8.05E-02	1.6344E 00	4.88E-01	1.6940E-12	1.45E 00	0.	2.94E 00	0.	4.93E 00	0.
8.94E-02	8.9460E-01	5.10E-01	3.8177E-13	1.49E 00	0.	3.00E 00	0.	5.00E 00	0.
9.89E-02	4.7024E-01	5.32E-01	8.6034E-14	1.53E 00	0.	3.04E 00	0.	0.	0.1148E-40
1.09E-01	2.3732E-01	5.55E-01	1.8118E-14	1.57E 00	0.	3.10E 00	0.	0.	0.5166E-40
1.19E-01	1.2056E-01	5.78E-01	3.8154E-15	1.61E 00	0.	3.15E 00	0.	0.	1.8845E-37
1.30E-01	5.7255E-02	6.02E-01	7.5083E-16	1.65E 00	0.	3.21E 00	0.	0.	-0.0001E-25

FG 600K A=12 MSH(.0001(161)5.0)S(APPROX.) (GTP-3) 2.

INITIAL ENERGY, 5.00000E-04

FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY
10.00E-03	1.6649E 02	1.41E-01	2.1996E-02	6.26E-01	1.3335E-16	1.69E 00	0.	3.26E 00	0.
1.60E-04	2.2424E 02	1.53E-01	9.7892E-03	6.50E-01	2.6371E-17	1.73E 00	0.	3.32E 00	0.
3.00E-04	2.9115E 02	1.65E-01	4.3565E-03	6.75E-01	4.8743E-18	1.77E 00	0.	3.37E 00	0.
5.00E-04	2.8725E 02	1.78E-01	1.8123E-03	7.01E-01	8.4202E-19	1.81E 00	0.	3.43E 00	0.
7.00E-04	2.8340E 02	1.91E-01	7.5585E-04	7.27E-01	1.4545E-19	1.85E 00	0.	3.49E 00	0.
10.00E-04	2.7773E 02	2.05E-01	2.9312E-04	7.53E-01	2.5122E-20	1.89E 00	0.	3.54E 00	0.
1.42E-03	2.6997E 02	2.19E-01	1.1397E-04	7.80E-01	0.	1.93E 00	0.	3.60E 00	0.
2.10E-03	2.5787E 02	2.34E-01	4.1419E-05	8.08E-01	0.	1.98E 00	0.	3.66E 00	0.
2.82E-03	2.4565E 02	2.49E-01	1.5053E-05	8.35E-01	0.	2.02E 00	0.	3.72E 00	0.
3.70E-03	2.3149E 02	2.65E-01	5.1133E-06	8.64E-01	0.	2.06E 00	0.	3.78E 00	0.
4.70E-03	2.1640E 02	2.75E-01	2.6039E-06	8.93E-01	0.	2.11E 00	0.	3.84E 00	0.
5.80E-03	2.0092E 02	2.81E-01	1.7369E-06	9.22E-01	0.	2.15E 00	0.	3.90E 00	0.
7.03E-03	1.8493E 02	2.90E-01	9.4623E-07	9.52E-01	0.	2.20E 00	0.	3.96E 00	0.
8.40E-03	1.6861E 02	2.97E-01	5.8997E-07	9.82E-01	0.	2.24E 00	0.	4.02E 00	0.
9.84E-03	1.5300E 02	3.07E-01	3.0042E-07	1.01E 00	0.	2.29E 00	0.	4.08E 00	0.
1.15E-02	1.3679E 02	3.14E-01	1.8731E-07	1.04E 00	0.	2.34E 00	0.	4.15E 00	0.
1.31E-02	1.2260E 02	3.25E-01	8.9154E-08	1.07E 00	0.	2.38E 00	0.	4.21E 00	0.
1.69E-02	9.5036E 01	3.32E-01	5.5586E-08	1.11E 00	0.	2.43E 00	0.	4.27E 00	0.
2.11E-02	7.1594E 01	3.40E-01	3.2394E-08	1.14E 00	0.	2.48E 00	0.	4.34E 00	0.
2.58E-02	5.2145E 01	3.49E-01	1.7646E-08	1.17E 00	0.	2.53E 00	0.	4.40E 00	0.
3.10E-02	3.6720E 01	3.60E-01	8.3988E-09	1.21E 00	0.	2.58E 00	0.	4.47E 00	0.
3.67E-02	2.5000E 01	3.68E-01	4.8945E-09	1.24E 00	0.	2.63E 00	0.	4.53E 00	0.
4.28E-02	1.6507E 01	3.87E-01	1.3575E-09	1.28E 00	0.	2.68E 00	0.	4.60E 00	0.
4.94E-02	1.0614E 01	4.06E-01	3.7649E-10	1.31E 00	0.	2.73E 00	0.	4.66E 00	0.
5.64E-02	6.6197E 00	4.26E-01	9.7595E-11	1.35E 00	0.	2.78E 00	0.	4.73E 00	0.
6.40E-02	3.9646E 00	4.46E-01	2.5298E-11	1.38E 00	0.	2.83E 00	0.	4.80E 00	0.
7.20E-02	2.3113E 00	4.67E-01	6.1290E-12	1.42E 00	0.	2.88E 00	0.	4.86E 00	0.
8.05E-02	1.3027E 00	4.88E-01	1.4848E-12	1.45E 00	0.	2.94E 00	0.	4.93E 00	0.
8.94E-02	7.1469E-01	5.10E-01	3.3622E-13	1.49E 00	0.	3.00E 00	0.	5.00E 00	0.
9.89E-02	3.7653E-01	5.32E-01	7.6127E-14	1.53E 00	0.	3.04E 00	0.	0.	3.6160E-40
1.09E-01	1.9050E-01	5.55E-01	1.6110E-14	1.57E 00	0.	3.10E 00	0.	0.	0.1722E-40
1.19E-01	9.7034E-02	5.78E-01	3.4092E-15	1.61E 00	0.	3.15E 00	0.	0.	-0.0000E-27
1.30E-01	4.6200E-02	6.02E-01	6.7428E-16	1.65E 00	0.	3.21E 00	0.	0.	-0.0000E-21

FG 600K A=12 MSH(.0001(161)5.0)S(APPROX.) (GTP-3) 2.

INITIAL ENERGY, 5.00000E-04

FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY
10.00E-05	9.8929E 01	1.41E-01	1.8286E-02	6.26E-01	1.3091E-16	1.69E 00	0.	3.26E 00	0.
1.80E-04	1.3325E 02	1.53E-01	8.1759E-03	6.50E-01	2.6077E-17	1.73E 00	0.	3.32E 00	0.
3.00E-04	1.7302E 02	1.65E-01	3.6554E-03	6.75E-01	4.8561E-18	1.77E 00	0.	3.37E 00	0.
5.00E-04	2.2550E 02	1.78E-01	1.5282E-03	7.01E-01	8.4537E-19	1.81E 00	0.	3.43E 00	0.
7.00E-04	2.2250E 02	1.91E-01	6.3884E-04	7.27E-01	1.4714E-19	1.85E 00	0.	3.49E 00	0.
10.00E-04	2.1807E 02	2.05E-01	2.4971E-04	7.53E-01	2.5607E-20	1.89E 00	0.	3.54E 00	0.
1.42E-03	2.1202E 02	2.19E-01	9.7600E-05	7.80E-01	0.	1.93E 00	0.	3.60E 00	0.
2.10E-03	2.0257E 02	2.34E-01	3.5669E-05	8.08E-01	0.	1.98E 00	0.	3.66E 00	0.
2.82E-03	1.9303E 02	2.49E-01	1.3034E-05	8.35E-01	0.	2.02E 00	0.	3.72E 00	0.
3.70E-03	1.8196E 02	2.65E-01	4.4536E-06	8.64E-01	0.	2.06E 00	0.	3.78E 00	0.
4.70E-03	1.7016E 02	2.75E-01	2.2762E-06	8.93E-01	0.	2.11E 00	0.	3.84E 00	0.
5.80E-03	1.5809E 02	2.81E-01	1.5216E-06	9.22E-01	0.	2.15E 00	0.	3.90E 00	0.
7.03E-03	1.4556E 02	2.90E-01	8.3161E-07	9.52E-01	0.	2.20E 00	0.	3.96E 00	0.
8.40E-03	1.3281E 02	2.97E-01	5.1981E-07	9.82E-01	0.	2.24E 00	0.	4.02E 00	0.
9.84E-03	1.2059E 02	3.07E-01	2.6564E-07	1.01E 00	0.	2.29E 00	0.	4.08E 00	0.
1.15E-02	1.0769E 02	3.14E-01	1.6603E-07	1.04E 00	0.	2.34E 00	0.	4.15E 00	0.
1.31E-02	9.6920E 01	3.25E-01	7.9333E-08	1.07E 00	0.	2.38E 00	0.	4.21E 00	0.
1.69E-02	7.5129E 01	3.32E-01	4.9584E-08	1.11E 00	0.	2.43E 00	0.	4.27E 00	0.
2.11E-02	5.6696E 01	3.40E-01	2.8978E-08	1.14E 00	0.	2.48E 00	0.	4.34E 00	0.
2.58E-02	4.1376E 01	3.49E-01	1.5835E-08	1.17E 00	0.	2.53E 00	0.	4.40E 00	0.
3.10E-02	2.9200E 01	3.60E-01	7.5653E-09	1.21E 00	0.	2.58E 00	0.	4.47E 00	0.
3.67E-02	1.9927E 01	3.68E-01	4.4209E-09	1.24E 00	0.	2.63E 00	0.	4.53E 00	0.
4.28E-02	1.3239E 01	3.87E-01	1.2341E-09	1.28E 00	0.	2.68E 00	0.	4.60E 00	0.
4.94E-02	8.5056E 00	4.06E-01	3.4448E-10	1.31E 00	0.	2.73E 00	0.	4.66E 00	0.
5.64E-02	5.3196E 00	4.26E-01	8.9699E-11	1.35E 00	0.	2.78E 00	0.	4.73E 00	0.
6.40E-02	3.1960E 00	4.46E-01	2.3458E-11	1.38E 00	0.	2.83E 00	0.	4.80E 00	0.
7.20E-02	1.8695E 00	4.67E-01	5.7227E-12	1.42E 00	0.	2.88E 00	0.	4.86E 00	0.
8.05E-02	1.0572E 00	4.88E-01	1.3959E-12	1.45E 00	0.	2.94E 00	0.	4.93E 00	0.
8.94E-02	5.8211E-01	5.10E-01	3.1833E-13	1.49E 00	0.	3.00E 00	0.	5.00E 00	0.
9.89E-02	3.0765E-01	5.32E-01	7.2584E-14	1.53E 00	0.	3.04E 00	0.	0.	5.5101E-40
1.09E-01	1.5630E-01	5.55E-01	1.5472E-14	1.57E 00	0.	3.10E 00	0.	0.	0.5740E-40
1.19E-01	7.9971E-02	5.78E-01	3.2978E-15	1.61E 00	0.	3.15E 00	0.	0.	1.8845E-37
1.30E-01	3.8241E-02	6.02E-01	6.5710E-16	1.65E 00	0.	3.21E 00	0.	0.	1.8845E-37

FG 600K A=12 MSH(.0001(161)5.0)S(APPROX.) (GTP-3) 2.

INITIAL ENERGY, 7.00000E-04

FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY	FINAL ENERGY	TRANSFER PROBABILITY
10.00E-05	6.9981E 01	1.41E-01	1.6547E-02	6.26E-01	1.3770E-16	1.69E 00	0.	3.26E 00	0.
1.80E-04	9.4259E 01	1.53E-01	7.4313E-03	6.50E-01	2.7604E-17	1.73E 00	0.	3.32E 00	0.
3.00E-04	1.2240E 02	1.65E-01	3.3370E-03	6.75E-01	5.1741E-18	1.77E 00	0.	3.37E 00	0.
5.00E-04	1.5954E 02	1.78E-01	1.4016E-03	7.01E-01	9.0677E-19	1.81E 00	0.	3.43E 00	0.
7.00E-04	1.9056E 02	1.91E-01	5.8863E-04	7.27E-01	1.5887E-19	1.85E 00	0.	3.49E 00	0.
10.00E-04	1.8679E 02	2.05E-01	2.3122E-04	7.53E-01	2.7830E-20	1.89E 00	0.	3.54E 00	0.
1.42E-03	1.8164E 02	2.19E-01	9.0814E-05	7.80E-01	0.	1.93E 00	0.	3.60E 00	0.
2.10E-03	1.7360E 02	2.34E-01	3.3360E-05	8.08E-01	0.	1.98E 00	0.	3.66E 00	0.
2.82E-03	1.6547E 02	2.49E-01	1.2253E-05	8.35E-01	0.	2.02E 00	0.	3.72E 00	0.
3.70E-03	1.5605E 02	2.65E-01	4.2092E-06	8.64E-01	0.	2.06E 00	0.	3.78E 00	0.
4.70E-03	1.4600E 02	2.75E-01	2.1584E-06	8.93E-01	0.	2.11E 00	0.	3.84E 00	0.
5.80E-03	1.3566E 02	2.81E-01	1.4457E-06	9.22E-01	0.	2.15E 00	0.	3.90E 00	0.
7.03E-03	1.2501E 02	2.90E-01	7.9249E-07	9.52E-01	0.	2.20E 00	0.	3.96E 00	0.
8.40E-03	1.1411E 02	2.97E-01	4.9649E-07	9.82E-01	0.	2.24E 00	0.	4.02E 00	0.
9.84E-03	1.0367E 02	3.07E-01	2.5455E-07	1.01E 00	0.	2.29E 00	0.	4.08E 00	0.
1.15E-02	9.2822E 01	3.14E-01	1.5946E-07	1.04E 00	0.	2.34E 00	0.	4.15E 00	0.
1.31E-02	8.3439E 01	3.25E-01	7.6462E-08	1.07E 00	0.	2.38E 00	0.	4.21E 00	0.
1.69E-02	6.4780E 01	3.32E-01	4.7897E-08	1.11E 00	0.	2.43E 00	0.	4.27E 00	0.
2.11E-02	4.8971E 01	3.40E-01	2.8062E-08	1.14E 00	0.	2.48E 00	0.	4.34E 00	0.
2.58E-02	3.5807E 01	3.49E-01	1.5378E-08	1.17E 00	0.	2.53E 00	0.	4.40E 00	0.
3.10E-02	2.5323E 01	3.60E-01	7.3725E-09	1.21E 00	0.	2.58E 00	0.	4.47E 00	0.
3.67E-02	1.7322E 01	3.68E-01	4.3190E-09	1.24E 00	0.	2.63E 00	0.	4.53E 00	0.
4.28E-02	1.1537E 01	3.87E-01	1.2128E-09	1.28E 00	0.	2.68E 00	0.	4.60E 00	0.
4.94E-02	7.4314E 00	4.06E-01	3.4048E-10	1.31E 00	0.	2.73E 00	0.	4.66E 00	0.
5.64E-02	4.6609E 00	4.26E-01	8.9390E-11	1.35E 00	0.	2.78E 00	0.	4.73E 00	0.
6.40E-02	2.8086E 00	4.46E-01	2.3464E-11	1.38E 00	0.	2.83E 00	0.	4.80E 00	0.
7.20E-02	1.6479E 00	4.67E-01	5.7595E-12	1.42E 00	0.	2.88E 00	0.	4.86E 00	0.
8.05E-02	9.3509E-01	4.88E-01	1.4134E-12	1.45E 00	0.	2.94E 00	0.	4.93E 00	0.
8.94E-02	5.1663E-01	5.10E-01	3.2436E-13	1.49E 00	0.	3.00E 00	0.	5.00E 00	0.
9.89E-02	2.7422E-01	5.32E-01	7.4418E-14	1.53E 00	0.	3.04E 00	0.	0.	7.4042E-40
1.09E-01	1.3984E-01	5.55E-01	1.5965E-14	1.57E 00	0.	3.10E 00	0.	0.	0.1148E-40
1.19E-01	7.1760E-02	5.78E-01	3.4243E-15	1.61E 00	0.	3.15E 00	0.	0.	-0.0047E 18
1.30E-01	3.4466E-02	6.02E-01	6.8677E-16	1.65E 00	0.	3.21E 00	0.	0.	-0.0000E-27

Note: The remaining 156 pages of kernel output for this case are omitted.

GTP FORTRAN LISTING

```
C     GTP.  FREE GAS KERNEL. UPSCATTER CALC. BY DETAILED BALANCE.     REV
      DIMENSION Z(4),ERFZ(4),E(161),SIGMA(161,161),SE(161),
     1TITLE(12),CASE(12),C(5),GAM(5)
      B5#1.0614054                                                    18490101
      B4#-1.4531520                                                   14720106
      B3#1.4214137                                                    14720107
      B2#-.28449674                                                   14720108
      B1#.25482959                                                    14720109
      P#.32759110                                                     14720110
      SQRPIE#1.7724539                                                14720111
      REWIND 2                                                        16500104
      REWIND 3                                                        16500105
    4 READ INPUT TAPE 10,206,(TITLE(I),I#1,12)                        16500107
      IF(TITLE(12))300,300,5                                          16500109
    5 READ INPUT TAPE 10,207,TEMP,A,XJI,AN
      JI#XJI                                                          14720116
      DO 306 J#1,JI
      DO 307 I#1,JI
  307 SIGMA(J,I)#0.0
  306 CONTINUE
      NB#AN
      IF(NB-1)302,301,301
  302 NB#1
      C(1)#1.0
      GAM(1)#0.0
      GO TO 6
  301 READ INPUT TAPE 10,303,(C(J),GAM(J),J#1,NB)
    6 READ INPUT TAPE 10,201,(E(J),J#1,JI)                            16500115
      READ INPUT TAPE 10,201,(SE(J),J#1,JI)                           16500116
   98 READ TAPE 2,CASE                                                16500118
      READ TAPE 3                                                     16500119
      IF(CASE(12)) 95,96,96                                           16500121
   95 BACKSPACE 2                                                     16500123
      BACKSPACE 3                                                     16500124
      GO TO 8                                                         16500201
   96 DO 97 I#1,4                                                     16500420
      READ TAPE 2                                                     16500422
   97 READ TAPE 3                                                     16500423
      GO TO 98                                                        16500425
    8 TEMP#TEMP/1.16047E+4                                            16500203
      BETA#1.0/(2.0*TEMP)
      JN#1
      BB#2.0*A*(BETA**2)
  304 TAU#BB/(BB+GAM(JN))
      XLAM#1.0+A*(1.0-(TAU**2))
      ETA#0.5*(A+1.0)/(SQRTF(A)*TAU)
      RHO#TAU*SQRTF(A)-ETA
      J#JI                                                            16500103
    7 I#J                                                             16500105
      CONTINUE                                                        14720201
      EHIGH#E(J)                                                      14720203
   10 ELOW#E(I)                                                       14720205
   11 X2#EHIGH/TEMP                                                   14720207
      X#SQRTF(X2)                                                     14720208
      Y2#ELOW/TEMP                                                    14720210
      Y#SQRTF(Y2)                                                     14720211
      IF(X2-Y2*XLAM-75.0) 89,90,90
   90 EPWR#0.0
```

```
      GO TO 12
   89 EPWR#EXPF(X2-Y2*XLAM)
   12 Z(1)#ETA*X-RHO*Y                                                14720213
      Z(2)#ETA*X+RHO*Y                                                14720214
      Z(3)#ETA*Y-RHO*X                                                14720215
      Z(4)#ETA*Y+RHO*X                                                14720216
   13 DO 37 M#1,4                                                     14720218
      IF(Z(M))14,26,14                                                14720219
   14 V#ABSF(Z(M))                                                    14720221
   15 IF(V-8.66)16,16,24                                              14720223
   16 IF(V-1.7)17,17,20                                               14720301
   17 ETAN#1.0/(1.0+P*V)                                              14720303
      GZ#((((B5*ETAN+B4)*ETAN+B3)*ETAN+B2)                            14720305
     1*ETAN+B1)*ETAN                                                  14720306
   18 GEXP#GZ/EXPF(Z(M)**2)                                           14720308
      GO TO 30                                                        14720310
   20 CFZ#1.0/(V+1.0/(2.0*V+2.0/(V+3.0/(2.0*V+4.0/(V+                 14720312
     (5.0/(2.0*V+6.0/(V+7.0/(2.0*V+2.5)))))))))                       14720313
      GEXP#CFZ/(SQRPIE*EXPF(Z(M)**2))                                 14720315
      GO TO 30                                                        14720317
   24 GEXP#0.0                                                        14720319
      GO TO 30                                                        14720320
   26 GEXP#1.0                                                        14720322
   30 GO TO (31,31,32,35),M                                           18490104
   32 IF(Z(M)) 33,34,34                                               18490105
   33 NN#0                                                            18490106
      GO TO 31                                                        18490107
   34 NN#1                                                            18490108
      ERFZ(M)#GEXP-1.0                                                18490109
      GO TO 37                                                        18490110
   35 IF(NN) 31,31,36                                                 18490111
   36 ERFZ(M)#1.0-GEXP                                                18490112
      GO TO 37                                                        18490113
   31 ERFZ(M)#-GEXP                                                   18490114
   37 CONTINUE                                                        18490115
   38 FSIGHL#((A+1.0)**2/(8.0*A))*(TAU**3/XLAM)*((-ERFZ(3)+ERFZ(4))*
     1EXPF(-GAM(JN)*(TAU**2)*X2/(2.0*(BETA**2)))+EPWR*(ERFZ(1)-ERFZ(2)))
   40 SIGMA(J,I)#SIGMA(J,I)+C(JN)*FSIGHL/E(J)
      IF(SIGMA(J,I)-1.0E-20) 501,501,43                               18490101
  501 SIGMA(J,I)#0.0                                                  18490103
   43 IF(I-1)100,57,44                                                16500111
   44 IF(SIGMA(J,I)) 101,55,48                                        16500205
   48 I#I-1                                                           16500113
      GO TO 10                                                        14720425
   55 I#I-1                                                           16500115
      SIGMA(J,I)#0.0                                                  16500117
   56 IF(I-1)99,57,55                                                 16500119
   57 IF(J-1)102,61,58                                                16500121
   58 J#J-1                                                           16500123
   60 GO TO 7                                                         14720511
   99 NSTOP#56                                                        14720521
      GO TO 103                                                       14720522
  100 NSTOP#43                                                        14720524
      GO TO 103                                                       14720525
  101 SIGMA(J,I)#0.0
      GO TO 55
  102 NSTOP#57                                                        14720604
  103 WRITE OUTPUT TAPE 9,203,NSTOP                                   16500207
```

```
      GO TO 4                                                           14720608
   61 JN#JN+1
      IF(JN-NB) 304,304,305
  305 DO 70 J#1,JI
      DO71I#J,JI                                                        16500203
      SIGMA(J,I)#SIGMA(I,J)*EXPF((E(J)-E(I))/TEMP)*E(I)/E(J)            18490105
      IF(SIGMA(J,I)-1.0E-20) 500,500,71                                 18490107
  500 SIGMA(J,I)#0.0                                                    18490109
   71 CONTINUE                                                          18490111
   70 CONTINUE                                                          16500207
      WRITE TAPE 2,TITLE                                                16500209
      WRITE TAPE 3,TITLE                                                16500210
      WRITE TAPE 2,JI                                                   16500212
      WRITE TAPE 3,JI                                                   16500213
      WRITE TAPE 2,(E(J),J#1,JI)                                        16500215
      WRITE TAPE 3,(E(J),J#1,JI)                                        16500216
      WRITE TAPE 2,(SE(J),J#1,JI)                                       16500218
      WRITE TAPE 3,(SE(J),J#1,JI)                                       16500219
      WRITE TAPE 2,((SIGMA(J,I),I#1,JI),J#1,JI)                         16500323
      WRITE TAPE 3,((SIGMA(J,I),I#1,JI),J#1,JI)                         16500324
      WRITE OUTPUT TAPE 9,206,(TITLE(I),I#1,12)                         18490101
      WRITE OUTPUT TAPE 9,80,JI                                         18490103
   80 FORMAT(6H0SIZE,I6///2H0 )                                         18490101
      WRITEOUTPUTTAPE9,81                                               18490107
   81 FORMAT(117H0   ENERGY      SOURCE      ENERGY      SOURCE      ENE18490109
     1RGY      SOURCE      ENERGY      SOURCE      ENERGY      SOURCE/2H018490111
     2 )                                                                18490113
      J2#JI/5+1                                                         18490119
      DO 82 I#1,J2                                                      18490117
      K1#I+J2                                                           18490119
      K2#K1+J2                                                          18490120
      K3#K2+J2                                                          18490121
      K4#K3+J2                                                          18490122
   82 WRITE OUTPUT TAPE 9,83,E(I),SE(I),E(K1),SE(K1),E(K2),             18490201
     1SE(K2),E(K3),SE(K3),E(K4),SE(K4)                                  18490203
   83 FORMAT(10(1PE12.4))                                               18490205
      DO 75 J#1,JI                                                      16500303
      WRITE OUTPUT TAPE 9,206,TITLE                                     16500305
      WRITE OUTPUT TAPE 9,209,E(J)                                      16500306
      WRITE OUTPUT TAPE 9,210                                           16500307
      DO 76 I#1,J2                                                      16500309
      K1#I+J2                                                           16500311
      K2#K1+J2                                                          16500312
      K3#K2+J2                                                          16500313
      K4#K3+J2                                                          16500314
   76 WRITE OUTPUT TAPE 9,211,E(I),SIGMA(J,I),E(K1),SIGMA(J,K1),        16500318
     1E(K2),SIGMA(J,K2),E(K3),SIGMA(J,K3),E(K4),SIGMA(J,K4)             16500320
   75 CONTINUE                                                          16500323
      CASE(12)#-100.0                                                   18490101
      WRITE TAPE 2,CASE                                                 18490102
      WRITE TAPE 3,CASE                                                 18490103
      BACKSPACE 2
      BACKSPACE 3
      GO TO 4                                                           16500401
  201 FORMAT(7E10.5)                                                    14720610
  203 FORMAT(17H0ERROR STATEMENT#I4)                                    14720612
  206 FORMAT(11A6,F6.0)                                                 16500113
  303 FORMAT(6E10.4)
```

```
207 FORMAT(4E10.5)
209 FORMAT(16H0INITIAL ENERGY,1PE12.5///2H0 )                          16500316
210 FORMAT(109H0 FINAL       TRANSFER     FINAL      TRANSFER     FINAL    16500415
   1  TRANSFER     FINAL      TRANSFER     FINAL      TRANSFER/            16500101
   2111H  ENERGY     PROBABILITY  ENERGY    PROBABILITY  ENERGY    PROBAB16500417
   3ILITY  ENERGY    PROBABILITY  ENERGY    PROBABILITY/2H0 )             16500418
211 FORMAT(1PE10.2,1PE12.4,4(1PE10.2,1PE12.4))                          18490116
300 TITLE(12)#-100.0
    WRITE TAPE 2,TITLE
    WRITE TAPE 3,TITLE
    END FILE 2
    END FILE 3                                                          16500409
    REWIND 2
    REWIND 3
    CALL EXIT                                                           16500411
    END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

III. IMS – An IBM 7090 Program for the Calculation of Neutron Spectra in Infinite Homogeneous Media

Description of the Problem

Program IMS obtains a numerical solution to the space independent Boltzmann equation by means of a normalized extrapolated Gauss iteration scheme (NEG). From Eqs. (3) and (4) we have,

$$\phi(E) = \frac{\int_{E_1}^{E_2} \phi(E') \, \Sigma(E' \rightarrow E) \, dE' + S(E)}{\Sigma_a(E) + \int_{E_1}^{E_2} \Sigma(E \rightarrow E') \, dE'} . \tag{7}$$

The (NEG) method requires that each iteration be normalized in the sense that the total absorptions are equal to the total source. Let the superscript m be an iteration index and $\phi^m(E)$ be a set of fluxes normalized in the above sense but not yet converged. We denote as $\phi_c(E)$ the set of fluxes obtained by substituting $\phi^m(E)$ into the right side of Eq. (7). This new set is not normalized but may be made so by multiplying by the number η^{m+1} defined according to the neutron conservation condition,

$$\eta^{m+1} \int_{E_1}^{E_2} \phi_c(E) \, \Sigma_a(E) \, dE = \int_{E_1}^{E_2} S(E) \, dE . \tag{8}$$

The set $\eta^{m+1} \phi_c(E)$ is normalized and would be the next approximation for the fluxes in a simple normalized Gauss iteration scheme. However, in the (NEG) method an extrapolation is made from the two sets $\phi^m(E)$ and $\eta^{m+1} \phi_c(E)$ to obtain the next approximation. The (NEG) iteration method can thus be stated,

$$\phi^{m+1}(E) = \phi^m(E) + \alpha[\eta^{m+1} \phi_c(E) - \phi^m(E)] , \tag{9}$$

where α is a linear extrapolation factor. Some experimentation is required to find the optimum value for α, a value $\alpha \sim 1.2$ has been found

satisfactory for most IMS calculations. It is seen from Eq. (9) that for $\alpha = 1$, the method reduces to a simple normalized Gauss iteration scheme.

The selection of the limits of integration in Eq. (7) is arbitrary (except that $E_2 > E_1$). However, they should be chosen in such a way that $S(E)$ is easy to calculate. For example, in the calculation of thermal neutron spectra, for which this program is most useful, E_1 should be chosen low enough that $\Sigma(E_1 \rightarrow E)$, $(E < E_1)$, is negligible, and E_2 should be chosen high enough that $\Sigma(E \rightarrow E')$, $(E < E_2 < E')$ is negligible and $\phi(E)$ in the region about E_2 is reasonably well known. If these conditions are satisfied, $S(E)$ is elementary to calculate. Program TKS, described in a latter section of this report, calculates the source terms $S(E)$ needed in Eq. (7).

Integration Technique Used in the IMS Program

An integration subroutine, SR1, has been written to evaluate the integrals required in Eq. (7). The choice of method is determined largely by the nature of the scattering kernel $\Sigma(E \rightarrow E')$ which exhibits a sharp discontinuity at $E = E'$. Furthermore, for large E values the kernel decreases very rapidly when $E' > E$ and has a rather large second derivative. Because of these properties of the kernel, simple trapezoidal integration was rejected as being too inaccurate. Instead, a generalized Simpson's rule integration was developed and incorporated into the SR1 integration subroutine. The SR1 integration method does not require equally spaced energy intervals, but does require an ODD number of mesh points. Provision is made for avoiding the point of discontinuity of the kernel from falling within a three point Simpson interval by defining two sets of weighting functions. The first set, to be used when i of $\Sigma(E_i \rightarrow E')$ is an ODD mesh point number, is obtained by simply applying Simpson's rule for unequal intervals. The second set, to be used when i is an even mesh point number, combines trapezoidal integration for the two boundary intervals of the mesh with Simpson's rule integration for interior mesh intervals. These two sets of weighting functions are generated when SR1 is initially called and are stored in the core memory for subsequent repeated use.

The mathematical formulation of the weighting functions is straightforward. We consider a parabola, $y(x)$, which satisfies the three points (x_1,y_1), (x_2,y_2), and (x_3,y_3) of a Simpson interval. If we let

$$A = (x_2 - x_1) \quad \text{and} \quad \alpha A = (x_3 - x_1) \text{ , where } x_1 < x_2 < x_3 \text{ ,}$$

then

$$\int_{x_1}^{x_3} y(x)\, dx = \frac{\alpha A(3-\alpha)}{6} y_1 + \frac{\alpha^3 A}{6(\alpha-1)} y_2 + \frac{\alpha A(2\alpha-3)}{6(\alpha-1)} y_3 \text{ ,} \tag{10}$$

$$\int_{x_1}^{x_2} y(x)\, dx = \frac{A(3\alpha-1)}{6\alpha} y_1 + \frac{A(2-3\alpha)}{6(1-\alpha)} y_2 + \frac{A}{6\alpha(1-\alpha)} y_3 \text{ ,} \tag{11}$$

and

$$\int_{x_2}^{x_3} y(x)\, dx = \frac{-A(\alpha-1)^3}{6\alpha} y_1 + \frac{A(\alpha+2)(\alpha-1)}{6} y_2 + \frac{A(2\alpha+1)(\alpha-1)}{6\alpha} y_3 \text{ .} \tag{12}$$

Since the scattering kernel, $\Sigma_s(E_i \rightarrow E_k)$, $k = 1,N$, contains only one point of discontinuity, namely at $k = i$, it is always possible to arrange the repeated application of Eq. (10) so that the point of discontinuity falls on the boundary of a three point Simpson interval. If i is ODD, repeated applications of Eq. (10) will exactly cover the range of the variable E_K since we require N to be ODD. If i is EVEN, however, there will be left over a two point interval at both the upper and lower boundaries of the mesh system. Integration over these intervals can be carried out either by means of Eqs. (11) and (12) or by the simpler trapezoidal method employed in the SR1 routine.

Macroscopic Absorption Cross Sections

A subroutine (SIGMA) of the IMS program is used to compute the required $\Sigma_a(E)$ term of Eq. (7) for each point of the energy mesh. Two different options are available. A 2200 m/s macroscopic cross section may be supplied and a $1/\sqrt{E}$ energy dependence assumed or, alternatively, any arbitrary dependence of the absorption cross section may be used.

In the latter case, input data specifying the microscopic cross sections at an arbitrary set of energies is required. The energy mesh of the cross section data need not correspond to the energy mesh of the flux calculation since a linear interpolation of the logarithm of the cross section against the logarithm of the energy is made by the SIGMA subroutine to obtain a cross section value for a particular energy. This interpolation is exact whenever the cross section can be expressed as some power of the energy. The sole requirement which the cross section energy mesh must fulfill is that its range must span the entire integration interval $E_1 \leqslant E \leqslant E_2$. The SIGMA subroutine will compute the composite macroscopic absorption cross section for each point of the integration interval by using up to seven different sets of microscopic cross sections and their corresponding number densities. This data must, of course, be supplied as input. We will compile, over a period of time, a library of microscopic absorption cross section decks to be used as input to either the IMS or ACS programs. (The ACS program is described in a latter section of this report.)

Preparation of Input Data

The input data required for an IMS calculation can be divided into two distinct parts, card input information, which is transferred to logical tape 10, and data obtained from the KERNEL LIBRARY TAPE, which is designated as logical tape 2. The card input data consists of the title of the calculation, parameters for the initial flux guess, iteration control numbers, cross section data, and the KERNEL NUMBER of the kernel to be selected from the KERNEL LIBRARY TAPE. It is seen that the selection of a kernel automatically specifies for the calculation an energy mesh, an integration interval, a set of source values, S(E), and the model by which the transfer probabilities are calculated. The card input data must be assembled in the following order:

1. Card 1. Column 1 must contain a 1-punch. Columns 2-72 may contain any alphabetic or numeric information which identifies the calculation. These columns, together with the KERNEL title which is read in from logical tape 2, will be printed at the top of each page of output.

2. Card 2. Seven numbers are punched which give the following information.

Fields 1 and 2. These contain a neutron temperature (°K) and a value of λ for a modified Campbell-Freemantle initial guess for the spectrum. If T = 0, then the initial guess for the flux is taken to be the converged flux from the previous case in the same run.

Field 3. Each element in the table of transfer probabilities is multiplied by this number. Consequently this field should normally contain the macroscopic free atom scattering cross section or the atomic number density. An exception, however, is in the case where it is desired to run several calculations using the same kernel without reading in the kernel anew each time. This re-reading of the kernel can be avoided by placing a zero in field 1 of card 3. If this is done, however, field 3 of card 1 must then contain a 1.0 in order to retain the same normalization of the transfer probabilities as before.

Field 4. Any non-zero number in this field is used as the value at 0.0253 ev of a 1/v cross section (in cm^{-1}). If this field is punched, then no cross section cards will be read and the problem will use the prescribed 1/v cross section alone. Conversely, if this field is left blank, cross section data must be supplied.

Field 5. This field is ignored unless field 4 contains zero or is blank. If field 4 contains zero or is blank, then this field must contain a number between 1.0 and 7.0 inclusive which states the number of sets of cross sections that are to be read in.

Field 6. The convergence criterion is supplied in this field. Iteration will continue until the maximum fractional change in the flux at any point in the mesh is less than this number or until the maximum number of iterations specified in the next field has been reached. An acceptable convergence number, ϵ, will depend on the particular problem to some extent, but a value from 10^{-3} to 10^{-4} should be satisfactory for most cases.

Field 7. This field specifies the maximum number of flux iterations to be undertaken. If left blank the maximum number of iterations is automatically taken as 100.

3. Card 3. Field 1 of card 3 contains the number of the kernel which is to be selected from the KERNEL LIBRARY TAPE and used in the calculation. A zero in this field will cause the same kernel used in the previous calculation to be re-used. In this case, however, field 3 of card 1 must contain a 1.0 to prevent a renormalization of the transfer probabilities. (Unless, for some reason, a renormalization is desired.)

Field 2 contains the extrapolation factor, α, to be used in the normalized extrapolated Gauss iteration scheme employed in the flux iterations. An optimum choice of this factor can greatly reduce the running time of the program but is difficult to make without experience gained from several calculations. For initial runs, a factor $\alpha \cong 1.0$ to 1.2 is a reasonable choice to make.

4. Card 4. If field 4 of card 2 contains a zero or is blank, then this card must contain up to seven number densities (controlled by field 5 of card 2) which are used to form a composite macroscopic cross section from the sets of microscopic cross sections which follow. Units are cm^{-1}/barn.

5. Cards 5. If the option of reading cross section cards has been selected in field 4 of card 2 and card 4 has been supplied, then cards 5 must contain as many sets of microscopic absorption cross section decks as are specified in field 5 of card 2, and for which the normalizing factors have been supplied on card 4. A maximum of seven sets may be supplied and must be consistent in order with the number supplied on card 4. The format of these cards is as described for the cross section library for the ACS code. Fields 1 through 6 contain three pairs of numbers (less if required on the last card), giving values of the energy in electron volts and the cross section at that energy. Each card of a cross section deck must contain an identifying 4-punch in column 72, and the energy range specified by the deck must exceed the energy range over which an interpolation is to be made. A further requirement on the cross section decks is imposed by the method of reading in the data contained in the deck. The card records on logical tape 10 are read one by one and a running count is kept of the number of energy mesh point values. This is continued until a blank or zero number in an energy field (fields 1, 3 or 5) is encountered. This blank signifies that the end of the cross section deck has been reached. Hence, to those cross section decks with a number of energy mesh points exactly divisible by three, a final card must be added with all blanks except for a 4-punch in column 72.

Output

To operate the program, an input tape is prepared on the card-to-tape converter using the input data described above. This tape is selected as logical tape 10 and, together with the kernel library tape selected as logical tape 2, constitutes all of the data input. Two additional tapes are required for the output. A pool tape is selected as tape 6 from which the deck of cards containing the energy mesh and computed fluxes are punched. A complete listing of the output is obtained from logical tape 9. This output consists of the following lines:

1. Title of the flux calculation.
2. Title of the kernel used in the calculation.
3. Number of iterations, degree of convergence, extrapolation factor used.
4. A list of the energy mesh points and the computed fluxes.

If the calculation has failed to complete due to an error in the cross section deck, a test number LM = 1 will be written on the output; for example, the error may be due to a missing 4-punch in column 72. If the failure is due to an insufficient energy range in the cross section deck, the number LM = -1 appears in the output.

A Fortran listing of the IMS program and associated subroutines, data forms, and the output for a sample case are given in the following pages.

TEN DIGIT DATA FORM

PROBLEM	REQUEST
IMS	3325

CODER	DATE	PAGE
MET	10-29-62	1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80	
1 ← IMS.-COLUMNS-2-72-AVAILABLE-FOR-IDENTIFICATION. →															1	
T(°K)		λ		Σ_s		Σ_a^o		XN		ϵ		XNI			2	
XNK		α													3	
N_1		N_2		etc.		N_{XN}									4	
E_1		$\sigma(E_1)$		E_2		$\sigma(E_2)$		E_3		$\sigma(E_3)$				04	5	cross section deck 1
etc.														04	5	

Note: Cards 4 and 5 are omitted unless $\Sigma_a^o = 0.0$.

T(°K) = Neutron temperature for initial flux guess. The initial guess is $\phi(E) = M(E) + \lambda F(E)$.

Σ_s = Free atom macroscopic scattering cross section.

Σ_a = 2200 m/s value of the macroscopic absorption cross section.

XN = Number of microscopic cross section decks which will be provided.

ϵ = Degree of convergence desired.

XNI = Maximum number of iterations allowed.

XNK = The number of the kernel to be selected from the library tape.

α = Extrapolation factor of the iteration scheme.

N_1(etc.) = Atomic number density of the component associated with cross section deck 1.

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IMS INPUT DATA FORM

TEN DIGIT DATA FORM

PROBLEM	REQUEST
IMS	3325

CODER	DATE	PAGE
MET	10-29-62	1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 ← IMS-SAMPLE-PRØBLEM.—SPECTRUM-FRØM-KERNEL-2-.4 B/CA-FR=1.0														→	1
800.0		0.4		.39752		.0331265		0.0		.0001		0.0			2
2.0		1.0													3

UCN-3263
(3 11-61)

SAMPLE PROBLEM INPUT

IMS SAMPLE PROBLEM. SPECTRUM FROM KERNEL 2 .4B/CA FR=1.0

1 FG 600K A=12 MSH(.0001(161)5.0 S(APPROX.) (GTP-3) 2.00000

NUMBER OF ITERATIONS= 48 MAXIMUM DIVERGENCE= 0.990E-04 EXTRAPOLATION FACTOR=1.000

ENERGY	FLUX	ENERGY	FLUX	ENERGY	FLUX	ENERGY	FLUX	ENERGY	FLUX
10.0000E-05	7.2075E-01	1.4100E-01	1.7394E 02	6.2600E-01	2.6129E 01	1.6900E 00	9.4099E 00	3.2600E 00	4.9180E 00
1.8000E-04	1.2973E 00	1.5300E-01	1.6222E 02	6.5000E-01	2.5068E 01	1.7300E 00	9.1947E 00	3.3200E 00	4.8201E 00
3.0000E-04	2.1620E 00	1.6500E-01	1.5085E 02	6.7500E-01	2.4057E 01	1.7700E 00	8.9880E 00	3.3700E 00	4.7193E 00
5.0000E-04	3.6028E 00	1.7800E-01	1.3917E 02	7.0100E-01	2.3096E 01	1.8100E 00	8.7929E 00	3.4300E 00	4.6046E 00
7.0000E-04	5.0426E 00	1.9100E-01	1.2827E 02	7.2700E-01	2.2212E 01	1.8500E 00	8.6023E 00	3.4900E 00	4.4831E 00
10.0000E-04	7.2000E 00	2.0500E-01	1.1750E 02	7.5300E-01	2.1399E 01	1.8900E 00	8.4280E 00	3.5400E 00	4.3699E 00
1.4200E-03	1.0214E 01	2.1900E-01	1.0772E 02	7.8000E-01	2.0616E 01	1.9300E 00	8.2461E 00	3.6000E 00	4.2994E 00
2.1000E-03	1.5072E 01	2.3400E-01	9.8356E 01	8.0800E-01	1.9869E 01	1.9800E 00	8.0489E 00	3.6600E 00	4.3335E 00
2.8200E-03	2.0179E 01	2.4900E-01	9.0029E 01	8.3500E-01	1.9195E 01	2.0200E 00	7.8885E 00	3.7200E 00	4.3504E 00
3.7000E-03	2.6358E 01	2.6500E-01	8.2223E 01	8.6400E-01	1.8528E 01	2.0600E 00	7.7326E 00	3.7800E 00	4.3497E 00
4.7000E-03	3.3281E 01	2.7500E-01	7.7847E 01	8.9300E-01	1.7904E 01	2.1100E 00	7.5626E 00	3.8400E 00	4.3318E 00
5.8000E-03	4.0763E 01	2.8100E-01	7.5392E 01	9.2200E-01	1.7325E 01	2.1500E 00	7.4099E 00	3.9000E 00	4.3024E 00
7.0300E-03	4.8944E 01	2.9000E-01	7.1939E 01	9.5200E-01	1.6760E 01	2.2000E 00	7.2569E 00	3.9600E 00	4.2600E 00
8.4000E-03	5.7817E 01	2.9700E-01	6.9424E 01	9.8200E-01	1.6243E 01	2.2400E 00	7.1184E 00	4.0200E 00	4.2141E 00
9.8400E-03	6.6653E 01	3.0700E-01	6.6088E 01	1.0100E 00	1.5774E 01	2.2900E 00	6.9687E 00	4.0800E 00	4.1534E 00
1.1500E-02	7.6697E 01	3.1400E-01	6.3907E 01	1.0400E 00	1.5323E 01	2.3400E 00	6.8246E 00	4.1500E 00	4.0906E 00
1.3100E-02	8.6187E 01	3.2500E-01	6.0737E 01	1.0700E 00	1.4869E 01	2.3800E 00	6.7043E 00	4.2100E 00	4.0257E 00
1.6900E-02	1.0673E 02	3.3200E-01	5.8857E 01	1.1100E 00	1.4340E 01	2.4300E 00	6.5734E 00	4.2700E 00	3.9617E 00
2.1100E-02	1.2697E 02	3.4000E-01	5.6847E 01	1.1400E 00	1.3954E 01	2.4800E 00	6.4393E 00	4.3400E 00	3.8943E 00
2.5800E-02	1.4669E 02	3.4900E-01	5.4723E 01	1.1700E 00	1.3585E 01	2.5300E 00	6.3158E 00	4.4000E 00	3.8255E 00
3.1000E-02	1.6516E 02	3.6000E-01	5.2341E 01	1.2100E 00	1.3149E 01	2.5800E 00	6.1943E 00	4.4700E 00	3.7626E 00
3.6700E-02	1.8173E 02	3.6800E-01	5.0719E 01	1.2400E 00	1.2807E 01	2.6300E 00	6.0812E 00	4.5300E 00	3.6966E 00
4.2800E-02	1.9565E 02	3.8700E-01	4.7265E 01	1.2800E 00	1.2428E 01	2.6800E 00	5.9694E 00	4.6000E 00	3.6369E 00
4.9400E-02	2.0684E 02	4.0600E-01	4.4254E 01	1.3100E 00	1.2119E 01	2.7300E 00	5.8665E 00	4.6600E 00	3.5765E 00
5.6400E-02	2.1495E 02	4.2600E-01	4.1500E 01	1.3500E 00	1.1782E 01	2.7800E 00	5.7639E 00	4.7300E 00	3.5165E 00
6.4000E-02	2.2009E 02	4.4600E-01	3.9084E 01	1.3800E 00	1.1505E 01	2.8300E 00	5.6721E 00	4.8000E 00	3.4604E 00
7.2000E-02	2.2212E 02	4.6700E-01	3.6863E 01	1.4200E 00	1.1200E 01	2.8800E 00	5.5745E 00	4.8600E 00	3.4129E 00
8.0500E-02	2.2127E 02	4.8800E-01	3.4898E 01	1.4500E 00	1.0953E 01	2.9400E 00	5.4676E 00	4.9300E 00	3.3719E 00
8.9400E-02	2.1783E 02	5.1000E-01	3.3079E 01	1.4900E 00	1.0669E 01	3.0000E 00	5.3704E 00	5.0000E 00	3.4202E 00
9.8900E-02	2.1201E 02	5.3200E-01	3.1455E 01	1.5300E 00	1.0387E 01	3.0400E 00	5.2894E 00	5.2691E-01	7.2075E-01
1.0900E-01	2.0415E 02	5.5500E-01	2.9940E 01	1.5700E 00	1.0125E 01	3.1000E 00	5.2020E 00	3.9273E-01	1.2973E 00
1.1900E-01	1.9524E 02	5.7800E-01	2.8575E 01	1.6100E 00	9.8740E 00	3.1500E 00	5.1060E 00	3.0421E-01	2.1620E 00
1.3000E-01	1.8474E 02	6.0200E-01	2.7292E 01	1.6500E 00	9.6368E 00	3.2100E 00	5.0152E 00	2.3564E-01	3.6028E 00

IMS FORTRAN LISTING

```
C     IMS.  INFINITE MEDIUM SPECTRUM CODE.                                18490103
      DIMENSION E(161),SS(161,161),SA(161),PHI(161),CPHI(161),
     1SST(161),S(161),ARG(161),DIF(161),XNS(7),TITLE(12),WO(161),WE(161)
  100 READ INPUT TAPE 10,4                                                16500210
      WRITEOUTPUTTAPE9,4                                                  16500118
    4 FORMAT(72H                                                          16500120
     1                    )                                               16500122
      READ INPUT TAPE 10,1,T,XLAM,SS0,SA0,XN,EP,XNI                       16500121
    1 FORMAT(7E10.6)                                                      16500114
      READINPUTTAPE10,43,XNK,FR                                           IMS 0001
   43 FORMAT(2E10.4)                                                      IMS 0002
      IF(XNK) 90,99,90                                                    16500108
   90 READ TAPE 2,TITLE                                                   16500111
      IF (ABSF(TITLE(12)-XNK)-0.01) 93,93,91                              16500103
   91 DO 92 I=1,4                                                         16500115
   92 READ TAPE 2                                                         16500117
      GO TO 90                                                            16500119
   93 READ TAPE 2,N                                                       16500123
      READ TAPE 2,(E(J),J=1,N)                                            16500125
      READ TAPE 2,(S(J),J=1,N)                                            16500201
      READ TAPE 2,((SS(J,I),I=1,N),J=1,N)                                 16500203
      DO 94 I=1,N                                                         16500205
      WO(I)=0.0                                                           16500207
   94 WE(I)=0.0                                                           16500208
   99 NS=XN                                                               16500209
      WRITE OUTPUT TAPE 9,95,(TITLE(I),I=1,12)                            16500101
   95 FORMAT (1H011A6,F13.5)                                              16500214
      IF(XNI)2,2,3                                                        16500115
    2 XNI=100.0                                                           16500116
    3 YN=0.0                                                              16500117
   50 DO9J=1,N                                                            16500203
      DO10K=1,N                                                           16500205
   10 SS(J,K)=SS(J,K)*SS0                                                 16500207
    9 CONTINUE                                                            16500209
   51 IF(SA0)52,53,52                                                     16500211
   52 C1=0.1590597*SA0                                                    16500213
      DO54J=1,N                                                           16500215
   54 SA(J)=C1/SQRTF(E(J))                                                16500217
      GOTO8                                                               16500218
   53 READ INPUT TAPE 10,1,(XNS(J),J=1,7)                                 16500201
      DO57J=1,N                                                           16500220
   57 SA(J)=0.0                                                           16500221
      DO55K=1,NS                                                          16500222
      LL=K                                                                IMS 0101
      CALL SIGMA(E,N,LL,LM,XNS,SA)                                        IMS 0101
      IF(LM)36,55,36                                                      IMS 0005
   55 CONTINUE                                                            IMS 0102
    8 IF(T)11,12,11                                                       MAIN0223
   11 ET=0.0253*T/293.6                                                   MAIN0225
      DO13J=1,N                                                           MAIN0301
      PHI(J)=(E(J)/(ET*ET))*EXPF(-E(J)/ET)                                MAIN0303
      IF(E(J)-2.0*ET) 13,13,14                                            16500309
   14 IF(E(J)-5.0*ET) 15,15,16                                            16500311
   15 PHI(J)=PHI(J)+XLAM*(E(J)-2.0*ET)/(21.0*ET*ET)                       16500313
      GOTO13                                                              MAIN0311
   16 IF(E(J)-7.0*ET) 17,17,18                                            16500315
   17 PHI(J)=PHI(J)+XLAM/(7.0*ET)                                         16500317
      GOTO13                                                              MAIN0317
```

```
18 PHI(J)=PHI(J)+XLAM/E(J)                                          MAIN0319
13 CONTINUE                                                         MAIN0321
12 DO19J=1,N                                                        MAIN0401
   NJ=J                                                             16500216
   DO20K=1,N                                                        MAIN0403
20 ARG(K)=SS(J,K)                                                   MAIN0405
   CALL SR1 (ARG,E,N,NJ,WO,WE,ANS)                                  16500218
19 SST(J)=ANS                                                       18490103
   DO21J=1,N                                                        MAIN0411
   NJ=1                                                             16500220
21 ARG(J)=PHI(J)*SA(J)                                              MAIN0413
   CALL SR1 (ARG,E,N,NJ,WO,WE,TA)                                   16500222
   CALL SR1 (S,E,N,NJ,WO,WE,TS)                                     16500224
   R=TS/TA                                                          MAIN0419
   DO22J=1,N                                                        MAIN0421
22 PHI(J)=PHI(J)*R                                                  MAIN0423
40 DO23J=1,N                                                        MAIN0425
   NJ=J                                                             16500301
   DO24L=1,N                                                        MAIN0501
24 ARG(L)=SS(L,J)*PHI(L)                                            MAIN0503
   CALL SR1 (ARG,E,N,NJ,WO,WE,BS)                                   16500303
23 CPHI(J)=(BS+S(J))/(SA(J)+SST(J))                                 MAIN0507
   DO25J=1,N                                                        MAIN0509
   NJ=1                                                             16500305
25 ARG(J)=CPHI(J)*SA(J)                                             MAIN0511
   CALL SR1 (ARG,E,N,NJ,WO,WE,TA)                                   16500307
   R=TS/TA                                                          MAIN0515
   DO26J=1,N                                                        MAIN0517
26 CPHI(J)=(1.0-FR)*PHI(J)+FR*R*CPHI(J)                             IMS 0008
   DO27J=1,N                                                        MAIN0521
   DIF(J)=2.0*(CPHI(J)-PHI(J))/(CPHI(J)+PHI(J))                     MAIN0523
27 PHI(J)=CPHI(J)                                                   MAIN0525
   BIG=0.0                                                          MAIN0601
   SBIG=0.0                                                         MAIN0603
   DO29J=1,N                                                        MAIN0605
   IF(ABSF(DIF(J))-BIG)29,29,30                                     MAIN0607
30 BIG=ABSF(DIF(J))                                                 MAIN0609
   SBIG=DIF(J)                                                      MAIN0611
29 CONTINUE                                                         MAIN0613
   YN=YN+1.0                                                        16500205
   IF(XNI-YN) 34,34,35                                              16500207
34 FO=1.0                                                           MAIN0623
36 NYN=YN                                                           IMS 0010
   CALLOUTM(PHI,E,SBIG,NYN,FR,LM,N)                                 IMS 0011
   REWIND 2
   GOTO100                                                          MAIN0701
35 IF(BIG-EP)36,36,40                                               MAIN0703
   END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

```
C     SR1.  SIMPSONS RULE INTEGRATION WITH UNEQUAL INTERVALS.          18490106
      SUBROUTINE SR1(ARG,VAR,N,NJ,WO,WE,ANS)                           18490103
      DIMENSION ARG(161),VAR(161),WO(161),WE(161)
      ANS=0.0                                                          18490106
      AJ=0.0                                                           18490107
      BJ=0.0                                                           18490108
      IF(NJ-2*(NJ/2))1,4,1                                             18490109
    1 DO7J=1,3                                                         18490111
    7 AJ=AJ+WO(J)                                                      18490113
      IF(AJ)3,2,3                                                      18490115
    2 NNN=(N-1)/2                                                      18490117
      DO8M=1,NNN
      J1=2*M-1
      J2=J1+1
      J3=J2+1
      A=VAR(J2)-VAR(J1)
      AL=(VAR(J3)-VAR(J1))/A
      WO(J1)=WO(J1)+A*AL*(3.0-AL)/6.0
      WO(J2)=(AL**3)*A/(6.0*(AL-1.0))
      WO(J3)=(2.0*AL-3.0)*AL*A/(6.0*(AL-1.0))
    8 CONTINUE
    3 DO32J=1,N
      IF(ARG(J))33,32,33
   32 CONTINUE
   33 JSM=J
      DO35I=1,N
      J=N-I+1
      IF(ARG(J))34,35,34
   35 CONTINUE
   34 JLA=J
      DO14J=JSM,JLA                                                    18490302
   14 ANS=ANS+ARG(J)*WO(J)                                             18490304
      GOTO25                                                           18490306
    4 DO15J=1,3                                                        18490308
   15 BJ=BJ+WE(J)                                                      18490310
      IF(BJ)6,5,6                                                      18490312
    5 WE(1)=(VAR(2)-VAR(1))/2.0                                        18490316
      WE(2)=WE(1)                                                      18490317
      WE(N)=(VAR(N)-VAR(N-1))/2.0                                      18490318
      WE(N-1)=WE(N)                                                    18490319
      NNN=(N-3)/2
      DO19M=1,NNN
      J1=2*M
      J2=J1+1
      J3=J2+1
      A=VAR(J2)-VAR(J1)
      AL=(VAR(J3)-VAR(J1))/A
      WE(J1)=WE(J1)+A*AL*(3.0-AL)/6.0
      WE(J2)=(AL**3)*A/(6.0*(AL-1.0))
      WE(J3)=WE(J3)+(2.0*AL-3.0)*AL*A/(6.0*(AL-1.0))
   19 CONTINUE
    6 DO42J=1,N
      IF(ARG(J))43,42,43
   42 CONTINUE
   43 JSM=J
      DO45I=1,N
      J=N-I+1
      IF(ARG(J))44,45,44
```

```
45 CONTINUE
44 JLA=J
   DO24J=JSM,JLA                                                    18490515
24 ANS=ANS+ARG(J)*WE(J)                                             18490517
25 RETURN                                                           18490519
   END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

```
C     SIG.  MACROSCOPIC ABSORPTION CROSS SECTIONS FOR IMS.          18490104
      SUBROUTINE SIGMA(E,N,LL,LM,XNS,SA)                            SIG  102
      DIMENSION E(161),SA(161),SE(161),S(161),XNS(7),D(7)
    1 NSE0=0                                                        SIG  104
    2 READ INPUT TAPE10,3,(D(J),J=1,7),IC                           SIG  105
    3 FORMAT(7E10.7,I2)                                             SIG  106
    4 IC=IC+1                                                       SIG  107
    5 IF(IC-5)31,6,31                                               SIG  108
    6 IF(NSE0)9,7,9                                                 SIG  109
    7 NSE=0                                                         SIG  110
    8 NSE0=1                                                        SIG  111
    9 DO14J=1,5,2                                                   SIG  112
   10 K=NSE+(J+1)/2                                                 SIG  113
   11 SE(K)=D(J)                                                    SIG  114
   12 S(K)=D(J+1)                                                   SIG  115
   13 IF(SE(K))14,17,14                                             SIG  116
   14 CONTINUE                                                      SIG  117
   15 NSE=NSE+3                                                     SIG  118
   16 GO TO 2                                                       SIG  119
   17 NSE=K-1                                                       SIG  120
   18 DO 20 J=1,NSE                                                 SIG  121
   19 SE(J)=LOGF(SE(J))                                             SIG  122
   20 S(J)=LOGF(S(J))                                               SIG  123
   21 JMI=2                                                         SIG  124
   22 DO27K=1,N                                                     SIG  125
   28 EN=LOGF(E(K))                                                 SIG 0108
   23 DO26J=JMI,NSE                                                 SIG 0109
   24 JMI=J                                                         SIG 0110
   25 IF(SE(J)-EN)26,27,27                                          SIG 0111
   26 CONTINUE                                                      SIG 0112
   33 LM=-1                                                         SIG 0001
      GOTO32                                                        SIG 0002
   27 SA(K)=SA(K)+XNS(LL)*EXPF(((SE(J)-EN)*S(J-1)+(EN-              SIG 0113
     1SE(J-1))*S(J))/(SE(J)-SE(J-1)))                               SIG 0114
   29 LM=0                                                          SIG  208
   30 GO TO 32                                                      SIG  209
   31 LM=1                                                          SIG  210
   32 RETURN                                                        SIG  211
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

```
C     OUTM.  IMS OUTPUT SUBROUTINE.                                     18490105
      SUBROUTINE OUTM(PHI,E,SBIG,NYN,FR,LM,N)                           OUTM0002
      DIMENSION PHI(161),E(161)                                         OUTM0003
    1 IF(LM)2,5,2                                                       OUTM0004
    2 WRITE OUTPUT TAPE 9,3,LM                                          OUTM0005
    3 FORMAT(18HOSIGMA FAILURE LM=I3)                                   OUTM0006
    4 GO TO 24                                                          OUTM0007
    5 WRITE OUTPUT TAPE 6,6,(E(J),PHI(J),J=1,N)                         OUTM0008
    6 FORMAT(1P6E10.4,12H            5)                                 18490101
    7 ENDFILE6                                                          OUTM0010
    8 WRITEOUTPUTTAPE9,9,NYN,SBIG,FR                                    OUTM0011
    9 FORMAT(22HONUMBER OF ITERATIONS=I4,24H     MAXIMUM DIVERGENCE=E11.OUTM0012
   1013,25H    EXTRAPOLATION FACTOR=F5.3/2H0 )                          OUTM0013
   11 WRITE OUTPUT TAPE9,12                                             OUTM0014
   12 FORMAT(117H0   ENERGY       FLUX       ENERGY       FLUX       ENEOUTM0015
   131RGY       FLUX       ENERGY       FLUX       ENERGY       FLUX/2HOOUTM0016
   142 )                                                                OUTM0017
   15 NC=N/5+1                                                          OUTM0018
   16 DO21J=1,NC                                                        OUTM0019
   17 K1=J+NC                                                           OUTM0020
   18 K2=K1+NC                                                          OUTM0021
   19 K3=K2+NC                                                          OUTM0022
   20 K4=K3+NC                                                          OUTM0023
   21 WRITEOUTPUTTAPE9,23,(E(J),PHI(J),E(K1),PHI(K1),                   OUTM0024
   221E(K2),PHI(K2),E(K3),PHI(K3),E(K4),PHI(K4))                        OUTM0025
   23 FORMAT(10(1PE12.4))                                               OUTM0001
   24 RETURN                                                            OUTM0002
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

IV. TKS – An IBM 7090 Program for the Calculation of Source Terms for the IMS Program

Description of the Problem

In Section I it is shown that reducing the range of integration in the space independent Boltzmann equation to a finite energy interval necessitates the introduction of a source function S(E) defined by Eq. (4) as

$$S(E) = \int_{E_2}^{\infty} \phi(E') \, \Sigma(E' \to E) \, dE' - \phi(E) \int_{E_2}^{\infty} \Sigma(E \to E') \, dE' +$$

$$+ \int_{0}^{E_1} \phi(E') \, \Sigma(E' \to E) \, dE' - \phi(E) \int_{0}^{E_1} \Sigma(E \to E') \, dE' .$$

It is noted in this expression for S(E) that the first two terms represent the net number of neutrons (per cm^3/sec) entering the finite energy interval $E_1 \leqslant E \leqslant E_2$ from energies greater than E_2, whereas the second two terms represent the corresponding net number entering the interval from energies less than E_1. We select E_1 close to zero so that the latter influx is negligible. The expression for the source function then becomes

$$S(E) = \int_{E_2}^{\infty} \phi(E') \, \Sigma(E' \to E) \, dE' - \phi(E) \int_{E_2}^{\infty} \Sigma(E \to E') \, dE' . \qquad (13)$$

Program TKS evaluates Eq. (13) for each point of the energy mesh in the interval $E_1 \leqslant E \leqslant E_2$, using exact transfer kernels calculated by the GTP program. The resulting sources are then normalized to one net slowing down neutron (per cm^3/sec). In order to do the calculation an energy transfer kernel must first be computed for an energy range spanning E_2. The lower limit of the kernel mesh must meet the requirement that downscatter from E_2 is negligible and the upper limit must meet the requirement that downscatter to E_2 is negligible. Three different options are provided for defining the function $\phi(E)$ of Eq. (13),

1) $\phi(E)$ may be read in directly as input data,

2) $\phi(E) = 1/E$,

3) $\phi(E) = P(E)/[\xi\Sigma_s + \gamma\Sigma_a(E)]\ E$.

Flux option 3 is based on the derivation of the resonance-escape probability for slowly varying capture given in Ref. 4. The resonance-escape probability P(E), where

$$P(E) = \exp\left(-\int_E^{E_o} \frac{\Sigma_a(E)}{\xi\Sigma_s + \gamma\Sigma_a(E)} \frac{dE'}{E'}\right), \tag{14}$$

as well as ξ and γ are calculated automatically by the code if option 3 is selected. If flux option 3 is selected there are three different options available for the $\Sigma_a(E)$ quantity appearing in Eq. (14). These absorption cross section options are:

1) $\Sigma_a(E) = 0$,

2) $\Sigma_a(E) = \Sigma_a^{2200\ m/s}\sqrt{\frac{E_{2200}}{E}}$,

3) $\Sigma_a(E)$ is read in directly.

As in the IMS code, integration is done by the SR1 subroutine which uses Simpson's rule with unequal intervals. This imposes the requirement that the total number of energy mesh points in the source kernel be odd and also that the value E_2 is an odd numbered mesh point.

It is worth noting that if suitable simplifying assumptions are made, Eq. (13) may be solved analytically. Such an approach to the problem of calculating source terms for the IMS code may be as useful for many problems as the more complex procedure embodied in the TKS program. If E_2 is in the energy region where the flux has a 1/E energy dependence and is sufficiently high that upscatter is negligible, then neutron collisions are essentially with atoms at rest and obey the simple mechanics of elastic scattering. Under these conditions the energy transfer kernels of Eq. (13) have the simple form:

1) $P(E \rightarrow E') = 0$ when $E < E'$,

2) $P(E' \rightarrow E) = \frac{1}{(1-\alpha)E'}$ when $\alpha E' \leqslant E \leqslant E'$,

3) $P(E' \rightarrow E) = 0$ when $E < \alpha E'$,

where $\alpha = (\frac{A-1}{A+1})^2$ is the familiar parameter describing the maximum fractional energy loss in elastic collisions. Equation (13) then becomes

$$S(E) = \int_{E_2}^{E/\alpha} \frac{1}{E'} \cdot \frac{dE'}{(1-\alpha)E'} = \frac{1}{1-\alpha} [\frac{1}{E_2} - \frac{\alpha}{E}] . \tag{15}$$

We impose a normalization of one net slowing down neutron (per cm^3/sec) to obtain

$$S(E) = \frac{1}{\xi(1-\alpha)} [\frac{1}{E_2} - \frac{\alpha}{E}] . \tag{16}$$

IMS computed fluxes based on sources computed from Eq. (16) exhibit small perturbations in the region from αE_2 to E_2. However, if E_2 is of the order of several electron volts, this perturbation is of minor significance.

Preparation of Input Data

To operate the TKS program an input tape is prepared on the card-to-tape converter using the data cards described below. This tape is selected as tape 10 and together with the KERNEL LIBRARY TAPE selected as logical tape 2 constitutes all of the data input. An additional tape selected as tape 9 is required for output. The card input data are supplied on the Ten Digit Data Form with the same freedom of format as is described in the section dealing with the GTP program. The set of input cards which is to be transferred to tape 10 must be assembled in the following order:

1. Card 1. Column 1 must contain a 1-punch. Columns 2-72 may contain any alphabetic or numeric information which identifies the calculation. This information, together with the KERNEL title read in from logical tape 2, is printed at the top of each page of output.

2. Card 2. Seven numbers are punched which give the following information:

Field 1. Energy mesh number corresponding to E_2. This must be an ODD number.

Field 2. Macroscopic free atom scattering cross section of the moderator.

Field 3. Macroscopic 2200 m/s absorption cross section.

Field 4. Atomic mass of the scatterer.

Field 5. Number of the kernel to be selected from the KERNEL LIBRARY TAPE and used in the calculation.

Field 6. Flux option number as described on page 46.

Field 7. Absorption cross section option as described on page 46.

3. Card 3. If the absorption cross section option SAØPT = 3.0 is selected, cards 3 must contain the values of the macroscopic cross section for each energy point of the KERNEL mesh. Seven fields per card are required with as many cards as are necessary to read in all of the cross section values.

If flux option ØPT = 1.0 is chosen, cards 3 must contain the fluxes to be read in. Again, seven fields per card are required with as many cards allowed as are necessary to supply a flux value for each point of the KERNEL energy mesh.

Output

The output is listed from tape 9 and contains the title of the calculation, the title of the kernel used, and a list of the energies, fluxes, and sources for each mesh point. In addition, the normalizing factor which was applied to the calculated or read in fluxes to make the source normalization equal to one net slowing down neutron (per cm^3/sec) is listed as ASYMPTOTIC FLUX.

The Fortran listing of the TKS program and associated subroutines, data forms, and output for a sample problem are illustrated in the following pages.

TEN DIGIT DATA FORM

PROBLEM	REQUEST
TKS	3325

CODER	DATE	PAGE
MET	10-29-62	1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 ← CØLUMNS 2-72 AVAILABLE FØR IDENTIFICATIØN ØF THE CALCULATIØN →															1
A		SS		SA		AM		XNK		ØPT		SAØPT			2
SA(1)		SA(2)		etc.											3 or 3
PHI(1)		PHI(2)		etc.											

A = Energy mesh number (ODD) of the kernel corresponding to E_2.

SS = Macroscopic scattering cross section of the medium.

SA = Macroscopic absorption cross section at 2200 m/s of the medium.

AM = Atomic mass of the moderator.

XNK = Number of the KERNEL to be used in the calculation.

ØPT = Flux option = 1.0 → Read $\phi(E)$ directly

= 2.0 → $\phi(E) = 1.0/E$

= 3.0 → $\phi(E) = P(E)/[\xi\Sigma_s + \gamma\Sigma_a(E)]\,E$

SAØPT = $\Sigma_a(E)$ option = 1.0 → Set $\Sigma_a(E) = 0.0$

= 2.0 → $\Sigma_a(E) = \Sigma_a^{2200}\sqrt{E_o/E}$

= 3.0 → Read $\Sigma_a(E)$ directly

UCN-8263
(3 11-61)

TKS INPUT DATA FORM

TEN DIGIT DATA FORM

PROBLEM	REQUEST
TKS	3325

CODER	DATE	PAGE
MET	10-29-62	1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 ← TKS.-SAMPLE-PRØBLEM.- -SØURCES-FRØM-KERNEL-3.-FLUX=1/E →															1
89.0		0.3974		100.0		12.0		3.0		2.0		1.0			2

UCN-3263
(3 11-61)

SAMPLE PROBLEM INPUT

TKS SAMPLE PROBLEM. SOURCES FROM KERNEL 3. FLUX=1/E.

1 (FG 600 K A=12 MSH(1.49(161)13EV) TKS SOURCE KERNEL 3 3.00000

ENERGY	FLUX	SOURCE	ENERGY	FLUX	SOURCE
1.4900E 00	1.1172E 01	0.	4.7700E 00	3.4898E 00	1.0849E 00
1.5300E 00	1.0880E 01	0.	4.8000E 00	3.4680E 00	1.1027E 00
1.5700E 00	1.0603E 01	0.	4.8300E 00	3.4464E 00	1.1195E 00
1.6100E 00	1.0339E 01	0.	4.8600E 00	3.4252E 00	1.1525E 00
1.6500E 00	1.0089E 01	0.	4.9000E 00	3.3972E 00	1.1726E 00
1.6900E 00	9.8499E 00	0.	4.9300E 00	3.3765E 00	1.1842E 00
1.7300E 00	9.6222E 00	0.	4.9700E 00	3.3494E 00	1.2006E 00
1.7700E 00	9.4047E 00	0.	5.0000E 00	3.3293E 00	1.1962E 00
1.8100E 00	9.1969E 00	0.	5.0500E 00	3.2963E 00	0.
1.8500E 00	8.9980E 00	0.	5.1000E 00	3.2640E 00	0.
1.8900E 00	8.8076E 00	0.	5.1500E 00	3.2323E 00	0.
1.9300E 00	8.6250E 00	0.	5.2000E 00	3.2012E 00	0.
1.9800E 00	8.4072E 00	0.	5.2500E 00	3.1707E 00	0.
2.0200E 00	8.2408E 00	0.	5.3000E 00	3.1408E 00	0.
2.0600E 00	8.0807E 00	0.	5.3500E 00	3.1115E 00	0.
2.1100E 00	7.8893E 00	0.	5.4000E 00	3.0827E 00	0.
2.1500E 00	7.7425E 00	0.	5.4500E 00	3.0544E 00	0.
2.2000E 00	7.5665E 00	0.	5.5000E 00	3.0266E 00	0.
2.2400E 00	7.4314E 00	0.	5.5500E 00	2.9993E 00	0.
2.2900E 00	7.2691E 00	0.	5.6000E 00	2.9726E 00	0.
2.3400E 00	7.1138E 00	0.	5.6500E 00	2.9463E 00	0.
2.3800E 00	6.9943E 00	0.	5.7000E 00	2.9204E 00	0.
2.4300E 00	6.8503E 00	0.	5.7500E 00	2.8950E 00	0.
2.4800E 00	6.7122E 00	0.	5.8000E 00	2.8701E 00	0.
2.5300E 00	6.5796E 00	0.	5.8500E 00	2.8455E 00	0.
2.5800E 00	6.4521E 00	0.	5.9000E 00	2.8214E 00	0.
2.6300E 00	6.3294E 00	0.	5.9500E 00	2.7977E 00	0.
2.6800E 00	6.2113E 00	0.	6.0000E 00	2.7744E 00	0.
2.7300E 00	6.0976E 00	0.	6.0500E 00	2.7515E 00	0.
2.7800E 00	5.9879E 00	0.	6.1000E 00	2.7289E 00	0.
2.8300E 00	5.8821E 00	0.	6.1500E 00	2.7067E 00	0.
2.8800E 00	5.7800E 00	1.2826E-04	6.2000E 00	2.6849E 00	0.
2.9400E 00	5.6620E 00	8.6940E-04	6.2500E 00	2.6634E 00	0.
3.0000E 00	5.5488E 00	2.4573E-03	6.3000E 00	2.6423E 00	0.
3.0400E 00	5.4758E 00	3.4108E-03	6.3500E 00	2.6215E 00	0.
3.1000E 00	5.3698E 00	6.7076E-03	6.4000E 00	2.6010E 00	0.
3.1500E 00	5.2845E 00	1.0086E-02	6.4500E 00	2.5808E 00	0.
3.2100E 00	5.1858E 00	1.6210E-02	6.5000E 00	2.5610E 00	0.
3.2600E 00	5.1062E 00	2.2831E-02	6.5500E 00	2.5414E 00	0.
3.3200E 00	5.0140E 00	3.4448E-02	6.6000E 00	2.5222E 00	0.

TKS SAMPLE PROBLEM. SOURCES FROM KERNEL 3. FLUX=1/E.

1 (FG 600 K A=12 MSH(1.49(161)13EV) TKS SOURCE KERNEL 3 3.00000

ENERGY	FLUX	SOURCE	ENERGY	FLUX	SOURCE
3.3700E 00	4.9396E 00	4.6527E-02	6.6500E 00	2.5032E 00	0.
3.4300E 00	4.8532E 00	6.3786E-02	6.7000E 00	2.4845E 00	0.
3.4900E 00	4.7697E 00	8.5918E-02	6.7500E 00	2.4661E 00	0.
3.5400E 00	4.7024E 00	1.0726E-01	6.8000E 00	2.4480E 00	0.
3.6000E 00	4.6240E 00	1.3868E-01	6.8500E 00	2.4301E 00	0.
3.6300E 00	4.5858E 00	1.5474E-01	6.9000E 00	2.4125E 00	0.
3.6600E 00	4.5482E 00	1.7383E-01	6.9500E 00	2.3952E 00	0.
3.6900E 00	4.5112E 00	1.9305E-01	7.0000E 00	2.3780E 00	0.
3.7200E 00	4.4748E 00	2.1223E-01	7.1250E 00	2.3363E 00	0.
3.7500E 00	4.4390E 00	2.3454E-01	7.2500E 00	2.2960E 00	0.
3.7800E 00	4.4038E 00	2.5670E-01	7.3750E 00	2.2571E 00	0.
3.8100E 00	4.3691E 00	2.7851E-01	7.5000E 00	2.2195E 00	0.
3.8400E 00	4.3350E 00	3.0348E-01	7.6250E 00	2.1831E 00	0.
3.8700E 00	4.3014E 00	3.2796E-01	7.7500E 00	2.1479E 00	0.
3.9000E 00	4.2683E 00	3.5173E-01	7.8750E 00	2.1138E 00	0.
3.9300E 00	4.2357E 00	3.7867E-01	8.0000E 00	2.0808E 00	0.
3.9600E 00	4.2036E 00	4.0334E-01	8.1250E 00	2.0488E 00	0.
3.9900E 00	4.1720E 00	4.2975E-01	8.2500E 00	2.0177E 00	0.
4.0200E 00	4.1409E 00	4.5794E-01	8.3750E 00	1.9876E 00	0.
4.0500E 00	4.1102E 00	4.8337E-01	8.5000E 00	1.9584E 00	0.
4.0800E 00	4.0800E 00	5.1045E-01	8.6250E 00	1.9300E 00	0.
4.1100E 00	4.0502E 00	5.3925E-01	8.7500E 00	1.9024E 00	0.
4.1500E 00	4.0112E 00	5.7327E-01	8.8750E 00	1.8756E 00	0.
4.1800E 00	3.9824E 00	6.0041E-01	9.0000E 00	1.8496E 00	0.
4.2100E 00	3.9540E 00	6.2933E-01	9.1250E 00	1.8243E 00	0.
4.2400E 00	3.9260E 00	6.5440E-01	9.2500E 00	1.7996E 00	0.
4.2700E 00	3.8984E 00	6.8117E-01	9.3750E 00	1.7756E 00	0.
4.3000E 00	3.8712E 00	7.0976E-01	9.5000E 00	1.7522E 00	0.
4.3400E 00	3.8356E 00	7.4425E-01	9.6250E 00	1.7295E 00	0.
4.3700E 00	3.8092E 00	7.6810E-01	9.7500E 00	1.7073E 00	0.
4.4000E 00	3.7833E 00	7.9612E-01	9.8750E 00	1.6857E 00	0.
4.4300E 00	3.7576E 00	8.1933E-01	1.0000E 01	1.6646E 00	0.
4.4700E 00	3.7240E 00	8.5199E-01	1.0400E 01	1.6006E 00	0.
4.5000E 00	3.6992E 00	8.7928E-01	1.0800E 01	1.5413E 00	0.
4.5300E 00	3.6747E 00	9.0380E-01	1.1200E 01	1.4863E 00	0.
4.5600E 00	3.6505E 00	9.2539E-01	1.1600E 01	1.4350E 00	0.
4.6000E 00	3.6188E 00	9.5895E-01	1.2000E 01	1.3872E 00	0.
4.6300E 00	3.5953E 00	9.8242E-01	1.2400E 01	1.3424E 00	0.
4.6600E 00	3.5722E 00	1.0027E 00	1.2800E 01	1.3005E 00	0.
4.6900E 00	3.5493E 00	1.0284E 00	1.3000E 01	1.2805E 00	0.
4.7300E 00	3.5193E 00	1.0596E 00	0.	1.4082E-01	1.1172E 01

ASYMPTOTIC FLUX= 1.6646E 01/E

TKS FORTRAN LISTING

```
C     TKS.  TRANSFER KERNEL SOURCES CODE.                                18490111
      DIMENSION E(161),S1(161),SIG(161,161),F(161),ARG(161),
     1WO(161),WE(161),TITLE(12),SAE(161),VAR(161),HEAD(12)
  100 READINPUTTAPE10,3,HEAD                                            TKS10002
    2 FORMAT(7E10.2)                                                    18490105
    3 FORMAT(12A6)                                                      TKS10003
      READINPUTTAPE10,4,A,SS,SA,AM,XNK,OPT,SAOPT                        TKS10110
    4 FORMAT(7E10.4)                                                    TKS10112
   90 READTAPE2,TITLE                                                   TKS10114
      IF(ABSF(TITLE(12)-XNK)-0.01)93,93,91                              TKS10116
   91 DO92I=1,4                                                         TKS10118
   92 READTAPE2                                                         TKS10120
      GOTO90                                                            TKS10122
   93 READTAPE2,N                                                       TKS10124
      READTAPE2,(E(J),J=1,N)                                            TKS10201
      READTAPE2,(S1(J),J=1,N)                                           TKS10203
      READTAPE2,((SIG(J,K),K=1,N),J=1,N)                                TKS10205
   99 DO94I=1,N                                                         TKS10207
      WO(I)=0.0                                                         TKS10209
   94 WE(I)=0.0                                                         TKS10211
      NSA=SAOPT                                                             2A01
      IF(NSA-2)71,96,95                                                     2A02
   71 DO72J=1,N                                                             2A03
   72 SAE(J)=0.0                                                            2A04
      GOTO98                                                                2A05
   96 DO97I=1,N                                                         TKS10223
      C1=0.1590597*SA                                                   TKS10224
   97 SAE(I)=C1/SQRTF(E(I))                                             TKS10225
      GOTO98                                                            TKS10302
   95 READINPUTTAPE10,2,(SAE(I),I=1,N)                                  TKS10304
   98 NA=A                                                              TKS10306
      NI=N-NA+1                                                         TKS10308
      CALLFLUX(E,SS,SAE,AM,N,OPT,WO,WE,F)                               TKS10004
   14 DO10J=1,NA                                                        TKS10312
      DO9K=1,NI                                                         TKS10314
      L=NA+K-1                                                          TKS10316
      VAR(K)=E(L)                                                       TKS10317
    9 ARG(K)=SIG(J,L)                                                   TKS10318
      CALLSR1(ARG,VAR,NI,NA,WO,WE,ANS)                                  TKS10320
   10 S1(J)=-ANS*F(J)*SS                                                TKS10322
      DO12J=1,NA                                                        TKS10324
      DO11K=1,NI                                                        TKS10402
      L=NA+K-1                                                          TKS10404
      VAR(K)=E(L)                                                       TKS10405
   11 ARG(K)=SIG(L,J)*F(L)                                              TKS10406
      CALLSR1(ARG,VAR,NI,NA,WO,WE,ANS)                                  TKS10408
   12 S1(J)=S1(J)+ANS*SS                                                TKS10410
      DO200J=1,NA                                                       TKS10412
  200 WO(J)=0.0                                                         TKS10414
      CALLSR1(S1,E,NA,NA,WO,WE,ANS)                                     TKS10416
      ANS=1.0/ANS                                                       TKS 0001
      DO13J=1,NA                                                        TKS 0002
      F(J)=F(J)*ANS                                                     TKS 0003
   13 S1(J)=S1(J)*ANS                                                   TKS 0004
      KK=NA+1                                                           TKS 0005
      DO300J=KK,N                                                       TKS 0006
      S1(J)=0.0                                                         TKS 0007
  300 F(J)=F(J)*ANS                                                     TKS 0008
```

```
CALLOUT(E,S1,ANS,N,F,HEAD,TITLE)                                TKS10005
REWIND 2
GOTO100                                                         TKS10424
END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

```
C     FLUX.  FLUXES FOR TRANSFER KERNEL SOURCES.                        18490113
      SUBROUTINEFLUX(E,SS,SAE,AM,N,OPT,WO,WE,F)                         FLUX0001
      DIMENSION E(161),SAE(161),WO(161),WE(161),F(161),
     1ARGU(3),ED(3),DENOM(161),RI(161),P(161),ARG(161)
      NOPT=OPT                                                          FLUX0109
      IF(NOPT-2)1,2,3                                                   FLUX0111
    1 READ INPUT TAPE 10,20,(F(J),J=1,N)                                18490101
   20 FORMAT(7E10.4)                                                    18490103
      GOTO100                                                           FLUX0115
    2 DO4J=1,N                                                          FLUX0117
    4 F(J)=1.0/E(J)                                                     FLUX0119
      GOTO100                                                           FLUX0121
    3 Z1=((AM+1.0)/(AM-1.0))**2                                         FLUX0123
      Z2=1.0/(Z1-1.0)                                                   FLUX0125
      Z3=LOGF(Z1)                                                       FLUX0202
      XI=1.0-Z2*Z3                                                      FLUX0204
      Z4=Z2*Z3*Z3                                                       FLUX0206
      GAM=1.0-Z4/(2.0*XI)                                               FLUX 208
      DO5J=1,N                                                          FLUX0210
      DENOM(J)=XI*SS+GAM*SAE(J)                                         FLUX0212
    5 ARG(J)=SAE(J)/(E(J)*DENOM(J))                                     FLUX0214
      NTR=0                                                             FLUX0216
      RI(N)=0.0                                                         FLUX0218
      P(N)=1.0                                                          FLUX0220
      LL=(N-1)/2                                                        FLUX0222
   10 DO9K=1,LL                                                         FLUX0301
      I=N-2K                                                            FLUX0303
      DO8L=1,3                                                          FLUX0305
      KK=I+L-1                                                          FLUX0307
      ARGU(L)=ARG(KK)                                                   FLUX0309
    8 ED(L)=E(KK)                                                       FLUX0311
      NT=3                                                              FLUX0313
      CALLSR1(ARGU,ED,NT,NT,WO,WE,ANS)                                  FLUX0315
      DO11J=1,3                                                         FLUX0317
   11 WO(J)=0.0                                                         FLUX0319
      M=I+2                                                             FLUX0321
      RI(I)=RI(M)+ANS                                                   FLUX0323
    9 P(I)=EXPF(-RI(I))                                                 FLUX0325
      IF(NTR)12,13,12                                                   FLUX0402
   13 LL=LL-1                                                           FLUX0404
      N=N-1                                                             FLUX0406
      RI(N)=((ARG(N)+ARG(N+1))/2.0)*(E(N+1)-E(N))                       FLUX0101
      P(N)=EXPF(-RI(N))                                                 FLUX0102
      NTR=1                                                             FLUX0103
      GOTO10                                                            FLUX0104
   12 N=N+1                                                             FLUX0105
      DO14J=1,N                                                         FLUX0106
   14 F(J)=P(J)/(E(J)*DENOM(J))                                         FLUX0418
  100 RETURN                                                            FLUX0420
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

```
C     OUT.  TKS OUTPUT SUBROUTINE.                                      18490112
      SUBROUTINEOUT(E,S,ANS,N,F,HEAD,TITLE)                             OUT 0001
      DIMENSION E(161),S(161),F(161),HEAD(12),TITLE(12)
      NN=1                                                              OUT 0003
   32 WRITEOUTPUTTAPE9,30,(HEAD(I),I=1,12)                              OUT 0004
   30 FORMAT(12A6)                                                      OUT 0005
      WRITEOUTPUTTAPE9,31,(TITLE(I),I=1,12)                             OUT 0006
   31 FORMAT(1H011A6,F13.5)                                             OUT 0007
      WRITEOUTPUTTAPE9,14                                               OUT 0108
   14 FORMAT(2H0 //108H              ENERGY           FLUX           SOURCE OUT 0110
     1                        ENERGY           FLUX           SOURCE/2H0  OUT 0112
     2)                                                                 OUT 0114
      IF(NN-1)33,33,34                                                  OUT 0008
   33 J2=N/2+1                                                          OUT 0009
      DO15J=1,J2                                                        OUT 0118
      NL=J+1                                                            OUT 0120
      K=J2+J                                                            OUT 0122
      WRITE OUTPUT TAPE 9,16,(E(J),F(J),S(J),E(K),F(K),S(K))            18490107
      IF(NL-40)15,15,18                                                 OUT 0201
   15 CONTINUE                                                          OUT 0203
   16 FORMAT(1H 1PE19.4,1PE15.4,1PE15.4,1PE30.4,1PE15.4,                18490101
     11PE15.4)                                                          OUT 0011
   18 NN=2                                                              OUT 0012
      IF(N-80)21,21,32                                                  OUT 0013
   34 DO20J=NL,J2                                                       OUT 0014
      K=J2+J                                                            18490102
   20 WRITEOUTPUTTAPE9,16,(E(J),F(J),S(J),E(K),F(K),S(K))               OUT 0015
   21 WRITE OUTPUT TAPE9,17,ANS                                         18490104
   17 FORMAT(2H0 //17H0ASYMPTOTIC FLUX=1PE12.4,2H/E)                    OUT 0217
      RETURN                                                            OUT 0016
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

V. ACS – An IBM 7090 Program for the Calculation of Flux Weighted Cross Sections

Description of the Problem

This section describes a program which has been written to perform the numerical integrations encountered in the calculation of spectrum averaged cross sections. In general, the two integrals which are done are:

$$\text{REACTION} = \int \sigma(E)\, \phi(E)\, dE \ ,$$

$$\text{FLUX} = \int \phi(E)\, dE \ .$$

These integrals are done by fifth order Gaussian quadrature with either the Campbell-Freemantle analytic form for the neutron flux or with an arbitrary form for the flux which may be specified in the input by giving a table of flux versus energy. In all cases the cross section is specified by giving a table of cross section versus energy.

The analytic form for the flux as given by Campbell and Freemantle is

$$\phi(E) = M(E) + \lambda\, F(E) \ ,$$

where

$$M(E) = \frac{E}{(kT)^2} \exp\left(-\frac{E}{kT}\right)$$

and

$$F(E) = \begin{cases} \dfrac{1}{E} & E \geqslant \mu kT \\[2ex] \dfrac{1}{\mu kT} & \beta kT \leqq E < \mu kT \\[2ex] \dfrac{(E - \alpha kT)}{\mu(\beta-\alpha)(kT)^2} & \alpha kT \leqq E < \beta kT \\[2ex] 0 & E < \alpha kT \end{cases}$$

The spectrum is characterized by the five parameters T, α, β, μ, and λ which are all input numbers.

By providing the appropriate input numbers, as described later, the energy range is broken into 1 to 50 major intervals within which the following integrals are calculated:

$$TRR = \int M(E)\ \sigma(E)\ dE\ ,$$

$$TF = \int M(E)\ dE\ ,$$

$$ERR = \int F(E)\ \sigma(E)\ dE\ ,$$

$$EF = \int F(E)\ dE\ .$$

The numerical mesh for the integration is determined by specifying in the input data the number of subintervals into which the 1 to 50 major intervals are to be divided. In each of these subintervals a fifth order Gaussian quadrature is done to obtain the required integrals. The cross section is computed at the necessary points by interpolating in the table of cross section versus energy which is supplied as input. A linear interpolation of the logarithm of the cross section against the logarithm of the energy is done so that the interpolation gives the exact value if the cross section is expressible as a power of the energy (as, for example, with a 1/v cross section). If the analytic form of the flux is not used, the same interpolation is done with the flux table. Care must be taken that no flux or cross section values are negative or zero.

Preparation of Input Data

The input data for a calculation consist of one or more cards as described below. Except for the title card, each data card must contain a number between 00 and 05 in columns 71-72. This serves as data identification to the reading routine.

1. Title Card. Column 1 must contain a 1-punch. Columns 2-72 may contain any alphabetic or numeric information which identifies the calculation.

2. Card 01. T_N, α, β, and μ are punched in the first four fields and characterize the spectral shape. The λ_{max} and $\Delta\lambda$ which follow specify

the range of values of λ for which the average cross section over the entire spectrum is calculated. The seventh field contains an upper bound to the energy range of the integrations. The integration is done up to this energy or to the maximum energy of the flux or cross section table, whichever is lowest. If zero is inserted for the neutron temperature, then E_{max} is the only other data required on this card. In this case the analytic flux calculation is bypassed and a table of fluxes must be supplied in the input.

3. Cards 02. Seven numbers per card (less if required) are punched giving successive values of the energy which divide the range into the major intervals of the integration. Up to 50 values may be given, continuing on successive cards if necessary.

4. Cards 03. Seven numbers per card are punched giving the number of equal sized subintervals in each of the major intervals described by cards 02. In each of these subintervals a fifth order Gaussian quadrature is done.

5. Cards 04. Three pairs of numbers on each card specify the table of cross sections. A maximum of 500 pairs is allowed.

6. Cards 05. Three pairs of numbers on each card specify the table of fluxes if the analytic form is not used ($T_N = 0$). A maximum of 500 pairs is allowed.

7. The last card of each case must have 00 in columns 71-72 or else must be blank. No data are punched on this card.

Any number of cases may be run successively by stacking the input data. The last card in each case must be blank or punched with 00 in columns 71-72 as described above. If the cases are stacked in this manner it is permissible to omit blocks of cards when the data are the same as for the previous case. For example, the cross sections for a series of calculations on the same element may be read in with the first case and omitted from the cases which follow. If a change is made in a later case then the entire card or block of data cards must be read in.

Output

The output generated by this program is listed from tape 9, and consists of the following information:

1. Title of the ACS calculation.
2. Neutron temperature.
3. Values of α, β, and μ.
4. Maximum energy in electron volts.
5. Thermal and epithermal reaction and flux values for the specified energy ranges.
6. Average cross section values over the entire spectrum for the specified λ's.

The Fortran listing of the ACS program and associated subroutines, data form, listing of the data cards, and the output for the sample case are given in the following pages. The integrals encountered in this case are all analytic and the exact values of the integrals are shown in parentheses.

TEN DIGIT DATA FORM

PROBLEM	REQUEST
ACS	3325

CODER	DATE	PAGE
MET	10-30-62	1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 ← ACS.-CØLUMNS-2-72-AVAILABLE-FØR-IDENTIFICATIØN.-→															
T(DEG.K)		α		β		μ		λ_{max}		$\Delta\lambda$		E_{max}		01	
E_1(ev)		E_2		E_3		E_4		E_5		E_6		E_7		02	
N_1		N_2		N_3		N_4		N_5		N_6		N_7		03	
E_A(ev)		$\sigma(E_A)$		E_B		$\sigma(E_B)$		E_C		$\sigma(E_C)$		(BLANK)		04	
E_α(ev)		$\phi(E_\alpha)$		E_β		$\phi(E_\beta)$		E_γ		$\phi(E_\gamma)$		(BLANK)		05	
														00	

UCN-3263
(3 11-61)

ACS INPUT DATA FORM

TEN DIGIT DATA FORM

PROBLEM	REQUEST
ACS	3325

CODER	DATE	PAGE
MET	10-30-62	1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 ← ACS.-SAMPLE-PRØBLEM.- -Σ=1/SQRTF(E).-CAMPBELL-FREEMANTLE-FLUX.→															
293.6		1.0		3.5		5.0		0.2		0.05		2.0		01	
0.0001		0.001		0.01		0.1		1.0		10.0				02	
10.0		10.0		10.0		10.0		10.0						03	
0.0001		100.0		1.0		1.0		4.0		0.5				04	
														00	

UCN-9263
(8 11-61)

SAMPLE PROBLEM INPUT

ACS SAMPLE PROBLEM. E=1/SQRTF(E). CAMPBELL FREEMANTLE FLUX.

NEUTRON TEMPERATURE= 2.9360E 02

ALPHA= 1.0000E 00 BETA= 3.5000E 00 MU= 5.0000E 00

MAXIMUM ENERGY= 2.0000E 00 EV.

ENERGY LIMITS LOWER	UPPER	THERMAL REACTION	THERMAL FLUX	EPITHERMAL REACTION	EPITHERMAL FLUX
10.0000E-05	10.0000E-04	3.1126E-02	7.5306E-04	0.	0.
10.0000E-04	10.0000E-03	7.9391E-01	5.9523E-02	0.	0.
10.0000E-03	10.0000E-02	4.4781E 00	8.4460E-01	1.2793E 00	3.4053E-01
10.0000E-02	1.0000E 00	2.6752E-01	9.5117E-02	4.2455E 00	2.2765E 00
1.0000E 00	2.0000E 00	2.7324E-16	2.7670E-16	5.8579E-01	6.9315E-01

SPECTRUM AVERAGES

LAMBDA	AVERAGE SIGMA
0.	5.5707E 00
5.0000E-02	5.0417E 00
10.0000E-02	4.6443E 00
1.5000E-01	4.3349E 00
2.0000E-01	4.0870E 00

ACS FORTRAN LISTING

```
C     ACS.  AVERAGE CROSS SECTION CODE.                                18490107
      COMMON N,E,SE,S,FE,F,T,ALP,BET,XMU,EMAX,                         MAIN0103
     1KMIF,KMI,ET,EALP,EBET,EMU,ID,NE,NN,NSE,NFE,IE                    16500101
      DIMENSIONE(50),SE(500),S(500),FE(500),F(500),                    MAIN0107
     1N(50),ANS(2),TRR(50),TF(50),ERR(50),EF(50),D(7)                  16500203
  503 READ INPUT TAPE 10,100                                           16500103
      IE=0                                                             16500105
  100 FORMAT(72H                                                       MAIN0113
     1                    )                                            MAIN0114
      WRITEOUTPUTTAPE9,100                                             MAIN0115
      NE0=0                                                            16500309
      NN0=0                                                            16500311
      NSE0=0                                                           16500313
      NFE0=0                                                           16500315
      LS=0                                                             16500105
      LF=0                                                             16500107
  102 READ INPUT TAPE 10,101,(D(J),J=1,7),IC                           16500107
  101 FORMAT(7E10.7,I2)                                                MAIN0207
  120 IC=IC+1                                                          16500207
      GO TO (200,201,202,203,204,205),IC                               16500109
  201 T=D(1)                                                           MAIN0213
      ALP=D(2)                                                         MAIN0215
      BET=D(3)                                                         MAIN0217
      XMU=D(4)                                                         MAIN0219
      ULAM=D(5)                                                        MAIN0221
      DLAM=D(6)                                                        MAIN0223
      EMAX=D(7)                                                        MAIN0224
      GOTO102                                                          MAIN0225
  202 IF(NE0)361,360,361                                               16500201
  360 NE=0                                                             16500203
      NE0=1                                                            16500205
  361 DO300J=1,7                                                       16500207
      K=J+NE                                                           MAIN0303
      E(K)=D(J)                                                        MAIN0305
      IF(E(K))300,302,300                                              MAIN0307
  300 CONTINUE                                                         MAIN0309
      NE=NE+7                                                          MAIN0311
      GOTO102                                                          MAIN0313
  302 NE=K-1                                                           MAIN0315
      GOTO102                                                          MAIN0317
  204 IF(NSE0)362,363,362                                              16500209
  363 NSE=0                                                            16500211
      NSE0=1                                                           16500213
  362 DO304J=1,5,2                                                     16500215
      LS=1                                                             16500109
      K=NSE+(J+1)/2                                                    MAIN0321
      SE(K)=D(J)                                                       MAIN0323
      S(K)=D(J+1)                                                      MAIN0325
      IF(SE(K))304,303,304                                             MAIN0401
  304 CONTINUE                                                         MAIN0403
      NSE=NSE+3                                                        MAIN0405
      GOTO102                                                          MAIN0407
  303 NSE=K-1                                                          MAIN0409
      GOTO102                                                          MAIN0411
  205 IF(NFE0)364,365,364                                              16500217
  365 NFE=0                                                            16500219
      NFE0=1                                                           16500221
  364 DO305J=1,5,2                                                     16500223
```

```
      LF=1                                                              16500111
      K=NFE+(J+1)/2                                                     MAIN0415
      FE(K)=D(J)                                                        MAIN0417
      F(K)=D(J+1)                                                       MAIN0419
      IF(FE(K))305,306,305                                              MAIN0421
  305 CONTINUE                                                          MAIN0423
      NFE=NFE+3                                                         MAIN0425
      GOTO102                                                           MAIN0501
  306 NFE=K-1                                                           MAIN0503
      GOTO102                                                           MAIN0505
  203 IF(NNO)366,367,366                                                16500301
  367 NN=0                                                              16500303
      NNO=1                                                             16500305
  366 DO310J=1,7                                                        16500307
      K=J+NN                                                            MAIN0518
      N(K)=INTF(D(J))                                                   MAIN0520
      IF(N(K))310,311,310                                               MAIN0522
  310 CONTINUE                                                          MAIN0524
      NN=NN+7                                                           MAIN0601
      GOTO102                                                           16500209
  311 NN=K-1                                                            16500211
      GOTO102                                                           16500213
  200 ET=T/1.16047E+4                                                   MAIN0605
      EBET=BET*ET                                                       MAIN0606
      EALP=ALP*ET                                                       MAIN0607
      EMU=XMU*ET                                                        MAIN0608
      NEM1=NE-1                                                         MAIN0609
      IF(LS)350,352,350                                                 16500113
  350 DO103J=1,NSE                                                      16500115
      SE(J)=LOGF(SE(J))                                                 MAIN0614
  103 S(J)=LOGF(S(J))                                                   MAIN0616
  352 IF(T)104,105,104                                                  16500117
  105 IF(LF)351,104,351                                                 16500119
  351 DO106J=1,NFE                                                      16500121
      FE(J)=LOGF(FE(J))                                                 MAIN0622
  106 F(J)=LOGF(F(J))                                                   MAIN0624
  104 NNN=2                                                             16500215
      DO500K=1,NEM1                                                     MAIN0701
      IF(E(K+1)-EMAX)107,107,108                                        MAIN0702
  108 NNN=1                                                             16500217
      E(K+1)=EMAX                                                       MAIN0704
  107 IF(E(K+1)-EXPF(SE(NSE)))505,505,506                               16500111
  506 NNN=1                                                             16500113
      E(K+1)=EXPF(SE(NSE))                                              16500114
  505 IF(T)510,507,510                                                  16500116
  507 IF(E(K+1)-EXPF(FE(NFE)))510,510,508                               16500118
  508 NNN=1                                                             16500120
      E(K+1)=EXPF(FE(NFE))                                              16500121
  510 KMIF=1                                                            16500123
      KMI=1                                                             MAIN0706
      CALLGSS2(E(K),E(K+1),ANS,0,N(K))                                  MAIN0707
      NK=K                                                              MAIN0708
      TRR(K)=ANS(1)                                                     MAIN0709
      TF(K)=ANS(2)                                                      MAIN0710
      KMIF=1                                                            MAIN0711
      KMI=1                                                             MAIN0712
      IF(T)110,501,110                                                  MAIN0713
  110 CALLGSS2(E(K),E(K+1),ANS,1,N(K))                                  MAIN0714
```

```
      IF(IE)503,601,503                                                 16500124
  601 ERR(K)=ANS(1)                                                     16500125
      EF(K)=ANS(2)                                                      MAIN0716
  501 GOTO(502,500),NNN                                                 MAIN0717
  500 CONTINUE                                                          MAIN0718
  502 CALLOUTP(TRR,TF,ERR,EF,ULAM,DLAM,T,EMAX,                          MAIN0719
     1E,ALP,BET,XMU,NK)                                                 MAIN0721
      GOTO503                                                           MAIN0723
      END(1,1,0,0,1,0,0,0,0,0,0,0,0,0,0)
```

```
C     GFX2.  INTEGRAND FOR GSS2.                                        18490109
      SUBROUTINEGFX2(EI,ANS,ID)                                         GFX20102
      COMMONN,E,SE,S,FE,F,T,ALP,BET,XMU,EMAX,KMIF,                      GFX20103
     1KMI,ET,EALP,EBET,EMU,ID,NE,NN,NSE,NFE,IE                          16500201
      DIMENSIONE(50),SE(500),S(500),FE(500),F(500),N(50),               GFX20106
     1ANS(2)                                                            GFX20108
      NSE1=NSE+1                                                        16500221
      NFE1=NFE+1                                                        16500223
      IF(T)1,2,1                                                        GFX20110
    1 IF(ID)3,5,3                                                       GFX20112
    5 ANS(2)=(EI/(ET**2))*EXPF(-EI/ET)                                  GFX20114
   20 EIL=LOGF(EI)                                                      GFX20115
      DO4J=KMI,NSE1                                                     16500225
      KMI=J                                                             GFX20201
      IF(SE(J)-EIL)4,6,6                                                GFX20118
    4 CONTINUE                                                          GFX20120
    6 F1=EXPF(((SE(J)-EIL)*S(J-1)+(EIL-SE(J-1))                         GFX20122
     1*S(J))/(SE(J)-SE(J-1)))                                           GFX20124
      IF(KMI-NSE1)7,8,8                                                 16500301
    8 WRITE OUTPUT TAPE 9,9                                             16500206
      IE=1                                                              16500203
      GO TO 100                                                         16500204
    9 FORMAT(28H0ENTIRE SIGMA TABLE SEARCHED/                           16500305
     12H1 )                                                             16500306
    7 ANS(1)=ANS(2)*F1                                                  GFX20209
      GOTO100                                                           GFX20211
    3 IF(EI-EMU)10,11,11                                                GFX20213
   11 ANS(2)=1.0/EI                                                     GFX20215
      GOTO20                                                            GFX20217
   10 IF(EI-EBET)12,12,13                                               GFX20219
   13 ANS(2)=1.0/EMU                                                    GFX20221
      GOTO20                                                            GFX20223
   12 IF(EI-EALP)14,14,15                                               GFX20301
   15 ANS(2)=(EI-EALP)/(EMU*(EBET-EALP))                                16500308
      GOTO20                                                            GFX20305
   14 ANS(2)=0.0                                                        GFX20307
      GOTO20                                                            GFX20309
    2 EIL=LOGF(EI)                                                      GFX20311
      DO22J=KMIF,NFE1                                                   16500310
      KMIF=J                                                            GFX20323
      IF(FE(J)-EIL)22,23,23                                             GFX20315
   22 CONTINUE                                                          GFX20317
   23 ANS(2)=EXPF(((FE(J)-EIL)*F(J-1)+(EIL-FE(J-1))                     GFX20319
     1*F(J))/(FE(J)-FE(J-1)))                                           GFX20321
      IF(KMIF-NFE1)24,25,25                                             16500312
   25 WRITE OUTPUT TAPE 9,27                                            16500211
   27 FORMAT(27H0ENTIRE FLUX TABLE SEARCHED/                            16500403
     12H1 )                                                             16500315
      IE=1                                                              16500208
      GO TO 100                                                         16500209
   24 GOTO20                                                            GFX20405
  100 RETURN                                                            GFX20407
      END(1,1,0,0,1,0,0,0,0,0,0,0,0,0,0)
```

```
C     GSS2.  INTEGRATION BY FIFTH ORDER GAUSSIAN QUADRATURE.          18490110
      SUBROUTINE GSS2(EM,EMI,BNS,ID,NO)                               16500102
      DIMENSION YOU(5),FUN(5),BNS(2),FUNG(5),ANS(2),DUM(2066)         16500102
      COMMON DUM,IE                                                   16500104
      YOU(1)=-.45308992                                               16500108
      YOU(2)=-.26923466                                               16500109
      YOU(3)=0.0                                                      16500110
      YOU(4)=.26923466                                                16500111
      YOU(5)=.45308992                                                16500112
      HNO=NO                                                          16500114
      DELA=(EMI-EM)/HNO                                               16500115
      BNS(1)=0.0                                                      16500117
      BNS(2)=0.0                                                      16500118
      EX2=EM                                                          16500120
      DO 200 KKM=1,NO                                                 16500122
      EX1=EX2                                                         16500124
      EX2=EX1+DELA                                                    16500201
      DO 300 KKL=1,5                                                  16500203
      X=(EX2-EX1)*YOU(KKL)+0.5*(EX1+EX2)                              16500205
      CALL GFX2(X,ANS,ID)                                             16500207
      IF(IE) 201,301,201                                              16500209
  301 FUN(KKL)=ANS(1)                                                 16500210
  300 FUNG(KKL)=ANS(2)                                                16500212
      ADD=(EX2-EX1)*((FUN(1)+FUN(5))*.11846344+                       16500214
     1(FUN(2)+FUN(4))*.23931433+FUN(3)*.2844444)                      16500215
      BNS(1)=ADD+BNS(1)                                               16500217
      ADD=(EX2-EX1)*((FUNG(1)+FUNG(5))*.11846344+                     16500219
     1(FUNG(2)+FUNG(4))*.23931433+FUNG(3)*.2844444)                   16500220
      BNS(2)=ADD+BNS(2)                                               16500222
  200 CONTINUE                                                        16500223
  201 RETURN                                                          16500224
      END(1,1,0,0,1,0,0,0,0,0,0,0,0,0,0)
```

```
C     OUTP.  ACS OUTPUT SUBROUTINE.                                    18490108
      SUBROUTINEOUTP(TRR,TF,ERR,EF,ULAM,DLAM,                          OUTP0103
     1T,EMAX,E,ALP,BET,XMU,NK)                                         OUTP0104
      DIMENSIONTRR(50),TF(50),ERR(50),EF(50),E(50)                     OUTP0106
      IF(T)2,3,2                                                       OUTP0109
    2 WRITEOUTPUTTAPE9,1,T,ALP,BET,XMU                                 OUTP0111
    1 FORMAT(21HONEUTRON TEMPERATURE=1PE11.4/                          OUTP0113
     17HOALPHA=1PE11.4,9H    BETA=1PE11.4,7H    MU=1PE11.4)             OUTP0115
    3 WRITEOUTPUTTAPE9,4,EMAX                                          OUTP0117
    4 FORMAT(16HOMAXIMUM ENERGY=1PE11.4,4H EV.)                        OUTP0119
      IF(T)5,6,5                                                       OUTP0121
    5 WRITEOUTPUTTAPE9,7                                               OUTP0123
    7 FORMAT(2H0 //79H0     ENERGY LIMITS            THERMAL      THERMAOUTP0201
     1L     EPITHERMAL   EPITHERMAL/                                   OUTP0203
     276H   LOWER        UPPER          REACTION       FLUX       REACTIOUTP0205
     3ON       FLUX/2H  )                                              OUTP0207
      GOTO30                                                           16500101
    6 WRITEOUTPUTTAPE9,8                                               OUTP0209
    8 FORMAT(2H0 //50H0     ENERGY LIMITS              TOTAL        TOTALOUTP0211
     1/50H    LOWER        UPPER          REACTION       FLUX/2H  )    16500103
   30 IF(T)10,11,10                                                    16500105
   10 DO12 J=1,NK                                                      OUTP0217
      WRITEOUTPUTTAPE9,13,E(J),E(J+1),TRR(J),TF(J),                    OUTP0219
     1ERR(J),EF(J)                                                     OUTP0221
   13 FORMAT(1H 1PE11.4,1PE13.4,1PE15.4,1P3E13.4)                      16500107
   12 CONTINUE                                                         OUTP0225
      GOTO31                                                           16500109
   11 DO14 J=1,NK                                                      OUTP0301
      WRITEOUTPUTTAPE9,15,E(J),E(J+1),TRR(J),TF(J)                     OUTP0303
   15 FORMAT(1H 1PE11.4,1PE13.4,1PE15.4,1PE13.4)                       16500111
   14 CONTINUE                                                         OUTP0307
   31 IF(T)16,17,16                                                    16500113
   16 WRITEOUTPUTTAPE9,18                                              OUTP0311
   18 FORMAT(2H0 ///18HOSPECTRUM AVERAGES//                            OUTP0313
     132H0                        AVERAGE/                             16500115
     231H   LAMBDA                 SIGMA/2H  )                         OUTP0317
      CLAM=0.0                                                         OUTP0319
      TTRR=0.0                                                         16500407
      TTF=0.0                                                          16500409
      TERR=0.0                                                         16500411
      TEF=0.0                                                          16500413
      DO40J=1,NK                                                       16500415
      TTRR=TTRR+TRR(J)                                                 16500417
      TTF=TTF+TF(J)                                                    16500419
      TERR=TERR+ERR(J)                                                 16500421
   40 TEF=TEF+EF(J)                                                    16500423
   22 AVE=(TTRR+CLAM*TERR)/(TTF+CLAM*TEF)                              16500101
      WRITEOUTPUTTAPE9,21,CLAM,AVE                                     OUTP0323
   21 FORMAT(1H 1PE11.4,1PE22.4)                                       16500103
      CLAM=CLAM+DLAM                                                   OUTP0401
      IF(CLAM-ULAM)22,23,23                                            16500213
   23 GOTO100                                                          OUTP0405
   17 SUMR=0.0                                                         OUTP0407
      SUMF=0.0                                                         OUTP0409
      DO25K=1,NK                                                       OUTP0411
      SUMR=SUMR+TRR(K)                                                 OUTP0413
   25 SUMF=SUMF+TF(K)                                                  OUTP0415
      AVE=SUMR/SUMF                                                    OUTP0417
```

```
      WRITEOUTPUTTAPE9,24,AVE                                           OUTP0419
   24 FORMAT(2H0 ///34H0 SPECTRUM AVERAGED CROSS SECTION=1PE11.4)       OUTP0421
  100 RETURN                                                            OUTP0424
      END(1,1,0,0,1,0,0,0,0,0,0,0,0,0,0)
```

VI. THR – A Tape Handling Routine for the IBM 7090 Thermal Thermalization Codes

Purpose

The tape handling routine was written as an auxiliary to the KERNEL (GTP) program. This routine makes the library of kernels accessible to either inspection or modification.

Available Options

1. Option 1. This option is used to initialize logical tapes 2 and 3 by writing a negative number on the first record. This record enables the GTP program to write a kernel at the beginning of the kernel tape, and need not be used for the calculation of subsequent kernels.

2. Option 2. The selection of this option allows inspection of the kernel tapes, and the program writes a complete listing of all the kernel titles currently existing on the KERNEL library tape.

3. Option 3. If option 3 is selected, the program lists as printed output all five records of a particular kernel. Any number of desired kernels may be listed.

4. Option 4. The selection of option 4 enables the programmer to reproduce a particular kernel with the title and sources altered. The new kernel will be written on logical tapes 2 and 3 immediately following the existing kernels, and, in addition, the kernel will be written on logical tape 9 for subsequent off-line listing.

Preparation of Input Data

Any number of cases may be run successively by stacking the input data cards. A Ten Digit Data Form which illustrates the proper format for the selection of any of the above options is included at the end of this section.

1. Option 1 Input Data

a. Card 1. This card must contain a 1-punch in column 1. Columns 2-72 may contain any alphanumeric information which identifies the case.

b. Card 2. Field 1 must contain the number 1.0, and is the only input number required to initialize the kernel tapes. There will be no printed output from this option.

2. Option 2 Input Data

a. Card 1. Column 1 must contain a 1-punch, and columns 2-72 may contain any information which identifies the case. This card will be printed at the top of each page of output.

b. Card 2. Field 1 must contain the number 2.0, and is the only input number necessary. A complete list of kernel titles will be listed as output.

3. Option 3 Input Data

a. Card 1. Column 1 must contain a 1-punch, and columns 2-72 may contain any title which identifies the case.

b. Card 2. Field 1 must contain the number 3.0, and field 2 must contain the kernel number the programmer desires to be listed as output.

4. Option 4 Input Data

a. Card 1. Column 1 must contain a 1-punch, and columns 2-72 may contain any alphabetic or numeric information which identifies the case.

b. Card 2. Field 1 must contain the integer 4.0 which designates the selection of option 4. The kernel number the programmer desires to alter must be punched in field 2, and field 3 must contain the kernel size, that is, the number of points in the energy mesh.

c. Card 3. This card contains the new title of the original kernel punched in field 2 of card 2. Column 1 must contain a 1-punch, columns 2-66 may contain any numeric or alphabetic information which identifies the kernel, and columns 71-72 must contain the new kernel number. The decimal point is assumed to follow column 72.

d. Cards 4. Seven numbers per card (less if required on the last card) are punched giving the values of the new sources for each point in the energy mesh. The values are listed in exact correspondence to the energy values, and the number of sources listed must equal the number punched in field 3 of card 2.

The THR Fortran listing and option 2 output are given on the following pages.

TEN DIGIT DATA FORM

PROBLEM: THR | REQUEST: 3325

CODER: MET | DATE: 10-30-62 | PAGE: 1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 - ØPTIØN-1.-INITIALIZE-TAPES.															1
1.0															2
1 - ØPTIØN-2.-WRITE-ØUT-KERNEL-TITLES.															1
2.0															2
1 - ØPTIØN-3.-LIST-AS-PRINTED-ØUTPUT-5-RECØRDS-ØF-ANY-KERNEL.															1
3.0		KERNEL NØ.													2
1 - ØPTIØN-4.-ALTER-KERNEL-TITLE-AND-SØURCES.															1
4.0		KERNEL NØ.		KERNEL SIZE(N)											2
1 - NEW-KERNEL-TITLE-IN-CØLUMNS-2-66.-KERNEL-NØ.(NK)-IN-CØLUMNS-71-72														NK	3
S_1		S_2		S_3		S_4		S_5		S_6		S_7			4
S_8		S_9		etc.		etc.		etc.		S_N					4

UCN-3263 (3 11-61)

THR INPUT DATA FORM

TEN DIGIT DATA FORM

PROBLEM	REQUEST
THR	3325

CODER	DATE	PAGE
MET	10-30-62	1 of 1

```
1  - THR-SAMPLE.-ØPTIØN-2.-(WRITE-ØUT-KERNEL-TITLES.)
     2.0
```

UCN-3263
(3 11-61)

SAMPLE PROBLEM INPUT

```
THR SAMPLE OUTPUT OF OPTION 2.  (WRITE OUT KERNEL TITLES)
1 (GTP-4) FG 600K A#12 MSH (.0001(161)5.0) S(APPROX.)                1.
1 FG 600K A#12 MSH(.0001(161)5.0)S(APPROX.) (GTP-3)                  2.
1 (FG 600 K A#12 MSH(1.49(161)13EV) TKS SOURCE KERNEL 3              3.
1 (FG 1200K A#12 MSH(1.49(161)13EV) TKS SOURCE KERNEL 4              4.
1 (FG 300K A#12 MSH(1.49(161)13.0EV) TKS SOURCE KERNEL 5             5.
1 FG 600K A#12 MSH(.0001(161)5.0) SOURCES(TKS I/E KERNEL3)           6.
1 FG 1200K A#12 MSH(.0001(161)5.0) SOURCES(TKS I/E KERNEL4)          7.
1 FG 300K A#12 MSH(.0001(161)5.0) SOURCES(TKS I/E KERNEL 3)          8.
1 FG 400K A#12 MSH(.0001(161)5.0) SOURCES(TKS I/E KERNEL 3)          9.
1 FG 500K A#12 MSH(.0001(161)5.0) SOURCES(TKS I/E KERNEL 3)         10.
1 FG 700K A#12 MSH(.0001(161)5.0) SOURCE(TKS I/E KERNEL 3)          11.
1 FG 800K A#12 MSH(.0001(161)5.0) SOURCE(TKS I/E KERNEL 3)          12.
1 FG 900K A#12 MSH(.0001(161)5.0) SOURCE(TKS I/E KERNEL 4)          13.
1 FG 1000K A#12 MSH(.0001(161)5.0) SOURCE(TKS I/E KERNEL 4)         14.
1 FG 1100K A#12 MSH(.0001(161)5.0) SOURCE(TKS I/E KERNEL 4)         15.
1 FG 569K A#12 MSH(.0001(161)5.0) SOURCES (TKS I/E KERNEL 3)        16.
```

THR FORTRAN LISTING

```
C     THR.  TAPE HANDLING ROUTINE.                                      18490102
      DIMENSION TITLE(12),E(161),S(161),HEAD(12),                       18490210
     1CASE(12),SIG(161,161),BASE(12),FIRST(12)                          18490211
  100 REWIND 2                                                          18490105
      READ INPUT TAPE 10,90                                             18490101
   90 FORMAT(72H                                                        18490103
     1                 )                                                18490104
      READ INPUT TAPE 10,2,XOPT,XNK,YN                                  18490107
    2 FORMAT(3E10.5)                                                    18490109
      IF(XOPT-3.0) 3,3,55                                               18490105
    3 IF(XOPT-2.0) 4,99,6                                               18490214
    4 DO 1 J=1,12                                                       18490115
      CASE(12)=-100.0                                                   18490117
      WRITE TAPE 2,(CASE(J),J=1,12)                                     18490119
    1 WRITE TAPE 3,(CASE(J),J=1,12)                                     18490120
      GO TO 50                                                          18490122
   99 WRITE OUTPUT TAPE 9,90                                            18490216
    5 READ TAPE 2,TITLE                                                 18490201
      IF(TITLE(12)) 100,100,8                                           18490108
    8 WRITEOUTPUTTAPE9,80,(TITLE(I),I=1,12)
   80 FORMAT(1H011A6,F6.0)
    9 FORMAT(11A6,F6.0)                                                 18490207
      DO 11 J=1,4                                                       18490209
   11 READ TAPE 2                                                       18490211
      GOTO5                                                             18490213
    6 READ TAPE 2,TITLE                                                 18490215
      IF(ABSF(TITLE(12)-XNK)-.01) 12,12,13                              18490217
   13 DO 14 J=1,4                                                       18490219
   14 READ TAPE 2                                                       18490221
      GO TO 6                                                           18490223
   12 READ TAPE 2,N                                                     18490301
      READ TAPE 2,(E(J),J=1,N)                                          18490303
      READ TAPE 2,(S(J),J=1,N)                                          18490305
      READ TAPE 2,((SIG(J,K),K=1,N),J=1,N)                              18490307
   70 WRITE OUTPUT TAPE 9,9,(TITLE(I),I=1,12)                           18490309
      NP=1                                                              18490310
      WRITE OUTPUT TAPE 9,41,NP                                         18490311
   41 FORMAT(116H0                                                      18490105
     1                                                        PAGE,I4) 18490106
      WRITE OUTPUT TAPE 9,16,N                                          18490316
   16 FORMAT(6HOSIZE,I6///2H0 )                                         18490318
      WRITE OUTPUT TAPE 9,29                                            18490320
   29 FORMAT(117H0   ENERGY      SOURCE      ENERGY      SOURCE      ENE18490101
     1RGY      SOURCE      ENERGY      SOURCE      ENERGY      SOURCE/2H018490113
     2 )                                                                18490115
      N2=N/5+1                                                          18490101
      DO 17 I=1,N2                                                      18490403
      K1=I+N2                                                           18490405
      K2=K1+N2                                                          18490406
      K3=K2+N2                                                          18490407
      K4=K3+N2                                                          18490408
   17 WRITE OUTPUT TAPE 9,30,E(I),S(I),E(K1),S(K1),E(K2),               18490410
     2S(K2),E(K3),S(K3),E(K4),S(K4)                                     18490411
   30 FORMAT(10(1PE12.4))                                               18490412
      DO 40 J=1,N                                                       18490413
      WRITE OUTPUT TAPE 9,9,TITLE                                       18490415
      NP=NP+1                                                           18490417
      WRITE OUTPUT TAPE 9,41,NP                                         18490419
```

```
      WRITE OUTPUT TAPE 9,310,E(J)                                      18490103
  310 FORMAT(16H0INITIAL ENERGY,1PE12.5//2H0 )                          18490105
      WRITE OUTPUT TAPE 9,42                                            18490421
   42 FORMAT(109H0 FINAL       TRANSFER    FINAL      TRANSFER    FINAL 18490422
     1  TRANSFER    FINAL      TRANSFER    FINAL      TRANSFER/        18490423
     2111H  ENERGY    PROBABILITY  ENERGY   PROBABILITY  ENERGY   PROBAB18490424
     3ILITY  ENERGY   PROBABILITY  ENERGY   PROBABILITY/2H0 )           18490425
      DO 60 I=1,N2                                                      18490501
      K1=I+N2                                                           18490503
      K2=K1+N2                                                          18490504
      K3=K2+N2                                                          18490505
      K4=K3+N2                                                          18490506
   60 WRITE OUTPUT TAPE 9,21,E(I),SIG(J,I),E(K1),SIG(J,K1),             18490508
     2E(K2),SIG(J,K2),E(K3),SIG(J,K3),E(K4),SIG(J,K4)                   18490509
   21 FORMAT(5(1PE10.2,1PE12.4))                                        18490511
   40 CONTINUE                                                          18490513
      GO TO 100                                                         18490515
   55 N=YN                                                              18490517
      READ INPUT TAPE 10,9,(HEAD(I),I=1,12)                             18490519
      READ INPUT TAPE 10,301,(S(J),J=1,N)                               18490101
  301 FORMAT(7E10.5)                                                    18490103
   24 READ TAPE 2,(TITLE(I),I=1,12)                                     18490101
      IF(ABSF(TITLE(12)-XNK)-.01) 91,91,22                              18490102
   91 READ TAPE 3, (FIRST(I),I=1,12)                                    18490104
      IF(ABSF(FIRST(12)-XNK)-.01) 25,25,94                              18490105
   22 DO 23 J=1,4                                                       18490108
   23 READ TAPE 2                                                       18490109
      GO TO 24                                                          18490110
   94 DO 95 J=1,4                                                       18490112
   95 READ TAPE 3                                                       18490113
      GO TO 91                                                          18490114
   25 READ TAPE 2,N                                                     18490612
      READ TAPE 3,N                                                     18490613
      READ TAPE 2,(E(J),J=1,N)                                          18490615
      READ TAPE 3,(E(J),J=1,N)                                          18490616
      READ TAPE 2                                                       18490618
      READ TAPE 3                                                       18490619
      READTAPE2,((SIG(J,K),K=1,N),J=1,N)                                18490104
      READTAPE3,((SIG(J,K),K=1,N),J=1,N)                                18490105
   28 READ TAPE 2,(CASE(I),I=1,12)                                      18490116
      IF(CASE(12)) 300,300,26                                           18490117
   26 DO 27 J=1,4                                                       18490119
   27 READ TAPE 2                                                       18490120
      GO TO 28                                                          18490121
  300 BACKSPACE 2                                                       18490122
  304 READ TAPE 3,(BASE(I),I=1,12)                                      18490123
      IF(BASE(12)) 305,305,302                                          18490124
  302 DO 303 J=1,4                                                      18490201
  303 READ TAPE 3                                                       18490202
      GO TO 304                                                         18490203
  305 BACKSPACE 3                                                       18490205
      WRITE TAPE 2,(HEAD(I),I=1,12)                                     18490711
      WRITE TAPE 3,(HEAD(I),I=1,12)                                     18490712
      WRITE TAPE 2,N                                                    18490714
      WRITE TAPE 3,N                                                    18490715
      WRITE TAPE 2,(E(J),J=1,N)                                         18490717
      WRITE TAPE 3,(E(J),J=1,N)                                         18490718
      WRITE TAPE 2,(S(J),J=1,N)                                         18490720
```

```
      WRITE TAPE 3,(S(J),J=1,N)                                         18490111
      WRITE TAPE 2,((SIG(J,K),K=1,N),J=1,N)                             18490723
      WRITE TAPE 3,((SIG(J,K),K=1,N),J=1,N)                             18490724
      TITLE(12)=-100.0                                                  18490801
      WRITE TAPE 2,TITLE                                                18490803
      WRITE TAPE 3,TITLE                                                18490804
      END FILE 2                                                        18490806
      END FILE 3                                                        18490807
      REWIND 2                                                          18490207
      REWIND 3                                                          18490208
      DO 71 I=1,12                                                      18490814
   71 TITLE(I)=HEAD(I)                                                  18490816
      GO TO 70                                                          18490818
   50 REWIND 2                                                          18490820
      REWIND 3                                                          18490107
      CALL EXIT                                                         18490822
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

VII. DCØM – An IBM 7090 Program for Decomposing the IMS Flux into a Maxwellian Component and an Epithermal Component

Purpose and Method of Decomposition

It has been noted that for a wide range of moderator temperatures and absorption cross sections, the total energy dependent flux can be represented by the sum of two components, a Maxwellian distribution and an epithermal residue that approaches 1/E in the asymptotic region. If, in particular, the 2200 m/s absorption cross section of the infinite medium under consideration is not too great and is a fairly smooth function with respect to energy, then a Maxwellian spectrum is a very good fit to the total spectrum over the thermal energy range.

If these conditions are satisfied, program DCØM can be used to separate the total flux distribution into a thermal and an epithermal component. These components can then be used by the ACS program to compute average thermal and epithermal cross sections. Letting $\phi(E)$ represent the undecomposed flux, we write

$$\phi(E) = C \frac{E}{(kT_n)^2} e^{-E/kT_n} + R(E) , \tag{17}$$

where C is the amplitude of the Maxwellian component and T_n is the effective neutron temperature. Once these parameters are determined by the DCØM program, the residue component is obtained by subtracting the Maxwellian distribution from the total flux.

The parameters C and T_n are determined by examining the energy range over which a Maxwellian distribution is assumed to be a good fit to the total flux spectrum. In this region, ($E_1 \sim 0.5\ E_{peak}$, $E_2 \sim 1.5\ E_{peak}$, where E_{peak} is the energy corresponding to the maximum value of the flux distribution), we can write:

$$\phi(E) \approx C \frac{E}{(kT_n)^2} e^{-E/kT_n} . \tag{18}$$

Dividing both sides of Eq. (18) by E and taking the logarithm, we obtain

$$B(E) = \ln \frac{\phi(E)}{E} = \ln \frac{C}{(kT_n)^2} - \frac{1}{kT_n} E , \qquad (19)$$

where B(E) is seen to be a linear function of E whose Y-intercept and slope uniquely determine the parameters C and T_n.

Program DCØM forms the function B(E) for the entire energy range of $\phi(E)$ and fits a straight line to it over a pre-selected energy range by the method of least squares. Since the values obtained for C and T_n clearly depend upon the range of the attempted fit, some care must be used in selecting this range. As noted earlier, an energy range 0.5 E_{peak} to 1.5 E_{peak} is generally appropriate for well thermalized spectra. If B(E) is linear over only a small energy range or not at all, the method of decomposition is no longer applicable.

Preparation of Input Data

The input data to DCØM consists of a title card, a card specifying the energy range of the fit, and a flux deck produced by the IMS program. The data must be assembled in the following order:

1. Card 1. Column 1 must contain a 1-punch. Columns 2-72 may contain any alphabetic or numeric information which identifies the calculation.

2. Card 2. The first two fields contain respectively the numbers PL and PH (0.5 and 1.5, for example) selecting the energy range of the fit.

3. Cards 3. These cards are the flux deck as produced by the IMS output. As for the ACS code, the method employed by DCØM in reading these cards requires a blank card or a zero energy to signify the end of the flux deck.

Output

To operate the program, an input tape is prepared on the card-to-tape converter using the input described above. This tape is selected as logical tape 10. A complete listing of the output is obtained from logical tape 9. This output consists of the following lines:

1. Title of the flux calculation.
2. Effective neutron temperature multiplied by Boltzmann constant, kT_n.
3. Amplitude of fitted Maxwellian distribution, C.
4. Tabular columns of results for E, E/kT, FLUX, MAXWELL, RESIDUE, and MAXWELL/FLUX.

A Fortran listing of the DCØM program and associated subroutines, data forms, and the input and output for a sample case are given on the following pages.

TEN DIGIT DATA FORM

PROBLEM	REQUEST
DCØM	3325

CODER	DATE	PAGE
MET	10-30-62	1 of 1

1	9	11	19	21	29	31	39	41	49	51	59	61	69	71	73 80
1 ← CØLUMNS 2-72 ARE AVAILABLE FØR TITLE. →															
PL		PH													
FLUX DECK GØES HERE															

UCN-3263
(3 11-61)

DCØM INPUT DATA FORM

TEN DIGIT DATA FORM

PROBLEM: DCØM

REQUEST: 3325

CODER: MET

DATE: 10-30-62

PAGE: 1 of 1

```
1 - DECØMPØSITIØN ØF FLUX NØ. 10      PL = 0.5      PH = 2.0
    0.50        2.00
  FLUX DECK GØES HERE
```

UCN-3263
(8 11-61)

SAMPLE PROBLEM INPUT

DECOMPOSITION OF FLUX NO. 10 PL#.5 PH#2.0

KT # 3.38078E-02

C # 6.31189E 01

E	E/KT	FLUX	MAXWELL	RESIDUE	MAXWELL/FLUX
1.00100E-04	2.96086E-03	5.12350E 00	5.51156E 00	-3.88062E-01	1.075741
1.80000E-04	5.32422E-03	9.20500E 00	9.88750E 00	-6.82506E-01	1.074145
3.00000E-04	8.87370E-03	1.53200E 01	1.64208E 01	-1.10079E 00	1.071853
5.00000E-04	1.47895E-02	2.54690E 01	2.72065E 01	-1.73755E 00	1.068222
7.00000E-04	2.07053E-02	3.55580E 01	3.78645E 01	-2.30651E 00	1.064866
1.00100E-03	2.96086E-02	5.06220E 01	5.36663E 01	-3.04431E 00	1.060138
1.42000E-03	4.20022E-02	7.13200E 01	7.51923E 01	-3.87233E 00	1.054295
2.10000E-03	6.21159E-02	1.04180E 02	1.08986E 02	-4.80562E 00	1.046128
2.82000E-03	8.34128E-02	1.37890E 02	1.43268E 02	-5.37825E 00	1.039004
3.70000E-03	1.09442E-01	1.77510E 02	1.83146E 02	-5.63626E 00	1.031752
4.70000E-03	1.39021E-01	2.20320E 02	2.25865E 02	-5.54462E 00	1.025166
5.80000E-03	1.71558E-01	2.64700E 02	2.69804E 02	-5.10357E 00	1.019280
7.03000E-03	2.07940E-01	3.10950E 02	3.15337E 02	-4.38667E 00	1.014107
8.40000E-03	2.48464E-01	3.58400E 02	3.61826E 02	-3.42569E 00	1.009558
9.84000E-03	2.91057E-01	4.03790E 02	4.06178E 02	-2.38854E 00	1.005915
1.15000E-02	3.40158E-01	4.50740E 02	4.51955E 02	-1.21523E 00	1.002696
1.31000E-02	3.87485E-01	4.90780E 02	4.91038E 02	-2.58134E-01	1.000526
1.69000E-02	4.99885E-01	5.67520E 02	5.66130E 02	1.39040E 00	0.997550
2.11000E-02	6.24117E-01	6.26300E 02	6.24250E 02	2.05003E 00	0.996726
2.58000E-02	7.63138E-01	6.65870E 02	6.64232E 02	1.63832E 00	0.997539
3.10000E-02	9.16949E-01	6.84630E 02	6.84325E 02	3.05084E-01	0.999554
3.67000E-02	1.08555E 00	6.83040E 02	6.84454E 02	-1.41450E 00	1.002071
4.28000E-02	1.26598E 00	6.63520E 02	6.66441E 02	-2.92108E 00	1.004402
4.94000E-02	1.46120E 00	6.29270E 02	6.32792E 02	-3.52254E 00	1.005598
5.64000E-02	1.66826E 00	5.84600E 02	5.87343E 02	-2.74264E 00	1.004691
6.40000E-02	1.89306E 00	5.32150E 02	5.32308E 02	-1.57784E-01	1.000296
7.20000E-02	2.12969E 00	4.76890E 02	4.72658E 02	4.23154E 00	0.991127
8.05000E-02	2.38111E 00	4.21310E 02	4.10979E 02	1.03308E 01	0.975479
8.94000E-02	2.64436E 00	3.68450E 02	3.50778E 02	1.76722E 01	0.952036
9.89000E-02	2.92536E 00	3.18890E 02	2.92991E 02	2.58992E 01	0.918783
1.09000E-01	3.22411E 00	2.74030E 02	2.39519E 02	3.45112E 01	0.874060
1.19000E-01	3.51990E 00	2.36830E 02	1.94536E 02	4.22939E 01	0.821416
1.30000E-01	3.84527E 00	2.03280E 02	1.53494E 02	4.97863E 01	0.755085
1.41000E-01	4.17064E 00	1.76070E 02	1.20243E 02	5.58268E 01	0.682928
1.53000E-01	4.52559E 00	1.52380E 02	9.14915E 01	6.08885E 01	0.600417
1.65000E-01	4.88053E 00	1.33510E 02	6.91865E 01	6.43235E 01	0.518212
1.78000E-01	5.26506E 00	1.17380E 02	5.08112E 01	6.65688E 01	0.432878
1.91000E-01	5.64959E 00	1.04570E 02	3.71172E 01	6.74528E 01	0.354951
2.05000E-01	6.06369E 00	9.36490E 01	2.63300E 01	6.73190E 01	0.281157
2.19000E-01	6.47780E 00	8.48480E 01	1.85908E 01	6.62572E 01	0.219107

DECOMPOSITION OF FLUX NO. 10 PL#.5 PH#2.0

KT # 3.38078E-02

C # 6.31189E 01

E	E/KT	FLUX	MAXWELL	RESIDUE	MAXWELL/FLUX
2.34000E-01	6.92148E 00	7.72840E 01	1.27462E 01	6.45378E 01	0.164926
2.49000E-01	7.36517E 00	7.10120E 01	8.70309E 00	6.23089E 01	0.122558
2.65000E-01	7.83843E 00	6.55680E 01	5.77011E 00	5.97979E 01	0.088002
2.75000E-01	8.13422E 00	6.25640E 01	4.45462E 00	5.81094E 01	0.071201
2.81000E-01	8.31170E 00	6.09520E 01	3.81161E 00	5.71404E 01	0.062535
2.90000E-01	8.57791E 00	5.86350E 01	3.01430E 00	5.56207E 01	0.051408
2.97000E-01	8.78496E 00	5.70180E 01	2.50970E 00	5.45083E 01	0.044016
3.00000E-01	8.87370E 00	5.63070E 01	2.31979E 00	5.39872E 01	0.041199
3.14000E-01	9.28780E 00	5.33940E 01	1.60477E 00	5.17892E 01	0.030055
3.25000E-01	9.61317E 00	5.13120E 01	1.19967E 00	5.01123E 01	0.023380
3.32000E-01	9.82023E 00	5.00740E 01	9.96310E-01	4.90777E 01	0.019897
3.40000E-01	1.00569E 01	4.87550E 01	8.05318E-01	4.79497E 01	0.016518
3.49000E-01	1.03231E 01	4.73190E 01	6.33432E-01	4.66856E 01	0.013386
3.60000E-01	1.06484E 01	4.57520E 01	4.71923E-01	4.52801E 01	0.010315
3.68000E-01	1.08851E 01	4.45980E 01	3.80757E-01	4.42172E 01	0.008538
3.87000E-01	1.14471E 01	4.22260E 01	2.28264E-01	4.19977E 01	0.005406
4.06000E-01	1.20091E 01	4.00530E 01	1.36515E-01	3.99165E 01	0.003408
4.26000E-01	1.26007E 01	3.80430E 01	7.92762E-02	3.79637E 01	0.002084
4.46000E-01	1.31922E 01	3.62020E 01	4.59354E-02	3.61561E 01	0.001269
4.67000E-01	1.38134E 01	3.44850E 01	2.58443E-02	3.44592E 01	0.000749
4.88000E-01	1.44345E 01	3.29030E 01	1.45111E-02	3.28885E 01	0.000441
5.10000E-01	1.50853E 01	3.14230E 01	7.91115E-03	3.14151E 01	0.000252
5.32000E-01	1.57360E 01	3.00500E 01	4.30496E-03	3.00457E 01	0.000143
5.55000E-01	1.64163E 01	2.87620E 01	2.27454E-03	2.87597E 01	0.000079
5.78000E-01	1.70967E 01	2.75630E 01	1.19969E-03	2.75618E 01	0.000044
6.02000E-01	1.78066E 01	2.64310E 01	6.14376E-04	2.64304E 01	0.000023
6.26000E-01	1.85165E 01	2.53850E 01	3.14129E-04	2.53847E 01	0.000012
6.50000E-01	1.92263E 01	2.44180E 01	1.60378E-04	2.44178E 01	0.000007
6.75000E-01	1.99658E 01	2.34900E 01	7.95031E-05	2.34899E 01	0.000003
7.01000E-01	2.07349E 01	2.25970E 01	3.82651E-05	2.25970E 01	0.000002
7.27000E-01	2.15039E 01	2.17730E 01	1.83918E-05	2.17730E 01	0.000001
7.53000E-01	2.22730E 01	2.10030E 01	8.82852E-06	2.10030E 01	0.000000
7.80000E-01	2.30716E 01	2.02610E 01	4.11477E-06	2.02610E 01	0.000000
8.08000E-01	2.38998E 01	1.95570E 01	1.86198E-06	1.95570E 01	0.000000
8.35000E-01	2.46985E 01	1.89020E 01	8.65781E-07	1.89020E 01	0.000000
8.64000E-01	2.55563E 01	1.82670E 01	3.79928E-07	1.82670E 01	0.000000
8.93000E-01	2.64140E 01	1.76660E 01	1.66535E-07	1.76660E 01	0.000000
9.22000E-01	2.72718E 01	1.71010E 01	7.29207E-08	1.71010E 01	0.000000
9.52000E-01	2.81592E 01	1.65540E 01	3.10011E-08	1.65540E 01	0.000000
9.82000E-01	2.90466E 01	1.60600E 01	1.31665E-08	1.60600E 01	0.000000

DECOMPOSITION OF FLUX NO. 10 PL#.5 PH#2.0

KT # 3.38078E-02

C # 6.31189E 01

E	E/KT	FLUX	MAXWELL	RESIDUE	MAXWELL/FLUX
1.01000E 00	2.98748E 01	1.55860E 01	5.91553E-09	1.55860E 01	0.000000
1.04000E 00	3.07622E 01	1.51880E 01	2.50799E-09	1.51880E 01	0.000000
1.07000E 00	3.16495E 01	1.46700E 01	1.06242E-09	1.46700E 01	0.000000
1.11000E 00	3.28327E 01	1.42300E 01	3.37595E-10	1.42300E 01	0.000000
1.14000E 00	3.37201E 01	1.38050E 01	1.42757E-10	1.38050E 01	0.000000
1.17000E 00	3.46074E 01	1.34320E 01	6.03253E-11	1.34320E 01	0.000000
1.21000E 00	3.57906E 01	1.30570E 01	1.91099E-11	1.30570E 01	0.000000
1.24000E 00	3.66780E 01	1.26480E 01	8.06335E-12	1.26480E 01	0.000000
1.28000E 00	3.78611E 01	1.23440E 01	2.54955E-12	1.23440E 01	0.000000
1.31000E 00	3.87485E 01	1.19710E 01	1.07435E-12	1.19710E 01	0.000000
1.35000E 00	3.99316E 01	1.17040E 01	3.39132E-13	1.17040E 01	0.000000
1.38000E 00	4.08190E 01	1.13660E 01	1.42736E-13	1.13660E 01	0.000000
1.42000E 00	4.20022E 01	1.11260E 01	4.49887E-14	1.11260E 01	0.000000
1.45000E 00	4.28895E 01	1.08310E 01	1.89149E-14	1.08310E 01	0.000000
1.49000E 00	4.40727E 01	1.05780E 01	5.95363E-15	1.05780E 01	0.000000
1.53000E 00	4.52559E 01	1.02900E 01	1.87261E-15	1.02900E 01	0.000000
1.57000E 00	4.64390E 01	1.00290E 01	5.88594E-16	1.00290E 01	0.000000
1.61000E 00	4.76222E 01	9.78110E 00	1.84885E-16	9.78110E 00	0.000000
1.65000E 00	4.88053E 01	9.54530E 00	5.80390E-17	9.54530E 00	0.000000
1.69000E 00	4.99885E 01	9.31980E 00	1.82089E-17	9.31980E 00	0.000000
1.73000E 00	5.11717E 01	9.10650E 00	5.70956E-18	9.10650E 00	0.000000
1.77000E 00	5.23548E 01	8.90050E 00	1.78933E-18	8.90050E 00	0.000000
1.81000E 00	5.35380E 01	8.70700E 00	5.60474E-19	8.70700E 00	0.000000
1.85000E 00	5.47211E 01	8.51670E 00	1.75473E-19	8.51670E 00	0.000000
1.89000E 00	5.59043E 01	8.35440E 00	5.49110E-20	8.35440E 00	0.000000
1.93000E 00	5.70875E 01	8.14480E 00	1.71757E-20	8.14480E 00	0.000000
1.98000E 00	5.85664E 01	7.98310E 00	4.01535E-21	7.98310E 00	0.000000
2.02000E 00	5.97496E 01	7.80430E 00	1.25479E-21	7.80430E 00	0.000000
2.06000E 00	6.09327E 01	7.63780E 00	3.91964E-22	7.63780E 00	0.000000
2.11000E 00	6.24117E 01	7.50250E 00	9.14874E-23	7.50250E 00	0.000000
2.15000E 00	6.35948E 01	7.30850E 00	2.85547E-23	7.30850E 00	0.000000
2.20000E 00	6.50738E 01	7.19760E 00	6.65828E-24	7.19760E 00	0.000000
2.24000E 00	6.62569E 01	7.02540E 00	2.07658E-24	7.02540E 00	0.000000
2.29000E 00	6.77359E 01	6.89130E 00	4.83766E-25	6.89130E 00	0.000000
2.34000E 00	6.92148E 01	6.76220E 00	1.12646E-25	6.76220E 00	0.000000
2.38000E 00	7.03980E 01	6.61670E 00	3.50944E-26	6.61670E 00	0.000000
2.43000E 00	7.18770E 01	6.50700E 00	8.16521E-27	6.50700E 00	0.000000
2.48000E 00	7.33559E 01	6.36640E 00	1.89895E-27	6.36640E 00	0.000000
2.53000E 00	7.48349E 01	6.24690E 00	4.41451E-28	6.24690E 00	0.000000
2.58000E 00	7.63138E 01	6.12190E 00	1.02585E-28	6.12190E 00	0.000000

DECOMPOSITION OF FLUX NO. 10 PL#.5 PH#2.0

KT # 3.38078E-02

C # 6.31189E 01

E	E/KT	FLUX	MAXWELL	RESIDUE	MAXWELL/FLUX
2.63000E 00	7.77928E 01	6.01170E 00	2.38297E-29	6.01170E 00	0.000000
2.68000E 00	7.92717E 01	5.89440E 00	5.53347E-30	5.89440E 00	0.000000
2.73000E 00	8.07507E 01	5.79230E 00	1.28447E-30	5.79230E 00	0.000000
2.78000E 00	8.22296E 01	5.68130E 00	2.98063E-31	5.68130E 00	0.000000
2.83000E 00	8.37086E 01	5.59400E 00	6.91433E-32	5.59400E 00	0.000000
2.88000E 00	8.51875E 01	5.47430E 00	1.60345E-32	5.47430E 00	0.000000
2.94000E 00	8.69622E 01	5.37230E 00	2.77493E-33	5.37230E 00	0.000000
3.00000E 00	8.87370E 01	5.28880E 00	4.80027E-34	5.28880E 00	0.000000
3.04000E 00	8.99201E 01	5.17000E 00	1.48997E-34	5.17000E 00	0.000000
3.10000E 00	9.16949E 01	5.11990E 00	2.57577E-35	5.11990E 00	0.000000
3.15000E 00	9.31738E 01	4.98310E 00	5.96426E-36	4.98310E 00	0.000000
3.21000E 00	9.49486E 01	4.95280E 00	1.03036E-36	4.95280E 00	0.000000
3.26000E 00	9.64275E 01	4.84940E 00	2.38454E-37	4.84940E 00	0.000000
3.32000E 00	9.82023E 01	4.80400E 00	4.11684E-38	4.80400E 00	0.000000
3.37000E 00	9.96812E 01	4.71150E 00	0.	4.71150E 00	0.
3.43000E 00	1.01456E 02	4.64630E 00	0.	4.64630E 00	0.
3.49000E 00	1.03231E 02	4.57720E 00	0.	4.57720E 00	0.
3.54000E 00	1.04710E 02	4.49250E 00	0.	4.49250E 00	0.
3.60000E 00	1.06484E 02	4.42620E 00	0.	4.42620E 00	0.
3.66000E 00	1.08259E 02	4.34270E 00	0.	4.34270E 00	0.
3.72000E 00	1.10034E 02	4.25460E 00	0.	4.25460E 00	0.
3.78000E 00	1.11809E 02	4.17840E 00	0.	4.17840E 00	0.
3.84000E 00	1.13583E 02	4.09510E 00	0.	4.09510E 00	0.
3.90000E 00	1.15358E 02	4.01900E 00	0.	4.01900E 00	0.
3.96000E 00	1.17133E 02	3.94320E 00	0.	3.94320E 00	0.
4.02000E 00	1.18908E 02	3.88860E 00	0.	3.88860E 00	0.
4.08000E 00	1.20682E 02	3.80550E 00	0.	3.80550E 00	0.
4.15000E 00	1.22753E 02	3.75890E 00	0.	3.75890E 00	0.
4.21000E 00	1.24528E 02	3.69790E 00	0.	3.69790E 00	0.
4.27000E 00	1.26302E 02	3.64150E 00	0.	3.64150E 00	0.
4.34000E 00	1.28373E 02	3.60530E 00	0.	3.60530E 00	0.
4.40000E 00	1.30148E 02	3.54350E 00	0.	3.54350E 00	0.
4.47000E 00	1.32218E 02	3.50390E 00	0.	3.50390E 00	0.
4.53000E 00	1.33993E 02	3.45220E 00	0.	3.45220E 00	0.
4.60000E 00	1.36063E 02	3.42050E 00	0.	3.42050E 00	0.
4.66000E 00	1.37838E 02	3.36060E 00	0.	3.36060E 00	0.
4.73000E 00	1.39909E 02	3.33040E 00	0.	3.33040E 00	0.
4.80000E 00	1.41979E 02	3.18330E 00	0.	3.18330E 00	0.
4.86000E 00	1.43754E 02	3.11290E 00	0.	3.11290E 00	0.
4.93000E 00	1.45824E 02	3.01710E 00	0.	3.01710E 00	0.

DECOMPOSITION OF FLUX NO. 10 PL#.5 PH#2.0

KT # 3.38078E-02

C # 6.31189E 01

E	E/KT	FLUX	MAXWELL	RESIDUE	MAXWELL/FLUX
5.00000E 00	1.47895E 02	3.12140E 00	0.	3.12140E 00	0.

DCØM FORTRAN LISTING

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C     DCOM.  FLUX DECOMPOSITION PROGRAM.
      DIMENSION E(165),XKT(165),PHI(165),PHIM(165),R(165),
     1B(165),TITLE(12),D(7),X(165),Y(165)
      COMMON E,XKT,PHI,PHIM,R,TITLE,NSE,TK,CO
  100 READ INPUT TAPE10,101,TITLE
  101 FORMAT(12A6)
  102 FORMAT(7E10.7,I2)
  103 FORMAT(2E10.7)
  104 READINPUTTAPE10,103,PL,PH
    1 NSE0#0
    2 READ INPUT TAPE10,102,(D(J),J#1,7),IC
    3 IC#IC+1
    4 IF(IC-6)100,5,100
    5 IF(NSE0)8,6,8
    6 NSE#0
    7 NSE0#1
    8 DO13J#1,5,2
    9 K#NSE+(J+1)/2
   10 E(K)#D(J)
   11 PHI(K)#D(J+1)
   12 IF(E(K))13,16,13
   13 CONTINUE
   14 NSE#NSE+3
   15 GOTO2
   16 NSE#K-1
   17 BIG#PHI(1)
   18 DO22I#2,NSE
   19 IF(BIG-PHI(I))20,22,22
   20 II#I
   21 BIG#PHI(II)
   22 CONTINUE
   23 DO24J#1,NSE
   24 B(J)#LOGF(PHI(J)/E(J))
   25 DO27J#1,II
   26 IF(PL*E(II)-E(J))28,28,27
   27 CONTINUE
   28 JSM#J-1
   29 DO31J#II,NSE
   30 IF(PH*E(II)-E(J))32,32,31
   31 CONTINUE
   32 JLA#J+1
   33 DO36K#JSM,JLA
   34 L#K-JSM+1
   35 X(L)#E(K)
   36 Y(L)#B(K)
   37 N#JLA-JSM+1
   38 CALLLSQ(X,Y,N,AA,BB)
   39 TK#-1.0/AA
   40 CO#EXPF(BB)/(AA*AA)
   41 DO44J#1,NSE
   42 XKT(J)#-E(J)*(AA)
   43 PHIM(J)#E(J)*(EXPF(AA*E(J)+BB))
   44 R(J)#(1.0-EXPF(AA*E(J)+BB-B(J)))*PHI(J)
   45 CALLOUTDCO
   46 GOTO100
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

```
CLSQ  LEASTSQUARESFIT                                          LSQ 0101
      SUBROUTINELSQ(X,Y,N,AA,BB)                               LSQ 0103
      DIMENSION X(165),Y(165)                                  LSQ 0001
      XN#N                                                     LSQ 0106
    1 X1#0.0                                                   LSQ 0107
    2 X2#0.0                                                   LSQ 0108
    3 Y1#0.0                                                   LSQ 0109
    4 XY#0.0                                                   LSQ 0110
    5 DO9J#1,N                                                 LSQ 0111
    6 X1#X1+X(J)                                               LSQ 0112
    7 X2#X2+X(J)*X(J)                                          LSQ 0113
    8 Y1#Y1+Y(J)                                               LSQ 0114
    9 XY#XY+X(J)*Y(J)                                          LSQ 0115
   10 D#XN*X2-X1*X1                                            LSQ 0116
   11 AA#(XN*XY-Y1*X1)/D                                       LSQ 0117
   12 BB#(Y1*X2-X1*XY)/D                                       LSQ 0118
   13 RETURN                                                   LSQ 0119
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

```
C     OUTDCO.  OUTPUT SUBROUTINE FOR DCO.
      SUBROUTINE OUTDCO                                                 OUTDC003
      DIMENSION E(165),XKT(165),PHI(165),PHIM(165),R(165),              OUTDC001
     1TITLE(12),Z(165)                                                  18490001
      COMMON E,XKT,PHI,PHIM,R,TITLE,NSE,TK,CO                           OUTDC004
      DO6J#1,NSE                                                        OUTDC001
    6 Z(J)#PHIM(J)/PHI(J)                                               OUTDC002
      WRITEOUTPUTTAPE9,1,(TITLE(I),I#1,12)                              OUTDC011
    1 FORMAT(12A6)                                                      OUTDC012
    4 FORMAT(1PE13.5,1P4E14.5,0PF12.6)
    2 FORMAT(5H0KT #,1PE12.5/4H0C #,1PE12.5////                         OUTDC004
     184H        E              E/KT           FLUX         MAXWELL       RESOUTDC005
     2ICUE      MAXWELL/FLUX//2H0 )                                     OUTDC006
      WRITEOUTPUTTAPE9,2,TK,CO                                          OUTDC014
      NL#0                                                              OUTDC020
      DO3J#1,NSE                                                        OUTDC021
      WRITEOUTPUTTAPE9,4,E(J),XKT(J),PHI(J),PHIM(J),R(J),Z(J)           OUTDC010
      NL#NL+1                                                           OUTDC024
      IF(NL-40)3,5,5                                                    OUTDC025
    3 CONTINUE                                                          OUTDC002
      RETURN                                                            OUTDC004
    5 WRITEOUTPUTTAPE9,1,(TITLE(I),I#1,12)                              OUTDC006
      WRITEOUTPUTTAPE9,2,TK,CO                                          OUTDC008
      NL#0                                                              OUTDC017
      GOTO3                                                             OUTDC010
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

References

1. E. P. Wigner and J. E. Wilkins, Jr., "Effect of the Temperature of the Moderator on the Velocity Distribution of Neutrons with Numerical Calculations for H as Moderator," USAEC Report AECD-2275, September 14, 1944.

2. M. J. Poole, M. S. Nelkin, and R. S. Stone, "The Measurement and Theory of Reactor Spectra," p. 91 in Progress in Nuclear Energy, Series I. Physics and Mathematics, Vol. 2, Pergamon Press, New York, 1959.

3. C. Hastings, Jr., Approximations for Digital Computers, Princeton University Press, Princeton, New Jersey, 1955.

4. S. Glasstone and M. E. Edlund, The Elements of Nuclear Reactor Theory, D. Van Nostrand Co., Inc., Princeton, New Jersey, 1952.

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