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ARMY GAS-COOLED REACTOR SYSTEMS PROGRAM

AGN-GAM, an IBM 7090 Code to Calculate Spectra
and Multigroup Constants

April 1965

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AGN-GAM, AN IBM 7090 CODE TO CALCULATE SPECTRA
AND MULTIGROUP CONSTANTS

by

T. P. Wilcox and S. T. Perkins

April 1965

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AGN-GAM, AN IBM 7090 CODE TO CALCULATE SPECTRA
AND MULTIGROUP CONSTANTS*

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T. P. Wilcox and S. T. Perkins

ABSTRACT

The AGN-GAM (IBM 7090) code is discussed together with the subroutines for writing and revising the library tapes.

The code solves either the P-1 or B-1 equations for 75 quarter lethargy energy groups from 10 Mev to 0.07 ev to determine the slowing down fluxes and currents in a reactor core. Provision is also made to solve P-1 equations to determine these quantities in a reflector region. Broad group constants, weighted by the flux (or current) quantities, are then derived for use in diffusion, isotropic transport or anisotropic transport calculations.

The method of Adler, Hinman and Nordheim is used to calculate resonance absorption and fission cross sections. Self-shielding factors can be included in the computations. The output cross section data can be punched directly into IBM cards for use in any of several nuclear codes.

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I. INTRODUCTION

A. SUMMARY

One of the major problems in reactor physics is obtaining good nuclear cross sections for the standard diffusion and transport theory codes. In order to obtain these constants, valid cross section data over the full energy range of reactor calculations must be available. Since most calculations are performed for relatively few energy groups, it is necessary to reduce the total body of cross section data to data pertaining to the few groups desired. This reduction is accomplished by weighting the cross sections with the system's neutron spectrum; the AGN-GAM code calculates the spectrum in a reactor core or reflector and then performs the weighting to obtain the group constants.

The code generates the macroscopic cross sections and scattering matrices for 75 quarter lethargy groups, adding together the values of each of the specified input materials. Special resonance calculations are performed to evaluate the absorption and fission cross sections of individual resonances depending upon the geometry and composition of the system. Following these operations, a slowing down spectrum is calculated by using specific values of system neutron leakages and sources. With this spectrum, broad group cross sections for use in either diffusion or transport type codes are obtained.

The organization of the code and the manner in which it functions is basically the same as for the General Atomics GAM-I code (Ref. 1). However, modifications were made to the original program to permit solution of the P-1 equations in a reflector and the entire code has been re-programmed.

The major features of the AGN-GAM code are:

- 1) Core fluxes and currents are calculated by the B-1 or P-1 methods. For the P-1 solution, a reflector region or coupled core region may be simulated.
- 2) The seventy-five subgroups used in the calculations are established as quarter lethargy groups, from 10 Mev to 0.07 ev.
- 3) Elastic scattering matrices maintain the energy-angle correlation by including both the P_0 and P_1 terms.
- 4) Isotropic scattering matrices for both the inelastic and (n, 2n) processes are included.
- 5) The resonance absorption and fission are calculated by a method proposed by F. T. Adler, G. W. Hirman, and L. W. Nordheim. The code calculates the effects of self-shielding in each resolved resonance as well as the volume and surface integral contributions in the unresolved regions.
- 6) Self-shielding factors may be specified for any component material.
- 7) Flux and current terms may be input, thus, eliminating the flux calculation. It is also possible to input the flux term alone to calculate the current term.
- 8) The moments method may be used to calculate age in an infinite homogeneous medium.
- 9) Using either the calculated or the input flux and current terms, macroscopic broad group constants are derived for use in either diffusion calculations, or isotropic or anisotropic transport calculations. A maximum of 32 broad groups is possible.
- 10) Microscopic broad-group cross sections can be obtained for any material on the data tape.
- 11) Both the macroscopic and microscopic cross sections can be punched directly onto cards for use in the DSN, TDC, 2DXY, DTK, DDK, PDQ-2, AIM-6, ANGIE or ZOOM codes. Space is left on these cards for thermal

group values, for activation cross sections, and for up-scattering in the matrices when one of the transport theory codes is chosen.

12) The library data tape currently includes 182 different materials. The data for most of these materials include all 75 groups of data. Ten different source spectra are included.

13) The code is written in FORTRAN-II with sub-routines that permit easy modification.

B. REPORT ORGANIZATION

This report consists of four sections in which the code is described and six appendices in which the pertinent derivations and other supplementary information are contained. Section I is an introduction. Section II provides details on subgroup library specifications, multigroup spectrum relations, and definitions of constants. The derivations germane to Section II are contained in Appendices A, B, and C; the energy dependent spectrum relations are developed in Appendix A, the scattering matrices are established in Appendix B, and the multigroup transport approximation is demonstrated in Appendix C.

In Section III, the use of the code is described and a sample problem is solved. Section IV contains a discussion of the operating procedures for the code. Appendix D provides details pertaining to the library tape and Appendix E gives the procedure for updating the AGN data tape. Finally, Appendix F provides a simplified block diagram of the AGN-GAM Code.

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II. RELATIONS AND DEFINITIONS OF THE MULTIGROUP CONSTANTS

A. LIBRARY TAPE DATA

1. Subgroup Cross Sections

The AGN library tape is composed of 75 quarter lethargy subgroups with zero lethargy starting at 10 Mev. (Appendix D gives a description of the data tape.) The required subgroup constants on this tape are the total-, absorption-, elastic scattering-, inelastic scattering-, (n,2n)- and fission cross sections as well as the number of neutrons emitted per fission.

The absorption and fission cross sections are specified in two different ways. If resonance parameters are included for the material in question, these cross sections are equal to the total absorption (or fission) minus the resonance absorption (or fission); that is, to the underlying "background" cross section. If no resonance parameters are included, they are equal to the total absorption (or fission) cross section.

The n, 2n reaction is included explicitly, but due to lack of information, it may be desirable to distribute both emergent neutrons in the inelastic spectrum. In this case a new inelastic cross section is defined as:

$$\sigma'_{1e} = \sigma_{1e} + 2 \sigma_{n,2n}$$

and, to conserve neutrons, a new absorption cross section as:

$$\sigma'_a = \sigma_a - \sigma_{n,2n}$$

where the primed quantities appear on the tape and $\sigma_{n,2n}$ is set identically equal to zero.

Two other subgroup quantities that appear on the data tape, L-1 and L-2, are used in the transport approximation. L-1 is the angle average of the $\ell = 1$ Legendre scattering polynomial; that is, $\bar{\mu}$, the average cosine of the L system scattering angle. L-2 is the angle average of the $\ell = 2$ Legendre polynomial.

2. Scattering Matrices

In addition to the subgroup cross section data, the subgroup transfer cross sections are required on the library tape. These matrices are given by Eq. (B-22) of Appendix B. (Appendix B gives a complete specification of the elastic and inelastic scattering matrices.)

$$\sigma_{x j \rightarrow i}^{\ell} = \frac{\int_j dE' f_{\ell}(E') \int_i dE \sigma_x^{\ell}(E \rightarrow E')}{\int_j dE' f_{\ell}(E')}$$

where:

$\ell = 0, 1$ for $x = \text{el.}$ (elastic scattering)

$\ell = 0$ for $x = \text{ie. or n,2n}$ (inelastic scattering or n,2n reaction)

and where the n,2n scattering kernel is normalized to one emergent neutron.

In the cross section generating codes the flux is assumed constant across a subgroup and the integrations for elastic scattering are carried-through analytically with linear anisotropic scattering in the CM system. Statistical inelastic scattering is assumed and Simpson's rule integration is used. The emergent n,2n neutrons are both distributed in the inelastic spectrum.

3. Resonance Data

For those materials that use the resonance calculation, additional (resonance) parameters are included on the library tape. These parameters include values for each individual resolved resonance and a set describing the unresolved region. The individual resolved resonances consist of the energy of the resonance; the radiative, neutron, and fission widths; the statistical weight factor; and the abundance of the isotopes that contain the specified resonance. In addition, a parameter is supplied that determines whether the resonance should be calculated with narrow-resonance or infinite-mass approximation. The unresolved region is described by a

lower cut-off energy, the average level spacing, the average reduced neutron width, average radiative and fission widths, the potential scattering cross section of the material, and the average statistical weight factor.

B. RESONANCE EVALUATION

The AGN-GAM code uses the method of Adler, Hinman, and Nordheim (Ref. 2 and 3) to calculate the effective absorption cross sections of materials with high resonance absorption. This method is much more efficient in obtaining correct cross sections than the normally used infinite dilution integral method. The following paragraphs present a brief description of this method and a tabulation of the equations used. A further explanation of the theory is contained in Reference 4, Chapters 3 and 5.

1. Resolved Region

The total integral of the absorption under any given resonance, i , can be expressed as the sum of a "volume" and a "surface" term.

$$RI_i = RI(\text{volume})_i + RI(\text{surface})_i$$

$$RI_i = \int_{-\infty}^{+\infty} \frac{dE}{E} \frac{\sigma_a \sigma_P}{\sigma_t} + \frac{1}{N \bar{r}} \int_{-\infty}^{+\infty} \frac{dE}{E} \frac{\sigma_a (\sigma_t - \sigma_P)}{\sigma_t^2} F \quad (1)$$

where: σ_a and σ_t are the absorption and total cross sections at the energy, E

$\bar{r}$ is the average cord length in the absorber lump ($\bar{r} = 4 V/S$),

F is the probability that a neutron passing into the lump suffers a collision in it,

The other terms are defined in Table 1.

The method outlined by Adler, Hinman, and Nordheim defines the cross sections on the right side of this relationship and then solves for the resulting integrals. The results yield the following equation:

$$RI_i = \frac{\sigma_P(\Gamma_{\gamma})_i}{E_i} J(\xi_i, \beta_i) + \frac{\sigma_P(\Gamma_{\gamma})_i}{E_i \beta_i} L(t, \xi_i, \beta_i) \quad (2)$$

TABLE 1 - DEFINITION OF TERMS

i	=	subscript indicating values for a specific resonance
A	=	atomic weight of absorber atom
k	=	Boltzmann constant; 8.6167×10^{-5} ev/ $^{\circ}$ K
g	=	statistical weight factor
T	=	material temperature, $^{\circ}$ K
N	=	number density of resonance material, 10^{24} atoms/cc
a	=	radius of cylinder or sphere, thickness of slab, cm
σ_{pot}	=	potential scattering cross section of resonance material barns
σ_M	=	total non-resonance scattering cross section of moderating materials within pin, sphere, or slab containing resonance absorber, Barns per absorber atom
σ_P	=	total non-resonance scattering cross section of all materi- als within the pin, sphere, or slab containing resonance absorber. Barns per absorber atom
E_i	=	energy of resonance, ev
$(\Gamma_n)_i$	=	neutron width of resonance, ev
$(\Gamma_\gamma)_i$	=	radiative width of resonance, ev
$(\Gamma_f)_i$	=	fission width of resonance, ev
$(\Gamma)_i$	=	total width = $(\Gamma_n + \Gamma_f + \Gamma_\gamma)_i$, ev
$(\sigma_0)_i$	=	total resonance cross section at E_c , barns
E_c	=	cutoff energy, resonances at energies higher than this will be treated as unresolved, ev
$\langle \Gamma_n^0 \rangle$	=	average reduced neutron width, $\sqrt{\text{ev}}$
D	=	average level spacing, ev

where (in general terms):

σ_p is a measure of the non-resonance scattering in the lump,
 ξ_i is the ratio of natural to Doppler resonance widths,
 β_i is the ratio of the scattering to the total cross section.

The functions $J(\xi, \beta)$ and $L(t, \xi, \beta)$ have been computed and are tabulated in Reference 5.

Equation (2) results if the assumption is made that the practical width of the resonance is narrow in relation to the average energy loss of a neutron when scattered. This is the so-called narrow resonance (NR) approximation. Very similar results are obtained when the narrow resonance, infinite mass (NRIA) approximation is used for wider resonances. The definitions of β , σ_p , and the width Γ_y are modified slightly for the latter case but the basic idea is the same. Whether the NR or the NRIA method is used depends upon the physical characteristics of the resonance.

When the NRIA method is to be used for a lump of pure metal, the "volume" term becomes small and the "surface" term does not depend upon the dimensions of the lump. For this special case, the $L(\tau, \xi, \beta)$ table is replaced by an $L'(\xi, \beta)$ table.

Table 2 summarizes the equations for all three of the cases mentioned above. These equations include the single level fission integrals by assuming that;

$$\text{RI (fission)}_i = \left[\frac{\Gamma_f}{(\Gamma_f + \Gamma_y)} \right]_i \text{RI (absorption)}_i \quad (3)$$

2. Un-Resolved Region

The previous discussion concerned the general equation with which to determine the resonance integral of a given resonance with known physical properties (E , Γ_n , Γ_y , etc.). For any given material there exists a so-called unresolved region, which extends above some cutoff energy E_c and in which the properties (E , Γ_n , Γ_y , etc.) have not been measured. To evaluate the resonance integral of this region, an estimate must be made of the resonance properties as a function of energy and these properties must then be integrated upwards from E_c to infinity. A Porter-Thomas distribution of

TABLE 2 SUMMARY OF EQUATIONS FOR CALCULATING RESONANCE
ABSORPTION AND FISSION INTEGRALS

Resolved Region

Type, basic relationships	Part	Absorption Integral	Fission Integral
<u>NARROW RESONANCE (NR)</u> $\xi_1 = \frac{1}{2} \sqrt{\frac{(A+1)\Gamma_1^2}{E_1 k T}}$ $(\sigma_0)_1 = 2.60 \times 10^6 g \frac{(\Gamma_n)_1}{E_1 \Gamma_1}$ $\beta_1 = \sigma_p / (\sigma_0)_1$ $t = N \sigma_p a$	Volume	$\frac{\sigma_p (\Gamma_Y + \Gamma_f)_1}{E_1} J(\beta_1, \xi_1)$	$\frac{\sigma_p (\Gamma_f)_1}{E_1} J(\beta_1, \xi_1)$
	Surface	$\frac{\sigma_p (\Gamma_Y + \Gamma_f)_1}{E_1 \beta_1} L(t, \xi_1, \beta_1)$	$\frac{\sigma_p (\Gamma_f)_1}{E_1 \beta_1} L(t, \xi_1, \beta_1)$
<u>NARROW RESONANCE-INFINITE MASS (NRIM)</u> ξ_1 same as above $(\sigma_0)_1$ same as above $\beta_1 = \frac{\sigma_m}{\sigma} \frac{\Gamma_1}{(\Gamma_Y + \Gamma_f)_1}$ $t = N \sigma_m a$	Volume	$\frac{\sigma_m \Gamma_1}{E_1} J(\xi_1, \beta_1)$	$\frac{\sigma_m \Gamma_1}{E_1} \left(\frac{\Gamma_f}{\Gamma_Y + \Gamma_f} \right)_1 J(\beta_1, \xi_1)$
	Surface	$\frac{\sigma_m \Gamma_1}{E_1 \beta_1} L(t, \xi_1, \beta_1)$	$\frac{\sigma_m \Gamma_1}{E_1 \beta_1} \left(\frac{\Gamma_f}{\Gamma_Y + \Gamma_f} \right)_1 L(t, \xi_1, \beta_1)$
<u>NRIM-PURE METALS</u> $(\sigma_0)_1, \xi_1$ same as above $\sigma_m = 0$ $t = N(\sigma_0)_1 \left(\frac{\Gamma_Y}{\Gamma} \right)_1 a$	Volume	$\frac{2}{A} \sigma_{pot}$	$\frac{2}{A} \sigma_{pot} \left(\frac{\Gamma_f}{\Gamma_f + \Gamma_Y} \right)_1$
	Surface	$\frac{(\sigma_0)_1 (\Gamma_Y + \Gamma_f)_1}{E_1} L'(t, \xi_1)$	$\frac{(\sigma_0)_1 (\Gamma_f)_1}{E_1} L'(t, \xi_1)$

TABLE 3 - SUMMARY OF EQUATIONS FOR UNRESOLVED REGION

<u>Volume</u>	absorption = $\frac{\sigma_P (\Gamma_Y + \Gamma_f)}{D} \int_{E_c}^{\infty} \overline{J(E)} \frac{dE}{E}$
	fission = $\frac{\sigma_P \Gamma_f}{D} \int_{E_c}^{\infty} \overline{J(E)} \frac{dE}{E}$
<u>Surface</u>	absorption = $\frac{\sigma_P (\Gamma_Y + \Gamma_f)}{D} \int_{E_c}^{\infty} \frac{\overline{L(E)}}{\beta} \frac{dE}{E}$
	fission = $\frac{\sigma_P \Gamma_f}{D} \int_{E_c}^{\infty} \frac{\overline{L(E)}}{\beta} \frac{dE}{E}$

Definition of Terms

$$H = \frac{1}{2} \sqrt{\frac{A}{k T}} \left(\langle \Gamma_n^0 \rangle \right)$$

$$B = \frac{1}{2} \sqrt{\frac{A}{k T E}} \left(\Gamma_Y + \Gamma_f \right)$$

$$C = \frac{\sigma_P E}{2.6 \times 10^6} \quad y = \frac{\Gamma_n^0}{\langle \Gamma_n^0 \rangle}$$

$$\xi = Hy + B \quad \beta(\xi) = \frac{C \xi}{\xi - B}$$

$$\overline{J(E)} = \frac{1}{\sqrt{2\pi H}} \int_B^{\infty} \frac{d\xi}{\sqrt{\xi - B}} J(\xi, \beta(\xi)) e^{-(\xi - B)/2H}$$

$$\frac{\overline{L(E)}}{\beta} = \frac{1}{\sqrt{2\pi H}} \int_B^{\infty} \frac{d\xi}{\xi C} \sqrt{\xi - B} L(t, \xi, \beta(\xi)) e^{-(\xi - B)/2H}$$

neutron widths and the NR approximations are used to derive the equations shown in Table 3.

Within the AGN-GAM code, the infinite limit of an upper integral is replaced with an energy bound so that there are 18 fine groups in the unresolved region. For this energy range the total integral is calculated by a Simpson's rule integration and subsequently divided into the 18 fine groups.

3. Table Interpolation

Several different methods are used to interpolate the tabular values of the J, L, and L' tables. In the ξ direction, interpolation is accomplished by a four point fit with Lagrange's formula. In the region between the last given point and infinity (still in the ξ direction) an exponential fit of the form, $y = a + b e^{-c\xi}$ is used. The constants a, b and c are found from three given points in the table. In the β direction, the fit is linear with β ; because the tables are log functions of β , a linear fit takes the form of an exponential curve. In the z direction in the L tables, a fit is made with Lagrange's equation to fit the quantity L/z. All checks of these routines have shown results as accurate as the tables are themselves.

C. SPECTRUM GENERATION

1. Method of Solution

Either the P_1 or B_1 relations (Appendix A) may be used for spectrum generation. The P_1 equations, which are evolved from volume integrations over the region of interest, are applicable to either a core or a reflector region. The B_1 equations, the usual Fourier transform relations, are only applicable to a bare normal-mode core. In either case, the equations are solved by the usual subgroup treatment (Figure 1).

FIGURE 1. SUBGROUP STRUCTURE

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

GROUP		ISOTROPIC SCATTERING CROSS SECTIONS			TOTAL	ANISOTROPIC ELASTIC
		ELASTIC	INELASTIC	N-2N		
FROM 1 TO 1	1	5.5453E-02	3.2616E-03	0.	5.8714E-02	1.2456E-02
FROM 1 TO 2	2	5.2753E-02	7.5206E-03	0.	6.0273E-02	2.2210E-02
FROM 1 TO 3	3	1.3051E-02	3.9194E-03	0.	1.6971E-02	6.4116E-03
FROM 1 TO 4	4	1.0615E-02	3.0538E-03	0.	1.3669E-02	3.8759E-03
FROM 1 TO 5	5	6.7805E-03	1.2248E-03	0.	8.0053E-03	1.5767E-03
FROM 1 TO 6	6	2.7227E-03	1.3951E-04	0.	2.8622E-03	2.8432E-04
FROM 2 TO 2	2	6.4004E-02	2.1609E-03	0.	6.6165E-02	7.5155E-03
FROM 2 TO 3	3	5.3897E-02	2.7664E-03	0.	5.6664E-02	2.9899E-02
FROM 2 TO 4	4	3.4596E-02	2.8478E-03	0.	3.7444E-02	1.9422E-02
FROM 2 TO 5	5	2.2099E-02	1.4089E-03	0.	2.3507E-02	7.9028E-03
FROM 2 TO 6	6	7.6728E-03	1.7816E-04	0.	7.8510E-03	1.3584E-03
FROM 2 TO 7	7	1.2009E-03	3.5666E-06	0.	1.2045E-03	6.9977E-05
FROM 3 TO 3	3	9.6604E-02	6.7144E-04	0.	9.7276E-02	-1.3722E-02
FROM 3 TO 4	4	1.2800E-01	1.6257E-03	0.	1.2963E-01	5.5688E-02
FROM 3 TO 5	5	5.6483E-02	1.0595E-03	0.	5.7542E-02	2.7015E-02
FROM 3 TO 6	6	1.9611E-02	1.5737E-04	0.	1.9768E-02	4.6464E-03
FROM 3 TO 7	7	2.3846E-03	3.3352E-06	0.	2.3879E-03	2.1667E-04
FROM 3 TO 8	8	6.8490E-04	1.1105E-07	0.	6.8501E-04	2.4496E-05
FROM 4 TO 4	4	1.7401E-01	5.8360E-04	0.	1.7460E-01	4.2466E-02
FROM 4 TO 5	5	1.7718E-01	8.8540E-04	0.	1.7807E-01	8.6096E-02
FROM 4 TO 6	6	4.9479E-02	1.5765E-04	0.	4.9637E-02	1.5825E-02
FROM 4 TO 7	7	6.0164E-03	3.5609E-06	0.	6.0199E-03	7.3971E-04
FROM 4 TO 8	8	1.4941E-03	1.6153E-07	0.	1.4943E-03	8.1700E-05
FROM 4 TO 9	9	2.3386E-04	0.	0.	2.3386E-04	3.5482E-06
FROM 5 TO 5	5	2.5075E-01	2.3945E-04	0.	2.5099E-01	5.4947E-02
FROM 5 TO 6	6	2.4390E-01	8.5927E-05	0.	2.4399E-01	1.2678E-01
FROM 5 TO 7	7	2.8153E-02	2.1655E-06	0.	2.8155E-02	6.1100E-03
FROM 5 TO 8	8	6.9917E-03	1.1226E-07	0.	6.9918E-03	6.8097E-04
FROM 5 TO 9	9	9.4622E-04	0.	0.	9.4622E-04	3.2694E-05
FROM 5 TO 10	10	1.4810E-04	0.	0.	1.4810E-04	9.7452E-07
FROM 6 TO 6	6	4.7497E-01	0.	0.	4.7497E-01	1.8730E-01
FROM 6 TO 7	7	2.7995E-01	0.	0.	2.7995E-01	1.3478E-01
FROM 6 TO 8	8	6.6917E-02	0.	0.	6.6917E-02	1.5370E-02
FROM 6 TO 9	9	9.0562E-03	0.	0.	9.0562E-03	7.6060E-04
FROM 6 TO 10	10	8.9601E-04	0.	0.	8.9601E-04	2.9950E-05
FROM 6 TO 11	11	5.2146E-04	0.	0.	5.2146E-04	7.0651E-06
FROM 7 TO 7	7	4.9779E-01	0.	0.	4.9779E-01	1.7397E-01
FROM 7 TO 8	8	4.5588E-01	0.	0.	4.5588E-01	2.3105E-01
FROM 7 TO 9	9	5.9404E-02	0.	0.	5.9404E-02	1.1723E-02
FROM 7 TO 10	10	5.8773E-03	0.	0.	5.8773E-03	4.7420E-04
FROM 7 TO 11	11	2.1621E-03	0.	0.	2.1621E-03	1.0442E-04
FROM 7 TO 12	12	1.2583E-03	0.	0.	1.2583E-03	2.7243E-05

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

FROM 8 TO 8	5.9114E-01	0.	0.	5.9114E-01	2.2851E-01
FROM 8 TO 9	3.9271E-01	0.	0.	3.9271E-01	1.9943E-01
FROM 8 TO 10	3.7715E-02	0.	0.	3.7715E-02	8.2499E-03
FROM 8 TO 11	1.3875E-02	0.	0.	1.3875E-02	1.8372E-03
FROM 8 TO 12	5.1042E-03	0.	0.	5.1042E-03	4.0776E-04
FROM 8 TO 13	2.9705E-03	0.	0.	2.9705E-03	1.1280E-04
FROM 9 TO 9	6.1508E-01	0.	0.	6.1508E-01	2.3162E-01
FROM 9 TO 10	2.9067E-01	0.	0.	2.9067E-01	1.6171E-01
FROM 9 TO 11	1.0272E-01	0.	0.	1.0272E-01	3.6840E-02
FROM 9 TO 12	3.7789E-02	0.	0.	3.7789E-02	8.2141E-03
FROM 9 TO 13	1.3902E-02	0.	0.	1.3902E-02	1.8292E-03
FROM 9 TO 14	8.0906E-03	0.	0.	8.0906E-03	5.1824E-04
FROM 10 TO 10	3.9032E-01	0.	0.	3.9032E-01	9.3651E-02
FROM 10 TO 11	4.3842E-01	0.	0.	4.3842E-01	2.7040E-01
FROM 10 TO 12	1.5273E-01	0.	0.	1.5273E-01	6.1898E-02
FROM 10 TO 13	5.6187E-02	0.	0.	5.6187E-02	1.3804E-02
FROM 10 TO 14	2.0670E-02	0.	0.	2.0670E-02	3.0755E-03
FROM 10 TO 15	1.2030E-02	0.	0.	1.2030E-02	8.7430E-04
FROM 11 TO 11	3.7882E-01	0.	0.	3.7882E-01	9.1435E-02
FROM 11 TO 12	4.3920E-01	0.	0.	4.3920E-01	2.7214E-01
FROM 11 TO 13	1.5309E-01	0.	0.	1.5309E-01	6.2276E-02
FROM 11 TO 14	5.6317E-02	0.	0.	5.6317E-02	1.3888E-02
FROM 11 TO 15	2.0718E-02	0.	0.	2.0718E-02	3.0942E-03
FROM 11 TO 16	1.2057E-02	0.	0.	1.2057E-02	8.7967E-04
FROM 12 TO 12	3.7245E-01	0.	0.	3.7245E-01	9.1904E-02
FROM 12 TO 13	4.4236E-01	0.	0.	4.4236E-01	2.7387E-01
FROM 12 TO 14	1.5422E-01	0.	0.	1.5422E-01	6.2662E-02
FROM 12 TO 15	5.6733E-02	0.	0.	5.6733E-02	1.3974E-02
FROM 12 TO 16	3.3017E-02	0.	0.	3.3017E-02	3.9986E-03
FROM 13 TO 13	3.7819E-01	0.	0.	3.7819E-01	9.5645E-02
FROM 13 TO 14	4.4780E-01	0.	0.	4.4780E-01	2.7655E-01
FROM 13 TO 15	1.5634E-01	0.	0.	1.5634E-01	6.3220E-02
FROM 13 TO 16	9.0985E-02	0.	0.	9.0985E-02	1.8132E-02
FROM 14 TO 14	4.1476E-01	0.	0.	4.1476E-01	1.2999E-01
FROM 14 TO 15	4.5891E-01	0.	0.	4.5891E-01	2.7487E-01
FROM 14 TO 16	2.5351E-01	0.	0.	2.5351E-01	5.941E-02
FROM 15 TO 15	5.5549E-01	0.	0.	5.5549E-01	2.5130E-01
FROM 15 TO 16	8.4949E-01	0.	0.	8.4949E-01	2.7686E-01

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

BROAD GROUP MICROSCOPIC CROSS SECTIONS FOR MATERIAL NUMBER 43 MANGANESE
(AVERAGED FOR USE IN ANISOTROPIC TRANSPORT CODES)

GROUP	SIGMA-TOTAL	SIGMA-SCAT.	SIGMA-ABSOR.	SIGMA-FISSION	AVERAGE NU	NU-SIGMA FISS.	SIGMA-CAPT.
1	4.0233E 00	4.0223E 00	1.0003E-03	0.	0.	0.	1.0003E-03
2	3.6908E 00	3.6882E 00	2.6277E-03	0.	0.	0.	2.6277E-03
3	3.2960E 00	3.2923E 00	3.7034E-03	0.	0.	0.	3.7034E-03
4	3.2389E 00	3.2345E 00	4.3580E-03	0.	0.	0.	4.3580E-03
5	3.6981E 00	3.6882E 00	9.8629E-03	0.	0.	0.	9.8629E-03
6	7.5631E 00	7.5418E 00	2.1268E-02	0.	0.	0.	2.1268E-02
7	2.0567E 01	2.0343E 01	2.2397E-01	0.	0.	0.	2.2397E-01
8	9.8776E 01	9.8182E 01	5.9413E-01	0.	0.	0.	5.9413E-01
9	1.2732E 02	1.2251E 02	4.8050E 00	0.	0.	0.	4.8050E 00
10	3.2300E 00	2.8840E 00	3.4602E-01	0.	0.	0.	3.4602E-01
11	2.9997E 00	2.4288E 00	5.7099E-01	0.	0.	0.	5.7099E-01
12	3.0124E 00	2.0895E 00	9.2289E-01	0.	0.	0.	9.2289E-01
13	3.5570E 00	2.0845E 00	1.4724E 00	0.	0.	0.	1.4724E 00
14	4.4432E 00	2.1244E 00	2.3188E 00	0.	0.	0.	2.3188E 00
15	5.6897E 00	2.1519E 00	3.5378E 00	0.	0.	0.	3.5378E 00

GROUP	SIGMA-OUT	SIGMA-REMOVAL	SIGMA-L
1	1.5674E 00	1.5684E 00	2.8864E 00
2	1.1215E 00	1.1242E 00	3.0769E 00
3	8.5758E-01	8.6128E-01	2.9464E 00
4	4.0598E-01	4.1034E-01	3.0400E 00
5	1.0253E-01	1.1240E-01	3.6262E 00
6	5.6012E-02	7.7280E-02	7.5430E 00
7	4.6572E-01	6.8959E-01	2.0560E 01
8	4.3195E-01	1.0261E 00	9.8743E 01
9	6.2701E-02	4.8677E 00	1.2727E 02
10	8.9881E-02	4.3590E-01	3.2290E 00
11	8.0481E-02	6.5148E-01	2.9989E 00
12	7.0764E-02	9.9365E-01	3.0117E 00
13	6.9214E-02	1.5417E 00	3.536E 00
14	7.0105E-02	2.3889E 00	4.442E 00
15	7.2098E-02	3.6099E 00	5.6890E 00

FIGURE 6. (CONTINUED)

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

AGN TM-407

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GROUP		ISOTROPIC SCATTERING CROSS SECTIONS				ANISOTROPIC	
		ELASTIC	INELASTIC	N-2N	TOTAL	ELASTIC	
FROM 1 TO 1	1	1.1131E 00	2.0484E-01	0.	1.3180E 00	1.0727E-01	
FROM 1 TO 2	2	7.0843E-02	6.7684E-01	0.	7.4788E-01	1.6438E-02	
FROM 1 TO 3	3	0.	3.8497E-01	0.	3.8497E-01	0.	
FROM 1 TO 4	4	0.	3.0163E-01	0.	3.0163E-01	0.	
FROM 1 TO 5	5	0.	1.1964E-01	0.	1.1964E-01	0.	
FROM 1 TO 6	6	0.	1.3465E-02	0.	1.3465E-02	0.	
FROM 2 TO 2	2	1.6528E 00	2.9986E-01	0.	1.9527E 00	3.4446E-01	
FROM 2 TO 3	3	7.4941E-02	4.1773E-01	0.	4.9267E-01	-1.6910E-04	
FROM 2 TO 4	4	0.	4.1154E-01	0.	4.1154E-01	0.	
FROM 2 TO 5	5	0.	1.9334E-01	0.	1.9334E-01	0.	
FROM 2 TO 6	6	0.	2.3529E-02	0.	2.3529E-02	0.	
FROM 2 TO 7	7	0.	4.6024E-04	0.	4.6024E-04	0.	
FROM 3 TO 3	3	1.9046E 00	1.8046E-01	0.	2.0851E 00	3.0361E-01	
FROM 3 TO 4	4	1.3508E-01	4.3737E-01	0.	5.7245E-01	-1.8706E-02	
FROM 3 TO 5	5	0.	2.5037E-01	0.	2.5037E-01	0.	
FROM 3 TO 6	6	0.	3.4040E-02	0.	3.4040E-02	0.	
FROM 3 TO 7	7	0.	6.9758E-04	0.	6.9758E-04	0.	
FROM 3 TO 8	8	0.	1.9349E-05	0.	1.9349E-05	0.	
FROM 4 TO 4	4	2.4238E 00	2.0591E-01	0.	2.6297E 00	2.3914E-01	
FROM 4 TO 5	5	1.0233E-01	2.6179E-01	0.	3.6412E-01	-2.1542E-02	
FROM 4 TO 6	6	0.	4.0948E-02	0.	4.0948E-02	0.	
FROM 4 TO 7	7	0.	8.8064E-04	0.	8.8064E-04	0.	
FROM 4 TO 8	8	0.	3.7696E-05	0.	3.7696E-05	0.	
FROM 4 TO 9	9	0.	0.	0.	0.	0.	
FROM 5 TO 5	5	3.4923E 00	2.1564E-02	0.	3.5138E 00	2.7169E-01	
FROM 5 TO 6	6	9.7635E-02	4.7856E-03	0.	1.0242E-01	-2.7864E-02	
FROM 5 TO 7	7	0.	1.0904E-04	0.	1.0904E-04	0.	
FROM 5 TO 8	8	0.	5.4132E-06	0.	5.4132E-06	0.	
FROM 5 TO 9	9	0.	0.	0.	0.	0.	
FROM 5 TO 10	10	0.	0.	0.	0.	0.	
FROM 6 TO 6	6	7.4657E 00	0.	0.	7.4657E 00	2.0971E-01	
FROM 6 TO 7	7	5.6012E-02	0.	0.	5.6012E-02	-1.4615E-02	
FROM 6 TO 8	8	0.	0.	0.	0.	0.	
FROM 6 TO 9	9	0.	0.	0.	0.	0.	
FROM 6 TO 10	10	0.	0.	0.	0.	0.	
FROM 6 TO 11	11	0.	0.	0.	0.	0.	
FROM 7 TO 7	7	1.9870E 01	0.	0.	1.9870E 01	3.7652E-01	
FROM 7 TO 8	8	4.6572E-01	0.	0.	4.6572E-01	-1.3697E-01	
FROM 7 TO 9	9	0.	0.	0.	0.	0.	
FROM 7 TO 10	10	0.	0.	0.	0.	0.	
FROM 7 TO 11	11	0.	0.	0.	0.	0.	
FROM 7 TO 12	12	0.	0.	0.	0.	0.	

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

FROM 8 TO 8	8	9.7717E 01	0.	0.	9.7717E 01	1.2931E 00	
FROM 8 TO 9	9	4.3195E-01	0.	0.	4.3195E-01	-1.3823E-01	
FROM 8 TO 10	10	0.	0.	0.	0.	0.	
FROM 8 TO 11	11	0.	0.	0.	0.	0.	
FROM 8 TO 12	12	0.	0.	0.	0.	0.	
FROM 8 TO 13	13	0.	0.	0.	0.	0.	
FROM 9 TO 9	9	1.2241E 02	0.	0.	1.2241E 02	1.4621E 00	
FROM 9 TO 10	10	6.2701E-02	0.	0.	6.2701E-02	-2.0160E-02	
FROM 9 TO 11	11	0.	0.	0.	0.	0.	
FROM 9 TO 12	12	0.	0.	0.	0.	0.	
FROM 9 TO 13	13	0.	0.	0.	0.	0.	
FROM 9 TO 14	14	0.	0.	0.	0.	0.	
FROM 10 TO 10	10	2.7931E 00	0.	0.	2.7931E 00	6.3312E-02	
FROM 10 TO 11	11	8.9881E-02	0.	0.	8.9881E-02	-2.9285E-02	
FROM 10 TO 12	12	0.	0.	0.	0.	0.	
FROM 10 TO 13	13	0.	0.	0.	0.	0.	
FROM 10 TO 14	14	0.	0.	0.	0.	0.	
FROM 10 TO 15	15	0.	0.	0.	0.	0.	
FROM 11 TO 11	11	2.3474E 00	0.	0.	2.3474E 00	5.4834E-02	
FROM 11 TO 12	12	8.0491E-02	0.	0.	8.0491E-02	-2.6196E-02	
FROM 11 TO 13	13	0.	0.	0.	0.	0.	
FROM 11 TO 14	14	0.	0.	0.	0.	0.	
FROM 11 TO 15	15	0.	0.	0.	0.	0.	
FROM 11 TO 16	16	0.	0.	0.	0.	0.	
FROM 12 TO 12	12	2.0181E 00	0.	0.	2.0181E 00	4.7532E-02	
FROM 12 TO 13	13	7.0764E-02	0.	0.	7.0764E-02	-2.2889E-02	
FROM 12 TO 14	14	0.	0.	0.	0.	0.	
FROM 12 TO 15	15	0.	0.	0.	0.	0.	
FROM 12 TO 16	16	0.	0.	0.	0.	0.	
FROM 13 TO 13	13	2.0146E 00	0.	0.	2.0146E 00	4.6703E-02	
FROM 13 TO 14	14	6.9214E-02	0.	0.	6.9214E-02	-2.2118E-02	
FROM 13 TO 15	15	0.	0.	0.	0.	0.	
FROM 13 TO 16	16	0.	0.	0.	0.	0.	
FROM 14 TO 14	14	2.0536E 00	0.	0.	2.0536E 00	4.7210E-02	
FROM 14 TO 15	15	7.0105E-02	0.	0.	7.0105E-02	-2.2155E-02	
FROM 14 TO 16	16	0.	0.	0.	0.	0.	
FROM 15 TO 15	15	2.0791E 00	0.	0.	2.0791E 00	4.7102E-02	
FROM 15 TO 16	16	7.2098E-02	0.	0.	7.2098E-02	-2.1779E-02	

FIGURE 6. (CONTINUED)

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

BROAD GROUP MICROSCOPIC CROSS SECTIONS FOR MATERIAL NUMBER 101 URANIUM-235
(AVERAGED FOR USE IN ANISOTROPIC TRANSPORT CODES)

GROUP	SIGMA-TOTAL	SIGMA-SCAT.	SIGMA-ABSOR.	SIGMA-FISSION	AVERAGE NU	NU-SIGMA FISSION	SIGMA-CAPT.
1	7.5861E 00	6.3753E 00	1.2108E 00	1.2641E 00	2.8212E 00	3.5863E 00	-5.3314E-02
2	7.1310E 00	5.7764E 00	1.3546E 00	1.2966E 00	2.6033E 00	3.3754E 00	5.8073E-02
3	6.4999E 00	5.1543E 00	1.3456E 00	1.2409E 00	2.5158E 00	3.1219E 00	1.0471E-01
4	7.2729E 00	5.8655E 00	1.4073E 00	1.2182E 00	2.4756E 00	3.0159E 00	1.8912E-01
5	9.5493E 00	7.7706E 00	1.7777E 00	1.4376E 00	2.4388E 00	3.5061E 00	3.4110E-01
6	1.3391E 01	1.0348E 01	3.0431E 00	2.3228E 00	2.4236E 00	5.6294E 00	7.2034E-01
7	1.3457E 01	1.2421E 01	6.0355E 00	4.3317E 00	2.4200E 00	1.0483E 01	1.7038E 00
8	7.8235E 01	1.5613E 01	1.2623E 01	9.1566E 00	2.4200E 00	2.2159E 01	3.4665E 00
9	4.1587E 01	1.2342E 01	2.9245E 01	2.0887E 01	2.4200E 00	5.0546E 01	8.3578E 00
10	7.2417E 01	1.1176E 01	6.1240E 01	3.6485E 01	2.4200E 00	8.8294E 01	2.4755E 01
11	7.8700E 01	1.0242E 01	6.8458E 01	3.7691E 01	2.4200E 00	9.1212E 01	3.0767E 01
12	4.7643E 01	1.2242E 01	3.541E 01	1.8880E 01	2.4200E 00	4.5690E 01	1.6521E 01
13	2.9961E 01	1.3487E 01	2.6474E 01	2.1047E 01	2.4200E 00	5.0934E 01	5.4269E 00
14	5.2075E 01	1.4000E 01	7.8075E 01	6.7910E 01	2.4200E 00	1.6434E 02	1.0166E 01
15	2.2184E 02	1.4000E 01	2.0764E 02	1.6560E 02	2.4200E 00	4.0075E 02	4.2244E 01
GROUP	SIGMA-DLT	SIGMA-REMOVAL	SIGMA-L				
1	1.4403E 00	3.0516E 00	4.48C5E 00				
2	1.4933E 00	2.8479E 00	5.21E2E 00				
3	1.2412E 00	2.5868E 00	5.6871E 00				
4	7.6023E-01	2.1676E 00	6.4626E 00				
5	1.1360E-01	1.8923E 00	8.73E9E 00				
6	2.5836E-02	3.0790E 00	1.3036E 01				
7	8.8092E-02	6.1236E 00	1.8457E 01				
8	5.4012E-02	1.2677E 01	2.8226E 01				
9	5.9235E-02	2.9304E 01	4.15E7E 01				
10	8.7738E-02	6.1328E 01	7.2437E 01				
11	9.0154E-02	6.8548E 01	7.87C0E 01				
12	1.0684E-01	3.5508E 01	4.7643E 01				
13	1.1235E-01	2.6586E 01	3.99E1E 01				
14	1.0893E-01	7.8184E 01	9.2075E 01				
15	1.0195E-01	2.0795E 02	2.2184E 02				

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

GROUP		ISOTROPIC SCATTERING CROSS SECTIONS			TOTAL	ANISOTROPIC ELASTIC
		ELASTIC	INELASTIC	N-2N		
FROM 1 TO 1	1	1.2481E 00	1.8078E-01	0.	1.4289E 00	8.9116E-01
FROM 1 TO 2	2	1.3260E-02	7.3324E-01	0.	7.4650E-01	-5.0764E-01
FROM 1 TO 3	3	0.	4.8581E-01	0.	4.8581E-01	0.
FROM 1 TO 4	4	0.	4.1356E-01	0.	4.1356E-01	0.
FROM 1 TO 5	5	0.	1.7453E-01	0.	1.7453E-01	0.
FROM 1 TO 6	6	0.	2.0359E-02	0.	2.0359E-02	0.
FROM 2 TO 2	2	2.0489E 00	3.2144E-01	0.	2.3703E 00	7.1686E-01
FROM 2 TO 3	3	2.5302E-02	5.3043E-01	0.	5.5573E-01	-2.0292E-01
FROM 2 TO 4	4	0.	5.9227E-01	0.	5.9227E-01	0.
FROM 2 TO 5	5	0.	3.0529E-01	0.	3.0529E-01	0.
FROM 2 TO 6	6	0.	3.9163E-02	0.	3.9163E-02	0.
FROM 2 TO 7	7	0.	7.9403E-04	0.	7.9403E-04	0.
FROM 3 TO 3	3	2.8343E 00	2.4596E-01	0.	3.0803E 00	8.1929E-01
FROM 3 TO 4	4	4.1155E-02	6.8857E-01	0.	7.2973E-01	-2.4594E-01
FROM 3 TO 5	5	0.	4.4519E-01	0.	4.4519E-01	0.
FROM 3 TO 6	6	0.	6.4844E-02	0.	6.4844E-02	0.
FROM 3 TO 7	7	0.	1.3603E-03	0.	1.3603E-03	0.
FROM 3 TO 8	8	0.	4.5968E-05	0.	4.5968E-05	0.
FROM 4 TO 4	4	3.8876E 00	4.0739E-01	0.	4.2950E 00	7.6008E-01
FROM 4 TO 5	5	3.4084E-02	6.1745E-01	0.	6.5153E-01	-1.3703E-01
FROM 4 TO 6	6	0.	1.0628E-01	0.	1.0628E-01	0.
FROM 4 TO 7	7	0.	2.3632E-03	0.	2.3632E-03	0.
FROM 4 TO 8	8	0.	1.0618E-04	0.	1.0618E-04	0.
FROM 4 TO 9	9	0.	0.	0.	0.	0.
FROM 5 TO 5	5	6.6534E 00	1.9123E-01	0.	6.8446E 00	3.6331E-01
FROM 5 TO 6	6	4.4747E-02	6.7106E-02	0.	1.1185E-01	-6.1069E-02
FROM 5 TO 7	7	0.	1.6589E-03	0.	1.6589E-03	0.
FROM 5 TO 8	8	0.	8.5608E-05	0.	8.5608E-05	0.
FROM 5 TO 9	9	0.	0.	0.	0.	0.
FROM 5 TO 10	10	0.	0.	0.	0.	0.
FROM 6 TO 6	6	9.9594E 00	0.	0.	9.9594E 00	2.4414E-01
FROM 6 TO 7	7	3.5836E-02	0.	0.	3.5836E-02	-1.1875E-02
FROM 6 TO 8	8	0.	0.	0.	0.	0.
FROM 6 TO 9	9	0.	0.	0.	0.	0.
FROM 6 TO 10	10	0.	0.	0.	0.	0.
FROM 6 TO 11	11	0.	0.	0.	0.	0.
FROM 7 TO 7	7	1.2333E 01	0.	0.	1.2333E 01	6.8246E-02
FROM 7 TO 8	8	8.8092E-02	0.	0.	8.8092E-02	-2.3387E-02
FROM 7 TO 9	9	0.	0.	0.	0.	0.
FROM 7 TO 10	10	0.	0.	0.	0.	0.
FROM 7 TO 11	11	0.	0.	0.	0.	0.
FROM 7 TO 12	12	0.	0.	0.	0.	0.

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

FROM 8 TO 8	1.5559E 01	0.	0.	1.5559E 01	5.9889E-02
FROM 8 TO 9	5.4012E-02	0.	0.	5.4012E-02	-1.5602E-02
FROM 8 TO 10	0.	0.	0.	0.	0.
FROM 8 TO 11	0.	0.	0.	0.	0.
FROM 8 TO 12	0.	0.	0.	0.	0.
FROM 8 TO 13	0.	0.	0.	0.	0.
FROM 9 TO 9	1.2283E 01	0.	0.	1.2283E 01	5.2216E-02
FROM 9 TO 10	5.9235E-02	0.	0.	5.9235E-02	-1.7192E-02
FROM 9 TO 11	0.	0.	0.	0.	0.
FROM 9 TO 12	0.	0.	0.	0.	0.
FROM 9 TO 13	0.	0.	0.	0.	0.
FROM 9 TO 14	0.	0.	0.	0.	0.
FROM 10 TO 10	1.1088E 01	0.	0.	1.1088E 01	5.7498E-02
FROM 10 TO 11	8.7738E-02	0.	0.	8.7738E-02	-2.5805E-02
FROM 10 TO 12	0.	0.	0.	0.	0.
FROM 10 TO 13	0.	0.	0.	0.	0.
FROM 10 TO 14	0.	0.	0.	0.	0.
FROM 10 TO 15	0.	0.	0.	0.	0.
FROM 11 TO 11	1.0151E 01	0.	0.	1.0151E 01	5.5531E-02
FROM 11 TO 12	9.0156E-02	0.	0.	9.0156E-02	-2.6487E-02
FROM 11 TO 13	0.	0.	0.	0.	0.
FROM 11 TO 14	0.	0.	0.	0.	0.
FROM 11 TO 15	0.	0.	0.	0.	0.
FROM 11 TO 16	0.	0.	0.	0.	0.
FROM 12 TO 12	1.2135E 01	0.	0.	1.2135E 01	6.5908E-02
FROM 12 TO 13	1.0684E-01	0.	0.	1.0684E-01	-3.1196E-02
FROM 12 TO 14	0.	0.	0.	0.	0.
FROM 12 TO 15	0.	0.	0.	0.	0.
FROM 12 TO 16	0.	0.	0.	0.	0.
FROM 13 TO 13	1.3375E 01	0.	0.	1.3375E 01	7.0646E-02
FROM 13 TO 14	1.1235E-01	0.	0.	1.1235E-01	-3.2409E-02
FROM 13 TO 15	0.	0.	0.	0.	0.
FROM 13 TO 16	0.	0.	0.	0.	0.
FROM 14 TO 14	1.3891E 01	0.	0.	1.3891E 01	7.0775E-02
FROM 14 TO 15	1.0893E-01	0.	0.	1.0893E-01	-3.1076E-02
FROM 14 TO 16	0.	0.	0.	0.	0.
FROM 15 TO 15	1.3898E 01	0.	0.	1.3898E 01	6.7499E-02
FROM 15 TO 16	1.0195E-01	0.	0.	1.0195E-01	-2.7799E-02

FIGURE 6. (CONTINUED)

112-65-770

PUNCHED CROSS SECTIONS FROM AN-GAM PROBLEM NO. 7.0001 FOR CODE TYPE 1						
9 0.	0E 4.31210	-3E 1.62093	-1E 5.87142	-2EG 0	1	ISOTROPIC MATRIX
9 0.	0E 0.	0E 0.	0E 0.	0EG 0	2	
9 0.	0E 0.	0E 4.01795	-3E 1.94808	-1EG 0	3	
9 6.61651	-2E 6.02732	-2E 0.	0E 0.	0EG 0	4	
9 0.	0E 0.	0E 0.	0E 3.64645	-3EG 0	5	
9 3.09055	-1E 9.72756	-2E 5.66636	-2E 1.69706	-2EG 0	6	
9 0.	0E 0.	0E 0.	0E 0.	0EG 0	7	
9 3.51718	-3E 4.11858	-1E 1.74596	-1E 1.29629	-1EG 0	8	
9 3.74442	-2E 1.35689	-2E 0.	0E 0.	0EG 0	9	
9 0.	0E 4.03789	-3E 5.33570	-1E 2.50994	-1EG 0	10	
.....						
9 4.14761	-1E 4.47802	-1E 1.54215	-1E 5.63171	-2EG 0	31	ANISOTROPIC MATRIX
9 2.06702	-2E 8.03061	-3E 0.	0E 4.67252	-1EG 0	32	
9 1.66461	0E 5.55491	-1E 4.58912	-1E 1.56338	-1EG 0	33	
9 5.67325	-2E 2.07180	-2E 1.20296	-2E 0.	0EG 0	34	
9 0.	0E 0.	0E 0.	0E 8.49494	-1EG 0	35	
9 2.53508	-1E 9.09850	-2E 3.30172	-2E 1.20574	-2EG 0	36	
9 0.	0E 0.	0E 0.	0E 1.24565	-2EG 0	1	
9 0.	0E 0.	0E 0.	0E 0.	0EG 0	2	
9 0.	0E 0.	0E 0.	0E 0.	0EG 0	3	
9 7.51554	-3E 2.22100	-2E 0.	0E 0.	0EG 0	4	
9 0.	0E 0.	0E 0.	0E 0.	0EG 0	5	
9 0.	0E -1.37223	-2E 2.98592	-2E 6.41163	-3EG 0	6	MATERIAL NUMBER ON AGN-GAM DATA TAPE, ZERO'S SHOW THE VALUES TO BE MACROSCOPIC CROSS SECTION
9 0.	0E 0.	0E 0.	0E 0.	0EG 0	7	
.....						
9 0.	0E 2.51296	-1E 2.74866	-1E 6.32200	-2EG 0	33	
9 1.39739	-2E 3.09424	-3E 8.74300	-4E 0.	0EG 0	34	
9 0.	0E 0.	0E 0.	0E 2.76857	-1EG 0	35	
9 5.94407	-2E 1.81324	-2E 3.99856	-3E 8.79675	-4EG 0	36	
PUNCHED CROSS SECTIONS FROM AN-GAM PROBLEM NO. 7.0001 FOR CODE TYPE 1						
9 0.	0E 0.	0E 2.88638	0E 1.31799	0EG 43	1	
9 0.	0E 0.	0E 0.	0E 0.	0EG 43	2	
9 0.	0E 0.	0E 0.	0E 3.07687	0EG 43	3	
9 1.95269	0E 7.47683	-1E 0.	0E 0.	0EG 43	4	
.....						
9 0.	0E 0.	0E 0.	0E 0.	0EG 43	36	
PUNCHED CROSS SECTIONS FROM AN-GAM PROBLEM NO. 7.0001 FOR CODE TYPE 1						
9 0.	0E 3.56633	0E 4.48046	0E 1.42890	0EG101	1	
9 0.	0E 0.	0E 0.	0E 0.	0EG101	2	
9 0.	0E 0.	0E 3.37541	0E 5.21822	0EG101	3	
9 2.37032	0E 7.46502	-1E 0.	0E 0.	0EG101	4	
.....						
9 0.	0E 0.	0E 0.	0E 0.	0EG101	36	

"G" INDICATES CARD SOURCE IS AGN-GAM CODE

FIGURE 7. PUNCHED CARD OUTPUT FROM SAMPLE PROBLEM

AGN TM-407

IV. OPERATION

The AGN-GAM code was written for the IBM-7090 or 7094 machine. The source program is in FORTRAN and MONITOR control is assumed. Since the program uses all but a few words of the 32K core storage, the binary program deck includes all program sub-routines. This prevents difficulties when changes are made in one of the minor control sub-routines.

Logical tape requirements for operation of the program are:

- Tape 5 - Erasable (TU B6)
- Tape 6 - AGN-GAM Data Tape (TU B7)
- Tape 7 - Erasable (TU B8)
- Tape 8 - Punched Card Output (TU B4)
- Tape 9 - Input (TU A2)
- Tape 10 - Printed Output (TU A3)

There are a number of error routines built into the code that produce printed off-line comments describing the error discovered. After the error has been stated, most routines skip to the next problem. However, one routine causes a machine pause when an incorrect data tape is placed on Tape Unit 6. On-line comments are printed describing the corrective action which should be taken.

One extra card must always accompany the data. This card is placed immediately after the data card and supplies the following information:

Col. 1-12 (E12.4) ID number of the AGN-GAM Data Tape which is to be used.

Col. 13-24 (E12.4) Material ID number of first material which contains the resonance parameters.

Co. 25-36 (E12.4) Material ID number of the last material which contained the resonance parameters. Every material between these two must be a resonance material.

The extra card is needed only once in the program deck and is followed by the AGN-GAM problems as specified in Section V. As many problems as desired may be stacked, one behind the other.

The operating times depend on the number of materials considered in each problem, the presence of resonance materials, and the output required. From one to one and one-half minutes are required for the sample problem (this length of time is typical).

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APPENDIX A
ENERGY DEPENDENT SPECTRUM GENERATION RELATIONS

In this appendix the relations for the energy dependent P_1 and B_1 approximations, as well as those for the second moment calculation, are developed. The description of the P_1 method is given in considerable detail and includes the effects of leakage from external regions. The B_1 routine and the second moment calculation are in the usual formulation and are only discussed briefly to preserve continuity.

I. THE VOLUME INTEGRATED P_1 EQUATIONS

A. SPECIFICATION OF THE PROBLEM

In the original version of the GAM (Ref. A-1) code, volume integrated P_1 relations were generated for a bare core with isotropic volume source. This method will be extended here to include regions of arbitrary P_1 source description, e.g., reflected cores and reflector regions.

In a complete system, the flux specification is solved by taking the inter-regional coupling into account with a multiregion analysis. If, for any arbitrary portion of the system, the inflow of neutrons through its surface as well as its volume source is assumed to be known, this particular portion can be considered as isolated and non-re-entrant; that is, as if surrounded by a pure black absorber. In such a region, the transport equation contains the inhomogeneous volume source term and also inhomogeneous boundary conditions which describe the inflow of neutrons. In the method that follows, the transport equation through the use of a delta function surface source, will incorporate these boundary conditions directly. The resultant equation

will then involve the homogeneous zero-inflow boundary condition.

The geometry of the isolated non-re-entrant region in question is shown in Figure A-1.

FIGURE A-1. ISOLATED NON-RE-ENTRANT REGION

The volume element is

$$dV = \vec{\Omega} \cdot \vec{n} dR dA = dZ' dA \quad \text{for } \vec{\Omega} \cdot \vec{n} > 0$$

Subscript e refers to conditions on the exterior of the surface while subscript i refers to conditions on the interior.

The transport equation in this region, including both volume and surface source components, is

$$\begin{aligned} \left[\vec{\Omega} \cdot \text{grad} + \Sigma_t(E, \vec{r}) \right] f(E, \vec{\Omega}, \vec{r}) &= \int dE' \int d\vec{\Omega}' \Sigma(E' \rightarrow E, \vec{\Omega}' \rightarrow \vec{\Omega}, \vec{r}) f(E', \vec{\Omega}', \vec{r}) + S_v(E, \vec{\Omega}, \vec{r}) \\ &+ S_s(E, \vec{\Omega}, \vec{r}_s) \delta(Z') \end{aligned} \quad (\text{A-1})$$

In the following discussion, the medium is assumed to be isotropic and homogeneous, i.e., scattering azimuthally symmetric with cross sections that are spatially independent.

B. THE SURFACE COMPONENT OF THE SOURCE

The surface source may be expressed in terms of assumed known flux conditions at the surface. To obtain the desired description, Equation (A-1) is integrated across an infinitely thin volume which includes the surface. Since $\vec{\Omega} \cdot \text{grad} = \partial/\partial R$, and with the volume integrals going to zero, the following expression is developed:

$$\int \frac{\partial}{\partial R} f(E, \vec{\Omega}, \vec{r}) dZ' = \int S_s(E, \vec{\Omega}, \vec{r}_s) \delta(Z') dZ'$$

when integrations over dZ' are performed:

$$\vec{\Omega} \cdot \vec{n} [f_i(E, \vec{\Omega}, \vec{r}_s) - f_e(E, \vec{\Omega}, \vec{r}_s)] = S_s(E, \vec{\Omega}, \vec{r}_s) \quad (\text{A-2})$$

The surface source thus introduces a discontinuity in the normal angular vector current at the surface.

For the specific case under consideration, the surface is a free boundary with no neutrons coming in from exterior sources and therefore, the following boundary conditions may be formulated.

$$\begin{aligned} f_e(E, \vec{\Omega}, \vec{r}_s) &= 0 \quad \text{for } \vec{\Omega} \cdot \vec{n} > 0 \\ f_i(E, \vec{\Omega}, \vec{r}_s) &= g(E, \vec{\Omega}, \vec{r}_s) \quad \text{for } \vec{\Omega} \cdot \vec{n} > 0 \\ f_i(E, \vec{\Omega}, \vec{r}_s) &= f_e(E, \vec{\Omega}, \vec{r}_s) \quad \text{for } \vec{\Omega} \cdot \vec{n} < 0 \end{aligned} \quad (\text{A-3})$$

The assumed known surface distribution is $g(E, \vec{\Omega}, \vec{r}_s)$. When these conditions are incorporated into Equation (A-2) the following equation evolves:

$$S_s(E, \vec{\Omega}, \vec{r}_s) = \vec{\Omega} \cdot \vec{n} H(\vec{\Omega} \cdot \vec{n}) g(E, \vec{\Omega}, \vec{r}_s) \quad (\text{A-4})$$

where $H(\vec{\Omega} \cdot \vec{n})$ is the Heaviside step function, which is defined as:

$$\left. \begin{aligned} H(\vec{\Omega} \cdot \vec{n}) &= 1 \quad \text{for } \vec{\Omega} \cdot \vec{n} > 0 \\ H(\vec{\Omega} \cdot \vec{n}) &= 0 \quad \text{for } \vec{\Omega} \cdot \vec{n} < 0 \end{aligned} \right\} \quad (\text{A-5})$$

C. THE SPATIALLY DEPENDENT P_1 EQUATIONS

The P_1 relations are obtained as shown in Chapter 9, Reference (A-2). First the transference function in Equation (A-1) is expanded in Legendre polynomials of the cosine of the L system scattering angle.

$$\Sigma(E' \rightarrow E, \vec{\Omega}' \rightarrow \vec{\Omega}) = \sum_{\ell=0}^{\infty} s_{\ell}(E' \rightarrow E) P_{\ell}(\mu_0)$$

where

$$s_{\ell}(E' \rightarrow E) = \frac{2\ell+1}{2} \int_{-1}^{+1} \Sigma(E' \rightarrow E, \vec{\Omega}' \rightarrow \vec{\Omega}) P_{\ell}(\mu_0) d\mu_0 \quad (A-6)$$

The resulting expression is multiplied by $P_{\ell m}^*(\vec{\Omega})$ (Ref. A-2) and integrated over $\vec{\Omega}$.

$$\begin{aligned} & \int P_{\ell m}^*(\vec{\Omega}) d\vec{\Omega} \left\{ \left[\vec{\Omega} \cdot \text{grad} + \Sigma_t(E) \right] f(E, \vec{\Omega}, \vec{r}) - S_v(E, \vec{\Omega}, \vec{r}) \right. \\ & \left. - \sum_{\ell=0}^{\infty} \int dE' s_{\ell}(E' \rightarrow E) \int d\Omega' P_{\ell}(\mu_0) f(E', \vec{\Omega}', \vec{r}) \right\} \\ & = \delta(Z') \vec{n} \cdot \int \vec{\Omega} H(\vec{\Omega} \cdot \vec{n}) g(E, \vec{\Omega}, \vec{r}) P_{\ell m}^*(\vec{\Omega}) d\Omega \end{aligned} \quad (A-7)$$

The angular flux is expanded in spherical harmonics:

$$f(E, \vec{\Omega}, \vec{r}) = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{+\ell} f_{\ell m}(E, \vec{r}) P_{\ell m}(\vec{\Omega})$$

where

$$f_{\ell m}(E, \vec{r}) = \frac{2\ell+1}{4\pi} \int f(E, \vec{\Omega}, \vec{r}) P_{\ell m}^*(\vec{\Omega}) d\Omega \quad (A-8)$$

A similar expansion is performed for the volume source term. Finally, using the addition theorem, the left hand side of Equation (A-7) reduces to the time independent form of Equation (9.6) of Reference A-2. The right hand side of Equation (A-7) is expanded as follows:

$$H(\vec{\Omega} \cdot \vec{n}) g(E, \vec{\Omega}, \vec{r}_s) = \sum_{\ell=0}^{\infty} g_{\ell m}(E, \vec{r}_s) P_{\ell m}(\vec{\Omega})$$

where

$$g_{\ell m}(E, \vec{r}_s) = \frac{2\ell+1}{4\pi} \int H(\vec{\Omega} \cdot \vec{n}) g(E, \vec{\Omega}, \vec{r}_s) P_{\ell m}^*(\vec{\Omega}) d\Omega \quad (A-9)$$

The expansion coefficients, $g_{\ell m}$, are made independent of $\vec{\Omega} \cdot \vec{n}$ by choosing $\vec{n}$ as the polar direction at each surface point. The right hand side of Equation (A-7) then becomes equal to

$$\begin{aligned} & \delta(Z') \vec{n} \cdot \int \vec{\Omega} H(\vec{\Omega} \cdot \vec{n}) g(E, \vec{\Omega}, \vec{r}_s) P_{\ell m}^*(\vec{\Omega}) d\Omega \\ &= \delta(Z') \sum_{\ell'=0}^{\infty} \sum_{m'=-\ell'}^{+\ell'} g_{\ell' m'}(E, \vec{r}_s) \vec{n} \cdot \int \vec{\Omega} P_{\ell' m'}(\vec{\Omega}) P_{\ell m}^*(\vec{\Omega}) d\Omega \end{aligned} \quad (A-10)$$

As could have been seen directly from Equation (A-7) and the subsequent reduction of its left hand side, $\vec{n} \cdot \int \vec{\Omega} P_{\ell' m'}(\vec{\Omega}) P_{\ell m}^*(\vec{\Omega}) d\Omega$ is equal to the integral involved in the reduction of the streaming term (Equation (9.6c), Ref. A-2) if the grad operator is replaced by $\vec{n}$, ($\partial/\partial x$ by n_x , etc.). Thus, the $P_{\ell m}$ equations of interest here are equal to Equation (9.6) of Ref. A-2 plus this additional term which accounts for the reduction of the surface source.

The $\ell=0, m=0$ equation is

$$\begin{aligned} & \left[-\frac{1}{3\sqrt{2}} \frac{\partial f_{11}}{\partial x} - \frac{i}{3\sqrt{2}} \frac{\partial f_{11}}{\partial y} + \frac{1}{3\sqrt{2}} \frac{\partial f_{1,-1}}{\partial x} - \frac{i}{3\sqrt{2}} \frac{\partial f_{1,-1}}{\partial y} + \frac{1}{3} \frac{\partial f_{10}}{\partial z} \right] \\ &= 4\pi \int f_{00} s_0(E' \rightarrow E) dE' - \sum_t f_{00} + S_{v_{00}} \end{aligned} \quad (A-11)$$

$$+ \delta(Z') \left[-\frac{1}{3\sqrt{2}} n_x g_{11} - \frac{i}{3\sqrt{2}} n_y g_{11} + \frac{1}{3\sqrt{2}} n_x g_{1,-1} - \frac{i}{3\sqrt{2}} n_y g_{1,-1} + \frac{1}{3} n_z g_{10} \right]$$

The $\ell=1, m=0$ relation is:

$$\frac{\partial f_{00}}{\partial z} = \frac{4\pi}{3} \int f_{10} s_1(E' \rightarrow E) dE' - \Sigma_t f_{10} + S_{v_{10}} + \delta(Z') n_z g_{00} \quad (A-12)$$

Equivalent relations exist for the other P_{1m} equations, (the $\ell=1, m=-1$ and $\ell=1, m=1$ expressions).

Using the relevant relations between the $f_{\ell m}$'s and the flux and current components (Equation (9.5) through (9.5b), Ref. A-2) in Equation (A-11) yields the P_0 relation.

$$\begin{aligned} \text{div } \vec{J}(E, \vec{r}) + \Sigma_t(E) \varphi(E, \vec{r}) &= \int dE' \Sigma^0(E' \rightarrow E) \varphi(E', \vec{r}) \\ &+ S_v(E, \vec{r}) + \delta(Z') \vec{n} \cdot \vec{J}^+(E, \vec{r}_s) \end{aligned} \quad (A-13)$$

Similarly for the P_{10} relation (Equation (A-12)):

$$\begin{aligned} \frac{\partial \varphi(E, \vec{r})}{\partial z} + 3\Sigma_t(E) J_z(E, \vec{r}) &= \int dE' \Sigma^1(E' \rightarrow E) J_z(E', \vec{r}) \\ &+ 3S_{v_z}(E, \vec{r}) + \delta(Z') n_z \varphi^+(E, \vec{r}_s) \end{aligned} \quad (A-14)$$

Combining Equation (A-14) with the other corresponding $P_{\ell m}$ equations yields the vector P_1 equation:

$$\begin{aligned} \text{grad} \varphi(E, \vec{r}) + 3\Sigma_t(E) \vec{J}(E, \vec{r}) &= \int dE' \Sigma^1(E' \rightarrow E) \vec{J}(E', \vec{r}) \\ &+ 3\vec{S}_v(E, \vec{r}) + \delta(Z') \vec{n} \varphi^+(E, \vec{r}_s) \end{aligned} \quad (A-15)$$

where:

$$\text{the neutron flux is } \varphi(E, \vec{r}) = \int d\Omega f(E, \vec{\Omega}, \vec{r}) \quad (A-16)$$

$$\text{the vector current is } \vec{J}(E, \vec{r}) = \int d\Omega \vec{\Omega} f(E, \vec{\Omega}, \vec{r})$$

φ^+ and $\vec{J}^+$ are defined with Equation (A-16) but with $H(\vec{\Omega} \cdot \vec{n}) g(E, \vec{\Omega}, \vec{r}_s)$ replacing the angular flux. S_v and $\vec{S}_v$ are also defined with Equation (A-16), but, the angular volume source replaces the angular flux term.

The ℓ^{th} mode transfer cross section is defined as:

$$\Sigma^{\ell}(E' \rightarrow E) = 4\pi s_{\ell}(E' \rightarrow E) \quad (\text{A-17})$$

D. THE VOLUME INTEGRATED P_1 EQUATIONS

To obtain the volume integrated P_0 equation, one integrates Equation (A-13) across the volume. (The volume integrations include the contribution across the surface as well as that through the volume.) The contribution from the surface source in the isolated region in question is

$$\begin{aligned} \int dV \vec{n} \cdot \vec{J}^+(E, \vec{r}_s) \delta(Z') &= \int dA \vec{n} \cdot \vec{J}^+(E, \vec{r}_s) \int \delta(Z') dZ' \\ &= \int dA \vec{n} \cdot \vec{J}^+(E, \vec{r}_s) \end{aligned} \quad (\text{A-18})$$

In the actual system, this is equal to the neutrons per second leaking in from other regions. Equation (A-13) then becomes the usual expression for the conservation of neutrons.

$$\begin{aligned} \int \text{div } \vec{J}(E, \vec{r}) dV + \Sigma_t(E) \int \varphi(E, \vec{r}) dV &= \int \Sigma^0(E' \rightarrow E) dE' \int \varphi(E', \vec{r}) dV \\ &+ \int S_v(E, \vec{r}) dV + \int \vec{J}^+(E, \vec{r}_s) \cdot \vec{n} dA \end{aligned} \quad (\text{A-19})$$

The equivalent volume integrated P_1 equation is obtained by integrating the divergence of Equation (A-15) across the volume. The following integral now emerges:

$$I = \int dV \text{div} \left[\vec{n} \varphi^+(E, \vec{r}_s) \delta(Z') \right]$$

Because the divergence term can be expressed as:

$$\begin{aligned} \text{div} \left[\vec{n} \varphi^+(E, \vec{r}_s) \delta(Z') \right] &= \vec{i}' \cdot \frac{\partial}{\partial X} (\vec{n} \varphi^+ \delta(Z')) + \vec{j}' \cdot \frac{\partial}{\partial Y} (\vec{n} \varphi^+ \delta(Z')) \\ &+ \vec{k}' \cdot \frac{\partial}{\partial Z} (\vec{n} \varphi^+ \delta(Z')) \end{aligned}$$

And, $\vec{i}' \cdot \vec{n} = \vec{j}' \cdot \vec{n} = 0$ and $\vec{k}' \cdot \vec{n} = 1$. The integral becomes

$$I = \int dV \frac{d}{dZ'} \left[\delta(Z') \varphi^+(E, \vec{r}_s) \right]$$

and since φ^+ is independent of Z'

$$I = \int dA \varphi^+(E, \vec{r}_s) \int \frac{d}{dZ'} \delta(Z') dZ'$$

and performing the Z' integration yields

$$I=0.$$

The volume integrated P_1 equation is then:

$$\begin{aligned} \int \text{div grad} \varphi(E, \vec{r}) dV + 3 \Sigma_t(E) \int \text{div} \vec{J}(E, \vec{r}) dV &= 3 \int \text{div} \vec{S}_v(E, \vec{r}) dV \\ &+ \int dE' \Sigma^1(E' \rightarrow E) \int \text{div} \vec{J}(E, \vec{r}) dV \end{aligned} \quad (\text{A-20})$$

Since the volume integrals include going across the region boundary, the use of the divergence theorem will pertain to conditions on the exterior surface of the region. And, since there was no inflow of neutrons from exterior regions in this isolated system, the current term becomes

$$\int \text{div} \vec{J}(E, \vec{r}) dV = - \int \vec{J}_e(E, \vec{r}_s) \cdot \vec{n} dA \quad (\text{A-21})$$

which is the leakage out of the region and is always positive. Similarly for the grad φ term

$$\int \text{div grad} \varphi(E, \vec{r}) dV = - \int \text{grad} \varphi_e(E, \vec{r}_s) \cdot \vec{n} dA \quad (\text{A-22})$$

This is the normal gradient at the surface of the outward directed component of the flux and this component is continuous across the boundary.

To further simplify the volume integrated expressions, we assume only an isotropic volume source and the following definitions will be made.

$$\left. \begin{aligned}
 \tilde{J}(E) &= \int \text{div } \vec{J}(E, \vec{r}) dV \\
 \varphi(E) &= \int \varphi(E, \vec{r}) dV \\
 S_v(E) &= \int S_v(E, \vec{r}) dV \\
 S_s(E) &= \int \vec{J}^+(E, \vec{r}_s) \cdot \vec{n} dA \\
 \mathcal{L}(E) &= \frac{\int \text{div grad} \varphi(E, \vec{r}) dV}{\int \varphi(E, \vec{r}) dV}
 \end{aligned} \right\} \quad (A-23)$$

The P_0 expression, Equation (A-19), becomes

$$\begin{aligned}
 \tilde{J}(E) + \Sigma_t(E)\varphi(E) &= \int \Sigma^0(E' \rightarrow E) \varphi(E') dE' \\
 &+ S_v(E) + S_s(E)
 \end{aligned} \quad (A-24)$$

Similarly for the P_1 expression, Equation (A-20)

$$\mathcal{L}(E)\varphi(E) + 3\Sigma_t(E)\tilde{J}(E) = \int dE' \Sigma^1(E' \rightarrow E) \tilde{J}(E') \quad (A-25)$$

These two relations may be solved for $\tilde{J}(E)$ and $\varphi(E)$ with the known data being the cross sections, sources and $\mathcal{L}(E)$.

E. THE TRANSPORT CROSS SECTION AND DIFFUSION COEFFICIENT

The transport cross section (an extensive parameter) is defined by Fick's law as

$$\vec{J}(E, \vec{r}) = \frac{1}{3\Sigma_{tr}(E)} \text{grad } \varphi(E, \vec{r}) \quad (A-26)$$

The diffusion coefficient is defined as

$$D(E) = \frac{1}{3\Sigma_{tr}(E)} \quad (A-27)$$

If the divergence of Equation (A-26) is integrated over the volume, the following expression emerges:

$$\Sigma_{tr}(E) = - \frac{\mathcal{L}(E)\varphi(E)}{3\tilde{J}(E)} \quad (A-28)$$

Substituting for $\mathcal{L}(E)\varphi(E)$ from Equation (A-25),

$$\Sigma_{tr}(E) = \Sigma_t(E) - \frac{\int dE' \Sigma^1(E' \rightarrow E) \tilde{J}(E')}{3\tilde{J}(E)} \quad (A-29)$$

Because this last relation is linear in the cross sections, it can also be used for the corresponding microscopic quantities.

II. THE B_1 APPROXIMATION

A. THE B_ℓ EQUATIONS

The derivation of the B_ℓ equations is based on the transport relation, Equation (A-1). In addition, the process considers only an isotropic volume source and a one-dimensional azimuthally-symmetric slab geometry with cross sections independent of position. When the transference function is expanded in Legendre polynomials as in Equation (A-6) and when integration is performed over the azimuthal angle, the pertinent slab equation emerges when the addition theorem for the Legendre polynomials is used.

$$\left[\mu \frac{\partial}{\partial z} + \Sigma_t(E) \right] f(E, \mu, z) = \sum_{\ell=0}^{\infty} 2\pi \int dE' s_\ell(E' \rightarrow E) P_\ell(\mu) \int_{-1}^{+1} d\mu' P_\ell(\mu') f(E', \mu', z) + \frac{S(E, z)}{4\pi} \quad (\text{A-30})$$

The Fourier transform of Equation (A-30) is taken, which involves multiplying by e^{ikz} and integrating over dz from $-\infty$ to $+\infty$. If the Fourier transform of the wave equation, $\nabla^2 \varphi + B^2 \varphi = 0$ is also taken, it is seen that the transform variable k is equal to B , the square root of the buckling of the system. Equation (A-30) becomes,

$$\Sigma_t(E) \left[1 - \eta_\mu \right] f(E, \mu, B) = \sum_{\ell=0}^{\infty} 2\pi \int dE' s_\ell(E' \rightarrow E) P_\ell(\mu) \int_{-1}^{+1} d\mu' P_\ell(\mu') f(E', \mu', B) + \frac{S(E, B)}{4\pi} \quad (\text{A-31})$$

where

$$\eta \equiv \eta(E, B) = \frac{iB}{\Sigma_t(E)} \quad (A-32)$$

The angular flux is expanded in Legendre polynomials to:

$$f(E, \mu, B) = \sum_{\ell=0}^{\infty} f_{\ell}(E, B) P_{\ell}(\mu) \quad (A-33)$$

with

$$f_{\ell}(E, B) = \frac{2\ell+1}{2} \int_{-1}^{+1} d\mu P_{\ell}(\mu) f(E, \mu, B)$$

When the above expansions are made in Equation (A-31), and the resulting equation is divided by $[1-\eta\mu]$, multiplied by $P_j(\mu)$ and integrated over $d\mu$, the B_{ℓ} equations are obtained:

$$\begin{aligned} \frac{1}{2j+1} \Sigma_t(E) f_j(E, B) &= \sum_{\ell=0}^{\infty} \frac{4\pi}{2\ell+1} A_{j\ell} \int dE' s_{\ell}(E'-E) f_{\ell}(E', B) \\ &+ \frac{1}{4\pi} A_{j0} S(E, B) \end{aligned} \quad (A-34)$$

where:

the symmetric functions, $A_{j\ell}$, are

$$\begin{aligned} A_{j\ell} \equiv A_{j\ell}(E, B) &= \frac{1}{2} \int_{-1}^{+1} \frac{d\mu P_{\ell}(\mu) P_j(\mu)}{1 - \eta\mu} \\ &= \frac{1}{\eta} Q_j\left(\frac{1}{\eta}\right) P_{\ell}\left(\frac{1}{\eta}\right) \text{ with } \ell \leq j \end{aligned} \quad (A-35)$$

The Q_j 's are the Legendre polynomials of the second kind. A few of the symmetric functions ($A_{j\ell}$'s) are:

$$\begin{aligned}
A_{00} &= \frac{\tan^{-1} X}{X} \\
A_{01} &= A_{10} = \frac{i(1-A_{00})}{X} \\
A_{11} &= -\frac{i A_{01}}{X} = \frac{(1-A_{00})}{X^2}
\end{aligned} \tag{A-36}$$

where

$$X \equiv X(E, B) = \frac{\eta(E, B)}{i} = \frac{B}{\Sigma_t(E)} \tag{A-37}$$

B. THE B_1 EQUATIONS

The B_L approximation is obtained by setting the sum over L equal to zero for $\ell > L$. In the case $L = 1$, one obtains the following two equations:

$$\begin{aligned}
\Sigma_t(E) f_0(E, B) &= \frac{A_{00}}{4\pi} S(E, B) + 4\pi A_{00} \int dE' s_0(E' \rightarrow E) f_0(E', B) \\
&+ \frac{4\pi}{3} A_{01} \int dE' s_1(E' \rightarrow E) f_1(E', B)
\end{aligned} \tag{A-38}$$

$$\begin{aligned}
\frac{1}{3} \Sigma_t(E) f_1(E, B) &= \frac{A_{10}}{4\pi} S(E, B) + 4\pi A_{10} \int dE' s_0(E' \rightarrow E) f_0(E', B) \\
&+ \frac{4\pi}{3} A_{11} \int dE' s_1(E' \rightarrow E) f_1(E', B)
\end{aligned} \tag{A-39}$$

To obtain the B_1 equations, Equation (A-36) is used to specify the $A_{j\ell}$'s all in terms of A_{00} ; the transfer cross sections are defined with Equation (A-17), i $J = \frac{4\pi}{3} f_1$, $\varphi = 4\pi f_0$. (A-40)

The B_1 relations are:

$$\begin{aligned}
\Sigma_t(E) \varphi(E, B) &= A_{00} S(E, B) + A_{00} \int dE' \Sigma^0(E' \rightarrow E) \varphi(E', B) \\
&- \frac{(1-A_{00})}{X} \int dE' \Sigma^1(E' \rightarrow E) J(E', B)
\end{aligned} \tag{A-41}$$

$$\begin{aligned}\Sigma_t(E)J(E,B) &= \frac{(1-A_{00})S(E,B)}{X} + \frac{(1-A_{00})}{X} \int dE' \Sigma^0(E' \rightarrow E) \varphi(E', B) \\ &+ \frac{(1-A_{00})}{X^2} \int dE' \Sigma^1(E' \rightarrow E) J(E', B)\end{aligned}\quad (A-42)$$

Multiplying Equation (A-42) by X and adding to Equation (A-41) yields the B_0 expression.

$$BJ(E,B) + \Sigma_t(E)\varphi(E,B) = \int dE' \Sigma^0(E' \rightarrow E) \varphi(E', B) + S(E,B) \quad (A-43)$$

Multiplying Equation (A-43) by $-\frac{(1-A_{00})}{X}$ and adding to Equation (A-42) yields the B_1 expression.

$$-B\varphi(E,B) + 3\Sigma_t(E)\alpha(E,B)J(E,B) = \int dE' \Sigma^1(E' \rightarrow E) J(E', B) \quad (A-44)$$

where

$$\alpha(E,B) = \frac{X^2 A_{00}}{3(1-A_{00})} \quad (A-45)$$

Equations (A-43) and (A-44) are the usual form of the B_1 equations.

C. THE TRANSPORT CROSS SECTION

The transport cross section is defined by Fick's law, Equation (A-26) which will be written here as

$$f_1(E, z) = -\frac{1}{\Sigma_{tr}(E)} \frac{\partial}{\partial z} f_0(E, z) \quad (A-46)$$

Taking the Fourier transform of this equation yields

$$f_1(E, B) = \frac{1B}{\Sigma_{tr}(E)} f_0(E, B) \quad (A-47)$$

Using Equation (A-40), and solving for $\Sigma_{tr}(E)$

$$\Sigma_{tr}(E) = \frac{B\varphi(E, B)}{3J(E, B)} \quad (A-48)$$

Substituting for B_p from Equation (A-44)

$$\Sigma_{tr}(E) = \alpha(E, B) \Sigma_t(E) - \frac{\int dE' \Sigma^1(E' \rightarrow E) J(E', B)}{3J(E, B)} \quad (A-49)$$

The diffusion coefficient is again defined by Equation (A-27).

If α is treated as an extensive quantity of the medium, Equation (A-49) is linear in the cross sections and a microscopic transport cross section for a given material can be defined as:

$$\sigma_{tr}(E) = \alpha(E, B) \sigma_t(E) - \frac{\int dE' \sigma^1(E' \rightarrow E) J(E', B)}{3J(E, B)} \quad (A-50)$$

III. THE SECOND MOMENT CALCULATION

A. THE $M_{n\ell}$ EQUATIONS

The development of the moment relations, is based on Equation (A-30) with an isotropic plane source at the origin in an infinite medium.

$$\left[\mu \frac{\partial}{\partial z} + \Sigma_t(E) \right] f(E, \mu, z) = \int_{j=0}^{\infty} 2\pi \int dE' s_j(E' \rightarrow E) P_j(\mu) \int_{-1}^{+1} d\mu' P_j(\mu') f(E', \mu', z) + S(E) \delta(z) \quad (A-51)$$

Using Equation (A-33), the angular flux is expanded in Legendre polynomials, the resulting equation is multiplied by $P_\ell(\mu)$ and integrated over $d\mu$. The P_ℓ relations that result are:

$$\begin{aligned} \frac{\ell+1}{2\ell+3} \frac{\partial}{\partial z} f_{\ell+1}(E, z) + \frac{\ell}{2\ell-1} \frac{\partial}{\partial z} f_{\ell-1}(E, z) + \Sigma_t(E) f_\ell(E, z) \\ = \frac{4\pi}{2\ell+1} \int dE' s_\ell(E' \rightarrow E) f_\ell(E', z) + S(E) \delta_{\ell 0} \delta(z) \end{aligned} \quad (A-52)$$

The plane moments are defined as:

$$M_{n\ell}(E) = \frac{1}{n!} \int z^n f_\ell(E, z) dz \quad \text{where } n \geq 0 \quad (A-53)$$

Equation (A-52) is multiplied by $z^n/n!$ and integrated over all space, to obtain the $M_{n\ell}$ relations

$$\begin{aligned} \Sigma_t(E)M_{n\ell}(E) &= \frac{1}{2\ell+1} \int dE' \Sigma^\ell(E' \rightarrow E) M_{n\ell}(E') + \delta_{\ell 0} \delta_{n 0} S(E) \\ &+ \frac{\ell+1}{2\ell+3} M_{n-1, \ell+1} + \frac{\ell}{2\ell-1} M_{n-1, \ell-1} \end{aligned} \quad (A-54)$$

In the $M_{n\ell}$ relations, the terms involving spatial derivatives were integrated by parts with the contribution at $\pm \infty$ vanishing due to the assumption that f_ℓ vanishes, at least exponentially, at $\pm \infty$. The definitions of the transfer cross sections were again obtained from Equation (A-17).

B. THE RELATIONS FOR THE SECOND MOMENT

The only relation that gives a nontrivial solution for $n = 0$ is the inhomogeneous equation for M_{00}

$$\Sigma_t(E)M_{00}(E) = \int dE' \Sigma^0(E' \rightarrow E) M_{00}(E') + S(E) \quad (A-55)$$

For $n = 1$, the only nontrivial relation is for M_{11}

$$\Sigma_t(E)M_{11}(E) = \frac{1}{3} \int dE' \Sigma^1(E' \rightarrow E) M_{11}(E') + M_{00}(E) \quad (A-56)$$

For $n = 2$, the only nontrivial relations are those for M_{20} and M_{22} .

For M_{20} :

$$\Sigma_t(E)M_{20}(E) = \int dE' \Sigma^0(E' \rightarrow E) M_{20}(E') + \frac{1}{3} M_{11}(E) \quad (A-57)$$

The relation for M_{22} is of no immediate interest since the so-called second moment, or age, in this geometry is

$$\tau(E) = \frac{\int_{-\infty}^{+\infty} z^2 f_0(E, z) dz}{2 \int_{-\infty}^{+\infty} f_0(E, z) dz} = \frac{M_{20}(E)}{M_{00}(E)} \quad (A-58)$$

We can further conclude that since the flux components are even spatial functions for ℓ even and odd spatial functions for ℓ odd, $M_{n\ell}$ is zero unless $n + \ell$ is even. In addition, the condition $\ell \leq n$ must exist to obtain the pertinent nontrivial solutions.

IV. SIMPLE APPROXIMATIONS TO THE P₁ LEAKAGE TERM, $\mathcal{L}(E)$ A. $\mathcal{L}(E)$ IN THE DIFFUSION APPROXIMATION

$\mathcal{L}(E)$ is defined by Equation (A-23) as:

$$\mathcal{L}(E) = \frac{\int \text{div grad}\varphi(E, \vec{r}) dV}{\int \varphi(E, \vec{r}) dV} \quad (\text{A-59})$$

Using the divergence theorem on the numerator (Equation (A-22)) yields:

$$\mathcal{L}(E) = - \frac{\int \vec{n} \cdot \text{grad}\varphi_e(E, \vec{r}_s) dA}{\int \varphi(E, \vec{r}) dV} \quad (\text{A-60})$$

Fick's law may be written as:

$$\vec{J}_e(E, \vec{r}_s) = - \frac{1}{3\Sigma_{tr}(E)} \text{grad}\varphi_e(E, \vec{r}_s) \quad (\text{A-61})$$

Using this result in Equation (A-60) gives:

$$\mathcal{L}(E) = 3\Sigma_{tr}(E) \frac{\int \vec{n} \cdot \vec{J}_e(E, \vec{r}_s) dA}{\int \varphi(E, \vec{r}) dV} \quad (\text{A-62})$$

This provides an expression for $\mathcal{L}(E)$ in terms of the leakage out of the region. Since $\vec{n} \cdot \vec{J}_e < 0$ always, the important result is that in the diffusion approximation, $\mathcal{L}(E) \leq 0$ always.

Returning to Equation (A-59), the divergence theorem can be used to express $\mathcal{L}(E)$ as follows:

$$\mathcal{L}(E) = \frac{\int \nabla^2 \varphi(E, \vec{r}) dV}{\int \varphi(E, \vec{r}) dV} + \frac{\int \vec{n} \cdot \text{grad} \varphi_i(E, \vec{r}_s) dA - \int \vec{n} \cdot \text{grad} \varphi_e(E, \vec{r}_s) dA}{\int \varphi(E, \vec{r}) dV} \quad (\text{A-63})$$

The integral in the numerator of the first term is the usual volume integral up to the surface.

Fick's law can be used on the numerator of the second term,

$$\begin{aligned} & \int \vec{n} \cdot \text{grad} \varphi_i(E, \vec{r}_s) dA - \int \vec{n} \cdot \text{grad} \varphi_e(E, \vec{r}_s) dA \\ &= -3\Sigma_{tr}(E) \int \vec{n} \cdot \vec{J}_i(E, \vec{r}_s) dA + 3\Sigma_{tr}(E) \int \vec{n} \cdot \vec{J}_e(E, \vec{r}_s) dA \end{aligned} \quad (\text{A-64})$$

However, with the assistance of the boundary conditions indicated by Equation (A-3)

$$\vec{n} \cdot \vec{J}_i(E, \vec{r}_s) - \vec{n} \cdot \vec{J}_e(E, \vec{r}_s) = \vec{n} \cdot \vec{J}^+(E, \vec{r}_s) \quad (\text{A-65})$$

Here, $\vec{n} \cdot \vec{J}^+$ is the direct contribution from the surface source (see comments after Equation (A-16)). Combining these last two expressions with Equation (A-63) gives

$$\mathcal{L}(E) = \frac{\int \nabla^2 \varphi(E, \vec{r}) dV}{\int \varphi(E, \vec{r}) dV} - 3\Sigma_{tr}(E) \frac{\int \vec{n} \cdot \vec{J}^+(E, \vec{r}_s) dA}{\int \varphi(E, \vec{r}) dV} \quad (\text{A-66})$$

The integral ratio in the first term is either positive or negative while the one in the second term is inherently positive.

B. MONOENERGETIC DIFFUSION VALUES OF $\mathcal{L}$

In the monoenergetic diffusion model, one assumes that the spatial flux dependence satisfies the wave equation. In the core, this gives:

$$\nabla^2 \varphi(\vec{r}) + B^2 \varphi(\vec{r}) = 0 \quad (\text{A-67})$$

A similar equation applies in the reflector,

$$\nabla^2 \varphi(\vec{r}) - \kappa^2 \varphi(\vec{r}) = 0 \quad (\text{A-68})$$

It would be expected that a first approximation to $\mathcal{L}$ in a core region would be equal to $-B^2$ (by neglecting the second term in Equation (A-66)). Such an approach would lead to trouble in a reflector region; taking $\mathcal{L} = +\kappa^2$ is a serious error, because Equation (A-62) states that $\mathcal{L} < 0$ always. Better values are obtained by using the solutions of Equation (A-67) or Equation (A-68) in the equation for $\mathcal{L}$ and performing the necessary integrations.

1. One Dimensional Cores

The fluxes (symmetrical solutions) and $\mathcal{L}$ values for one dimensional cores are tabulated below.

<u>Geometry</u>	<u>$\varphi(r)$</u>	<u>$\mathcal{L}$</u>	
Slab	$A \cos Bx$	$-\frac{B^2}{2} \left[1 + \left(\frac{1}{2BD} \right) \cot(BR) \right]$	
Cylinder	$A J_0(Br)$	$-\frac{B^2}{2} \left[\frac{\left(\frac{1}{2BD} \right) J_0(BR) + J_1(BR)}{J_1(BR)} \right]$	(A-69)
Sphere	$\frac{A \sin Br}{r}$	$-\frac{B^2}{2} \left[\frac{\left(\frac{R+2D}{2D} \right) \sin BR - BR \cos BR}{\sin BR - BR \cos BR} \right]$	

where:

R is the core half thickness or radius

D is the diffusion coefficient.

2. One Dimensional Reflectors

The case under consideration is a core surrounded by a single reflector of thickness, T. The flux is assumed to go to zero at an extrapolation distance, d, outside the reflector.

For a slab reflector, the solution to Equation (A-68) is:

$$\varphi(x) = C \sinh \kappa (R+T+d-x) \quad (\text{A-70})$$

and

$$\mathcal{L} = -\kappa^2 \left[\frac{1}{2D} \frac{\left(\frac{1}{2\kappa} \right) \sinh \kappa(T+d) + D \cosh \kappa(T+d)}{\cosh \kappa(T+d) - \cosh \kappa d} \right] \quad (\text{A-71})$$

This is the only geometry for which $\mathcal{L}$ is not a function of R.

The case of usual reflector interest is that in which the absorption is zero. The flux in the reflector then satisfies Laplace's equation. The flux (solutions going to zero at the extrapolated boundary) and β values under these conditions are tabulated below.

<u>Geometry</u>	$\varphi(\vec{r})$	$\beta(\Sigma_a = 0)$	
Slab	$C \left(\frac{R+T+d-X}{R+T+d} \right)$	$-\frac{1}{2DT} \frac{(T+d+2D)}{(T+2d)}$	(A-72)
Cylinder	$C \left(1 - \frac{\ln r}{\ln(R+T+d)} \right)$	$-\frac{R}{D} \left[\frac{\frac{1}{2} \ln \frac{R+T+d}{R} + \frac{D}{R}}{T(T+2R) \left(\ln \left(\frac{R+T+d}{R+T} \right) + \frac{1}{2} \right) - R^2 \ln \left(\frac{R+T}{R} \right)} \right]$	
Sphere	$C \left(\frac{R+T+d}{r} - 1 \right)$	$-\frac{3}{2DT} \frac{R(T+d) + 2D(R+T+d)}{T(T+3R+3d) + 6Rd}$	

REFERENCES - APPENDIX A

- A-1 GAM-1, A Consistent Multigroup Code for the Calculation of Fast Neutron Spectra and Multigroup Constants, General Atomic Report GA-1850, June 1961, G.D. Joanou and J. S. Dudek
- A-2 Weinberg, A. M. and E. P. Wigner, The Physical Theory of Neutron Chain Reactors, University of Chicago Press, 1958

APPENDIX B

SCATTERING MATRIX DEVELOPMENT

In this appendix, expressions for the multigroup transfer matrices are developed. First, the multigroup formulation is obtained to get the expression for the transfer cross section. The kernel for inelastic scattering to a specific level and the domain of integration of the transfer cross section are established. Next, inelastic scattering in the statistical approximation and a simple recipe for the $n, 2n$ reaction are stated. Finally, the pertinent information for elastic scattering is shown to be just a special case of the more general inelastic results and the domain is relatively simple so that the integrals may be explicitly expressed.

I. THE MULTIGROUP EQUATION

The quantity of immediate interest in the multigroup relations is the definition of the group transfer cross sections. Therefore, the form of the Boltzmann equation is investigated in which the transference function has been expanded in Legendre polynomials, but, where the treatment of the angular flux has been left arbitrary. (Except in the collision integral, where it has been expanded in spherical harmonics.)

The process is started with Equation (A-1) for the case of a volume source only, and the transference function is expanded in Legendre polynomials of the L system scattering angle with Equation (A-6). After using the addition theorem for the spherical harmonics to express $P_\ell(\mu_0)$ in terms of $\vec{\Omega}$ and $\vec{\Omega}'$, the integral over $d\Omega'$ is expressed in terms of the angular flux expansion (see Equation (A-8)) and the desired equation is obtained:

$$\begin{aligned} \left[\vec{\Omega} \cdot \text{grad}_{\mathbf{x}} + \Sigma_t(E) \right] f(E, \vec{\Omega}, \vec{r}) = \sum_{\ell=0}^{\infty} \frac{1}{(2\ell+1)} \int dE' \Sigma^{\ell}(E' \rightarrow E) \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}(E', \vec{r}) \\ + S(E, \vec{\Omega}, \vec{r}) \end{aligned} \quad (\text{B-1})$$

The transfer cross section, $\Sigma^{\ell}(E' \rightarrow E)$, is defined in terms of the coefficients $s_{\ell}(E' \rightarrow E)$ by Equation (A-17) of Appendix A and is given explicitly by

$$\Sigma^{\ell}(E' \rightarrow E) = 4\pi \left(\frac{2\ell+1}{2} \right) \int_{-1}^{+1} \Sigma(E' \rightarrow E, \vec{\Omega}' \rightarrow \vec{\Omega}) P_{\ell}(\mu_0) d\mu_0 \quad (\text{B-2})$$

The multigroup version of Equation (B-1) is obtained by multiplying by dE and integrating over g^{th} group.

$$\begin{aligned} \left[\vec{\Omega} \cdot \text{grad}_{\mathbf{x}} + \Sigma_t \right]_{\mathbf{g}} f_{\mathbf{g}}(\vec{\Omega}, \vec{r}) = \sum_{\ell=0}^{\infty} \sum_{\mathbf{g}' \leq \mathbf{g}} \frac{1}{(2\ell+1)} \Sigma_{\mathbf{g}' \rightarrow \mathbf{g}}^{\ell} \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}_{\mathbf{g}'} \\ + S_{\mathbf{g}}(\vec{\Omega}, \vec{r}) \end{aligned} \quad (\text{B-3})$$

When it is assumed that the intragroup spectrum is independent of direction, the group total cross section can be defined by the mean value theorem. In addition, the integral over dE' was replaced by a sum of integrals over the g^{th} group. The concept of a transfer cross section dependent on ℓ only has also been applied to the multigroup equations. This is done by using the mean value theorem on the various m modes and then arithmetically averaging over all m . The resultant transfer cross section is:

$$\Sigma_{\mathbf{g}' \rightarrow \mathbf{g}}^{\ell} = \frac{\int dE' \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}(E', \vec{r}) \int dE' \Sigma^{\ell}(E' \rightarrow E)}{\int dE' \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}(E', \vec{r})} \quad (\text{B-4})$$

where, in effect, suitable spatial flux averages are employed over the region of interest.

Equation (B-4) as it stands is a function of $\bar{\Omega}$. To remove this dependence it is assumed that over the g' th group, the spectral shapes are the same for all m ; that is, that $f_{\ell m}(E') = a_{\ell m} f_{\ell}(E')$ where $a_{\ell m}$ is not a function of energy. The directional dependence then cancels out and the usual form of the multigroup transfer cross section is obtained

$$\Sigma_{g' \rightarrow g}^{\ell} = \frac{\int_{g'} dE' f_{\ell}(E') \int_g dE \Sigma^{\ell}(E' \rightarrow E)}{\int_{g'} dE' f_{\ell}(E')} \quad (B-5)$$

The cross section $\Sigma_{g' \rightarrow g}^{\ell}$ is the one on the library tape and is used in the spectrum generating routines of this code. However, the cross section that is actually used in multigroup neutronic analysis, is the one defined by

$$\Sigma_{g' \rightarrow g}^{\ell} = \frac{1}{(2\ell+1)} \Sigma_{g' \rightarrow g}^{\ell} \quad (B-6)$$

It is this cross section that is the output of the spectral averaging routine.

II. INELASTIC SCATTERING

A. ENERGETICS OF THE REACTION

The expressions for the scattering kernel are developed for arbitrary Q values. This includes inelastic scattering to a specific level, when $Q = -W$ and where W is the level excitation energy and also elastic scattering, when $Q = 0$.

The Q equation, is obtained by conservation of energy and momentum in the L system; for the case of inelastic scattering (Ref. B-1):

$$E^{\frac{1}{2}} = \frac{E'^{\frac{1}{2}}}{(A+1)} \mu_0 \pm \left[\frac{E'}{(A+1)^2} \mu_0^2 + \frac{A}{(A+1)} Q + \left(\frac{A-1}{A+1} \right) E' \right]^{\frac{1}{2}} \quad (B-7)$$

The reaction becomes possible when the term inside the brackets is zero. The lowest possible incident neutron energy, E'_{th} , occurs at $\theta = 0^\circ$ and is

$$E'_{th} = - \left(\frac{A+1}{A} \right) Q \quad (B-8)$$

As the incident neutron energy is increased, other scattering angles become possible. According to Equation (B-7), two values of E are possible at each angle and given incident energy. When particles appear at 90° , the required incident energy is

$$E'_{90^\circ} = - \left(\frac{A}{A-1} \right) Q \quad (B-9)$$

At E'_{90° , the final neutron energy is zero. Above this incident energy, only the $+$ sign is possible in Equation (B-7) and the final neutron energy is, thus, single valued for all scattering angles.

The Q equation is rewritten in terms of the cosine of the scattering angle in the L system, μ_0 ,

$$\mu_0(E', E) = \frac{(A+1)}{2} \left(\frac{E}{E'} \right)^{\frac{1}{2}} - \frac{(A-1)}{2} \left(\frac{E'}{E} \right)^{\frac{1}{2}} - \frac{A}{2 \left(\frac{E'}{E} \right)^{\frac{1}{2}}} Q \quad (B-10)$$

A similar relation may be obtained for the cosine of the scattering angle in the CM system, η_0 , by using the appropriate conservation relations and then converting back to the L system.

$$\eta_0(E', E) = \frac{\gamma}{2} \left[(A+1)^2 \frac{E}{E'} - \left(1 + \frac{1}{\gamma^2} \right) \right] \quad (B-11)$$

where:

γ is the ratio of the velocity of the CM in the L system to that of the emergent neutron in the CM system:

$$\gamma = \frac{1}{A} \left[1 + \frac{(A+1)}{A} \frac{Q}{E'} \right]^{-\frac{1}{2}} \quad (B-12)$$

B. THE SCATTERING KERNEL

If the transference function is assumed to be azimuthally independent, the scattering kernel, expressed by Equation (B-2) is:

$$\Sigma^{\ell}(E' \rightarrow E) = (2\ell+1) \int_{-1}^{+1} \Sigma(E' \rightarrow E, \mu_0) P_{\ell}(\mu_0) d\mu_0 \quad (B-13)$$

The final neutron energy is uniquely determined by the scattering angle in the CM system with Equation (B-11). In the previous section it has been shown that this is generally not true in the L system, and the transference function will therefore, contain a delta function in the CM system.

$$\Sigma(E' \rightarrow E, \mu_0) = 2\pi \Sigma(E', \mu_0) \delta(E - E(\eta_0)) \quad (B-14)$$

where:

$E(\eta_0)$ is the solution of Equation (B-11) for E and $\Sigma(E', \mu_0)$ is the differential scattering cross section per unit solid angle in the L system.

By conservation of neutrons in both systems

$$\Sigma(E', \mu_0) d\mu_0 = \Sigma(E', \eta_0) d\eta_0 \quad (B-15)$$

Equation (B-14) becomes

$$\Sigma(E' \rightarrow E, \mu_0) = 2\pi \Sigma(E', \eta_0) \frac{d\eta_0}{d\mu_0} \delta(E - E(\eta_0)) \quad (B-16)$$

A scattering probability in the CM system is defined by:

$$\Sigma(E', \eta_0) = \Sigma_{ie}(E') f(E', \eta_0) \quad (B-17)$$

where:

$\Sigma_{ie}(E')$ is the inelastic scattering cross section to the specific level in question; $f(E', \eta_0)$ is now expanded in Legendre polynomials

$$f(E', \eta_0) = \sum_{\ell'=0}^{\infty} \frac{2\ell'+1}{4\pi} g_{\ell'}(E') P_{\ell'}(\eta_0) \quad (B-18)$$

$$g_{\ell'}(E') = \frac{2\pi}{\Sigma_{ie}(E')} \int_{-1}^{+1} \Sigma(E', \eta_0) P_{\ell'}(\eta_0) d\eta_0$$

where

Using these relations, Equation (B-16) becomes

$$\Sigma(E' \rightarrow E, \mu_0) = \delta(E - E(\eta_0)) \frac{d\eta_0}{d\mu_0} \Sigma_{ie}(E') \sum_{\ell'=0}^{\infty} \frac{2\ell'+1}{2} g_{\ell'}(E') P_{\ell'}(\eta_0) \quad (B-19)$$

If Equation (B-19) is substituted into (B-13), and the variable of integration is changed to η_0 , the integration yields the scattering kernel:

$$\Sigma^{\ell}(E' \rightarrow E) = \frac{(2\ell+1)(A+1)^2}{4E'} \gamma(E') \Sigma_{ie}(E') P_{\ell}(\mu_0(E', E)) \sum_{\ell'=0}^{\infty} (2\ell'+1) g_{\ell'}(E') P_{\ell'}(\eta_0(E', E)) \quad (B-20)$$

where (Ref. B-2):

$$\int_{-\alpha}^{+\alpha} \delta(b - ax) \varphi(x) dx = \frac{1}{a} \varphi\left(\frac{b}{a}\right) \quad (B-21)$$

C. THE DOMAIN OF THE SCATTERING INTEGRALS

The group scheme for the definition of the scattering matrices is shown in Figure B-1.

FIGURE B-1. GROUP SCHEME FOR DEFINITION OF SCATTERING MATRICES

Neutrons are transferred from group g to group $g + n$ and the transfer cross section of Equation (B-5) is written as:

$$\Sigma_{g \rightarrow g+n}^{\ell} = \frac{\int_{E'_{\min}}^{E'_{\max}} dE' f_{\ell}(E') \int_{E_{\min}}^{E_{\max}} dE \Sigma^{\ell}(E' \rightarrow E)}{\int_{E_g}^{E_{g-1}} dE' f_{\ell}(E')} \quad (\text{B-22})$$

The group scheme will now be resketched on the two-dimensional E, E' plane, but first, the range of neutron scattering must be established. The maximum or minimum final neutron energy for a particular incident neutron energy, $E'_{\max}$ or $E'_{\min}$, will occur when η_0 is equal to $+1$ or -1 , respectively, in

Equation (B-11).

$$E'_{\max/\min} = \frac{E'}{(A+1)^2} \left[A \left(1 - \frac{E'_{\text{th}}}{E'} \right) \pm 1 \right]^2 \quad (\text{B-23})$$

where the $+$ sign is used for $E'_{\max}$ and the $-$ sign for $E'_{\min}$.

To obtain the corresponding incident neutron energy, Equation (B-23) is solved backwards:

$$E' \left(\frac{E_{\max}}{E_{\min}} \right) = \frac{E_{\max}}{(A-1)^2} \left\{ 2 \left[1 \pm A \left(1 + \left(\frac{A-1}{A+1} \right) \frac{E'_{th}}{E_{\max}} \right)^{\frac{1}{2}} \right] + (A+1)(A-1) \left[1 + \left(\frac{A}{A+1} \right)^2 \frac{E'_{th}}{E_{\max}} \right] \right\} \quad (B-24)$$

where the - sign is used for $E'(E_{\max})$ and also for $E'(E_{\min}) < E'_{90^\circ}$. The + sign is used for $E'(E_{\min}) > E'_{90^\circ}$.

FIGURE B-2. TWO-DIMENSIONAL E-E' PLANE

In the two-dimensional E, E' plane (Figure B-2), the domain of integration of the transfer cross section is the shaded area between $E_{\max}(E')$ and $E_{\min}(E')$. The limits for the differential area integration ($dE'dE$) over the domain, are (from Equation B-22) $E_{\min} \leq E \leq E_{\max}$ and $E'_{\min} \leq E' \leq E'_{\max}$, and, since neutrons only scatter down in energy, $E \leq E'$.

The domain is integrated upwards in energy for both E' and E . For a given E' , all possible values for E are integrated, then, on to the next higher E' , etc. The limits in this order, are then:

$$\left. \begin{aligned} E'_{\min} &= \max \left(E_g; E'_{th}; \begin{array}{l} E'(E_{\max}=E_{g+n}) \text{ if } E_{\max}(E'=E'_{th}) < E_{g+n} \\ E'(E_{\min}=E_{g+n-1}) \text{ if } E_{g+n-1} < E_{\min}(E'=E'_{th}) \end{array} \right) \\ E_{\min} &= \max (E_{g+n}; E_{\min}(E')) \\ E_{\max} &= \min (E_{g+n-1}; E_{\max}(E')) \\ E'_{\max} &= \min (E_{g-1}; E'(E_{\min} = E_{g+n-1})) \end{aligned} \right\} \quad (B-25)$$

The limits as specified by Equation (B-25) for use in Equation (B-22) along with the kernel defined by Equation (B-20), completely specify the multigroup transfer matrix for inelastic scattering to a specific level. The total transfer cross section due to inelastic scattering is then, the sum over all levels.

D. STATISTICAL THEORY - THE EVAPORATION MODEL

When many levels are available for excitation, the isotropic statistical theory is used (Ref. B-3). Neglecting the conversion between the CM and L systems, the scattering kernel is obtained:

$$\Sigma^0(E' \rightarrow E) = \Sigma_{ie}(E') K(E') E e^{-E/\theta(E')} \quad (B-26)$$

where:

Σ_{ie} is the total inelastic cross section, e.g., the sum over all levels. The compound nucleus temperature is assumed to be a function of the incident neutron energy

$$\theta(E') = CE'^{\frac{1}{2}} \quad (B-27)$$

If no other information is available, C is taken as (Ref. B-3):

$$C \approx \frac{2}{0.62 \sqrt{A}} \quad (\text{Mev}^{\frac{1}{2}}) \quad (\text{B-28})$$

The normalization parameter, $K(E')$, is determined from the conservation relation

$$\int_0^{E'} \Sigma^0(E' - E) dE = \Sigma_{ie}(E')$$

which yields

$$K(E') = \frac{1}{\theta(E')^2 \left[1 - e^{-E'/\theta(E')} \left(\frac{E'}{\theta(E')} + 1 \right) \right]} \quad (\text{B-29})$$

With this statistical kernel, the group transfer cross section may be written as

$$\Sigma_{g \rightarrow g+n}^0 = \frac{\int_{E_g}^{E_{g-1}} \Sigma_{ie}(E') \varphi(E') K(E') dE' \int_{E_{g+n}}^{E_{g+n-1}} E e^{-E/\theta(E')} dE}{\int_{E_g}^{E_{g-1}} \varphi(E') dE'} \quad (\text{B-30})$$

where we define

$$E_{g+n-1} (n=0) \equiv E'$$

This is not to be confused with E_{g-1} which is the upper energy limit in the g^{th} group. The integration over dE may be performed analytically to yield

$$\int_{E_{g+n}}^{E_{g+n-1}} E e^{-E/\theta(E')} dE = \theta(E')^2 \left[e^{-E_{g+n}/\theta(E')} \left(\frac{E_{g+n}}{\theta(E')} + 1 \right) - e^{-E_{g+n-1}/\theta(E')} \left(\frac{E_{g+n-1}}{\theta(E')} + 1 \right) \right]$$

Substituting this result into Equation (B-30) gives the group transfer cross section for inelastic scattering in the statistical approximation.

E. THE (n,2n) REACTION

Because there is little information available about the decay modes of the (n,2n) reaction, the simple approach of placing both emergent neutrons in the statistical inelastic spectrum can be used. Thus, a new inelastic cross section, $\Sigma'_{ie}(E')$, is defined as:

$$\Sigma'_{ie}(E') = \Sigma_{ie}(E') + 2\Sigma_{n,2n}(E') \quad (B-31)$$

This new definition is used both in the group constants and in the transfer matrix, Equation (B-30). Then, to conserve neutrons, a new absorption cross section, $\Sigma'_a(E')$ is defined by

$$\Sigma'_a(E') = \Sigma_a(E') - \Sigma_{n,2n}(E') \quad (B-32)$$

When this approach is taken, the primed quantities are those which appear on the library tape.

III. ELASTIC SCATTERING

A. THE SCATTERING KERNEL

As mentioned earlier, the elastic scattering kernel is obtained as a special case of the more general inelastic formulation, Equation (B-20) with $Q = 0$.

$$\Sigma^{\ell}(E' \rightarrow E) = (2\ell+1) \frac{(A+1)^2}{4AE'} \Sigma_{el.}(E') P_{\ell}(\mu_0(E', E)) \sum_{\ell'=0}^{\infty} (2\ell'+1) g_{\ell'}(E') P_{\ell'}(\eta_0(E', E)) \quad (B-33)$$

The normalization integral of the kernel over all final energies is obtained by changing the integration variable to μ_0 .

$$\int_{\alpha E'}^{E'} \Sigma^{\ell}(E' \rightarrow E) dE = (2\ell+1) 2\pi \int_{-1}^{+1} P_{\ell}(\mu_0) \Sigma(E', \mu_0) d\mu_0 = (2\ell+1) \Sigma_{el.}(E') f_{\ell}(E') \quad (B-34)$$

where $f_{\ell}(E')$ is the equivalent expression to Equation (B-18) in the L system.

In actual practice, the sum over ℓ' is terminated at a finite value to make the normalization integral a function of the selected maximum value of ℓ' . For example, if the series had been carried through $\ell' = 1$, the normalization integral for $\ell = 1$ would have been equal to

$$\int_{\alpha E'}^{E'} \Sigma^1(E' \rightarrow E) dE = 3 \Sigma_{el.}(E') \left[\frac{2}{3A} + \bar{\eta}_0(E') \left(1 - \frac{3}{5A} \right) \right]$$

The term in the square brackets is the expression for $\overline{\mu}_0(E')$ if there is no scattering of a higher order than p scattering, but is not necessarily equal to the experimental value of $\overline{\mu}_0(E')$.

Another formulation of the kernel is possible for elastic scattering since, for this case, the cosine of the scattering angle in either system uniquely determines the final neutron energy. Thus, if instead of carrying the analysis through in the CM system, as was done for the results leading up to Equation (B-33), the equivalent L system relations had been used, the following series expansion over the L system coefficients would have been obtained:

$$\begin{aligned} & \Sigma^{\ell}(E' \rightarrow E) \\ &= \frac{(2\ell+1)}{8E} \Sigma_{el.}(E') \left[(A+1) \left(\frac{E}{E'} \right)^{\frac{1}{2}} + (A-1) \left(\frac{E'}{E} \right)^{\frac{1}{2}} \right] P_{\ell}(\mu_0(E, E')) \sum_{\ell'=0}^{\infty} (2\ell'+1) f_{\ell'}(E') P_{\ell'} \\ & (\mu_0(E, E')) \end{aligned} \quad (B-35)$$

B. THE DOMAIN OF THE SCATTERING INTEGRAL

The two-dimensional E, E' plane is much simpler for elastic scattering since the two bounds from the energetics, $E_{\max}(E')$ and $E_{\min}(E')$, are straight lines from the origin.

$$E_{\max}(E') = E'$$

$$E_{\min}(E') = \alpha E'$$

where

$$\alpha = \left(\frac{A-1}{A+1} \right)^2 \quad (B-36)$$

According to Equation (B-25), the following limits are obtained for elastic scattering:

$$E'_{\min} = E_g$$

$$E_{\min} = \max(E_{g+n}; \alpha E')$$

$$E_{\max} = \min (E_{g+n-1}; E')$$

$$E'_{\max} = \min (E_{g-1}; \frac{E_{g+n-1}}{\alpha}) \quad (B-37)$$

However, for elastic scattering, there is a small enough number of cases to permit the integrals to be explicitly specified. These integrals are easily obtained visually from the scattering domain on the E, E' plane, but the actual form of the limits will depend on whether the E' integration or the E integration is performed first.

For the integral limits, the curve number refers to the corresponding $E_{\min}(E')$ curve on the E, E' plane; the $E_{\min}(E')$ bounds are given after the curve number. The kernels of the integrals have been omitted from the tables to save space.

1. Ingroup Scattering

There are only two possible cases for ingroup scattering since $E_{\max}(E')$ is fixed and $E_{\min}(E')$ can only cut the square in two ways as shown in Figure B-3.

FIGURE B-3. THE TWO POSSIBLE CASES FOR IN-GROUP SCATTERING

Curve No. ($E_{\min}(E')$ bounds)	$\int dE' f_{\ell}(E') \int dE \Sigma^{\ell}(E' \rightarrow E)$	$\int dE \int dE' f_{\ell}(E') \Sigma^{\ell}(E' \rightarrow E)$ (B-38)
1. $(\alpha E_g < E < \alpha E_{g-1} < E_{g-1})$	$\int_{E_g}^{E_g/\alpha} dE' \int_{E_g}^{E'} dE + \int_{E_g}^{E_{g-1}} dE' \int_{\alpha E'}^{E'} dE$	$\int_{E_g}^{\alpha E_{g-1}} dE \int_{E/\alpha}^{E} dE' + \int_{\alpha E_{g-1}}^{E_{g-1}} dE \int_{\alpha E_{g-1}}^{E} dE'$
2. $(\alpha E_g < \alpha E_{g-1} < E < E_{g-1})$	$\int_{E_g}^{E_{g-1}} dE' \int_{E_g}^{E'} dE$	$\int_{E_g}^{E_{g-1}} dE \int_{E_g}^{E} dE'$

2. Out-of-Group Scattering

For out-of-group scattering, the line $E_{\max}(E')$ is always above the rectangle and there are only six ways in which $E_{\min}(E')$ can cut the rectangle. (Figure B-4)

FIGURE B-4. THE SIX POSSIBLE CASES FOR OUT-OF-GROUP SCATTERING

Curve No. ($E_{\min}(E')$ bounds)	$\int dE' f_{\ell}(E') \int dE \Sigma^{\ell}(E' \rightarrow E)$	$\int dE \int dE' f_{\ell}(E') \Sigma^{\ell}(E' \rightarrow E)$ (B-39)
1. $(E_{g+n} \leq E_{g+n-1} \leq \alpha E_g \leq \alpha E_{g-1})$	Integral = 0	Integral = 0
2. $(E_{g+n} \leq \alpha E_g \leq E_{g+n-1} \leq \alpha E_{g-1})$	$\int_{E_g}^{E_{g+n-1}/\alpha} dE' \int_{\alpha E_g}^{E_{g+n-1}} dE$	$\int_{\alpha E_g}^{E_{g+n-1}} dE \int_{E_g}^{E/\alpha} dE'$
3. $(\alpha E_g \leq E_{g+n} \leq E_{g+n-1} \leq \alpha E_{g-1})$	$\int_{E_g}^{E_{g+n}/\alpha} dE' \int_{E_{g+n}}^{E_{g+n-1}} dE + \int_{E_{g+n}/\alpha}^{E_{g+n-1}/\alpha} dE' \int_{\alpha E_g}^{E_{g+n-1}} dE$	$\int_{E_{g+n}}^{E_{g+n-1}} dE \int_{E_g}^{E/\alpha} dE' + \int_{E_{g+n}}^{E_{g+n-1}} dE \int_{E_g}^{E/\alpha} dE'$
4. $(E_{g+n} \leq \alpha E_g \leq \alpha E_{g-1} \leq E_{g+n-1})$	$\int_{E_g}^{E_{g-1}} dE' \int_{\alpha E_g}^{E_{g+n-1}} dE$	$\int_{\alpha E_g}^{E_{g-1}} dE \int_{E_g}^{E/\alpha} dE' + \int_{\alpha E_{g-1}}^{E_{g+n-1}} dE \int_{E_g}^{E/\alpha} dE'$
5. $(\alpha E_g \leq E_{g+n} \leq \alpha E_{g-1} \leq E_{g+n-1})$	$\int_{E_g}^{E_{g+n}/\alpha} dE' \int_{E_{g+n}}^{E_{g+n-1}} dE + \int_{E_{g+n}/\alpha}^{E_{g-1}} dE' \int_{\alpha E_g}^{E_{g+n-1}} dE$	$\int_{E_{g+n}}^{E_{g-1}} dE \int_{E_g}^{E/\alpha} dE' + \int_{\alpha E_{g-1}}^{E_{g+n-1}} dE \int_{E_g}^{E/\alpha} dE'$
6. $(\alpha E_g \leq \alpha E_{g-1} \leq E_{g+n} \leq E_{g+n-1})$	$\int_{E_g}^{E_{g-1}} dE' \int_{E_{g+n}}^{E_{g+n-1}} dE$	$\int_{E_{g+n}}^{E_{g+n-1}} dE \int_{E_g}^{E/\alpha} dE'$

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- B-2 Friedman, B., "Principles and Techniques of Applied Mathematics," Ch. 3, John Wiley and Sons (1956)
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APPENDIX C
THE MULTIGROUP TRANSPORT APPROXIMATION

When the series expansion is terminated at a finite value the transport approximation is used to include the effects of higher order scattering. This approximation has been investigated extensively for the energy dependent (Ref. C-1) and multigroup (Ref. C-2, C-3) cases in the isotropic approximation; much less extensively in the linear anisotropic approximation (Ref. C-4). G. Hansen (Ref. C-5) has expressed the general multigroup approximation with arbitrary termination of the scattering expansion.

In this appendix, the multigroup transport approximation is developed and then simplified to the monogroup case. Next, the resultant scattering law is investigated; and finally, the results for the isotropic and linear anisotropic cases are explicitly given as these approximations are programmed in this code.

I. DEVELOPMENT OF THE TRANSPORT APPROXIMATION

A. THE DERIVATION

The transport approximation is the correction to the cross sections that is used to allow for the effects of higher order scattering in transport theory when the scattering expansion is terminated at a given l^{th} mode. This development starts with the multigroup expression for the transport equation, Equation (B-3), in conjunction with Equation (B-6).

$$\left[\vec{\Omega} \cdot \text{grad}_{\mathbf{x}} + \Sigma_{t_g} \right] f_g(\vec{\Omega}) = \sum_{l=0}^{\infty} \sum_{g' \leq g} \Sigma_{l, g'-g} \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm, g'} + S_g(\vec{\Omega}) \quad (\text{C-1})$$

The term, $\sum_{l_0 g} \sum_{l=0}^{\infty} \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g}$ is subtracted from this equation,

where $\sum_{l_0 g}$ is as yet undefined. The result is

$$\begin{aligned} \left[\vec{\Omega} \cdot \text{grad}_x + \left(\Sigma_t - \sum_{l_0 g} \right) \right] f_g(\vec{\Omega}) &= \sum_{l=0}^{l_0-1} \sum_{g' \leq g} \left(\Sigma_{l g' -g} - \sum_{l_0 g} \delta_{g' g} \right) \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g'} \\ &+ S_g(\vec{\Omega}) + R \end{aligned} \quad (C-2)$$

where $\delta_{g' g}$ is the Kronecker delta and the remainder, R, is equal to

$$R = \sum_{l=l_0}^{\infty} \sum_{g' \leq g} \Sigma_{l g' -g} \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g'} - \sum_{l_0 g} \sum_{l=l_0}^{\infty} \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g} \quad (C-3)$$

To put Equation (C-2) into the usual multigroup format in which l is terminated at l_0-1 , R is required to be equal to zero. This then defines the unknown cross section, $\sum_{l_0 g}$.

$$\sum_{l_0 g} = \frac{\sum_{l=l_0}^{\infty} \sum_{g' \leq g} \Sigma_{l g' -g} \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g'}}{\sum_{l=l_0}^{\infty} \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g}} \quad (C-4)$$

Equation (C-2) with R equal to zero, is therefore, equal to the exact multigroup expression, Equation (C-1), if $\sum_{l_0 g}$ is defined by Equation (C-4). Thus, $\sum_{l_0 g}$ is the "transport correcting" cross section which introduces the higher scattering moments into the equation where l is terminated at $l = l_0-1$. Actually, $\sum_{l_0 g}$ from Equation (C-4) is in an unusable form as

it requires the complete solution of the multigroup equation and because it is a function of direction as well as energy. The simplifications of this expression lead to the transport approximation.

The multigroup transport approximation is obtained by rewriting Equation (C-4) in the form

$$\Sigma_{l_0 g} = \frac{1}{\sum_{l=l_0}^{\infty} \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g}} \sum_{l=l_0}^{\infty} \left[\frac{\sum_{g' \leq g} \Sigma_{l g'} \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g'}}{\sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g}} \right] \sum_{m=-l}^{+l} P_{lm}(\vec{\Omega}) f_{lm g} \quad (C-5)$$

If it is assumed that the term inside the square brackets is independent of l and is equal to its value at $l=l_0$, this term may be taken outside of the summation

$$\Sigma_{l_0 g} = \frac{\sum_{g' \leq g} \Sigma_{l_0 g'} \sum_{m=-l_0}^{+l_0} P_{l_0 m}(\vec{\Omega}) f_{l_0 m g'}}{\sum_{m=-l_0}^{+l_0} P_{l_0 m}(\vec{\Omega}) f_{l_0 m g}} \quad (C-6)$$

If in Equation (C-5) the term in square brackets is a decreasing monotonic function of l , then $\Sigma_{l_0 g}$, as given by Equation (C-6), furnishes an upper bound to the exact function. However, this last expression is still a function of direction. To remove this dependence, the assumption is made that over the entire energy range $g' \leq g$ such that $\Sigma_{l_0 g'}$ is non-zero, that the spectral shapes are the same for all m (that is, that $f_{l_0 m g'} = a_{l_0 m} f_{l_0 g'}$, where $a_{l_0 m}$ is not a function of the energy groups). Under this assumption the directional dependence cancels out to yield the multigroup l_0 type transport approximation:

$$\Sigma_{\ell_0 g} = \frac{\sum_{g' \leq g} \Sigma_{\ell_0 g' \rightarrow g} f_{\ell_0 g'}}{f_{\ell_0 g}} \quad (C-7)$$

Now, Equation (C-7) may be simplified further by considering the case in which the only anisotropic scattering is elastic. (This approach also holds for anisotropic inelastic scattering.) It is assumed that over the energy range of interest (e.g., over the groups g'), both the ℓ_0^{th} mode lethargy scattering density, $\Sigma_s(u') f_{\ell_0}(u')$ and the angular distribution coefficients $g_{\ell_0}(u')$, are constants. Under these assumptions, the numerator on the right hand side of Equation (C-7) becomes

$$\sum_{g' \leq g} \Sigma_{\ell_0 g' \rightarrow g} f_{\ell_0 g'} = \Sigma_{\text{el. } g} \overline{P_{\ell_0}(\mu_0)_g} f_{\ell_0 g} \quad (C-8)$$

where

$$\Sigma_{\text{el. } g} \overline{P_{\ell_0}(\mu_0)_g} = \frac{\int dE \Sigma_{\text{el.}}(E) \overline{P_{\ell_0}(E, \mu_0)} f_{\ell_0}(E)}{\int_g dE f_{\ell_0}(E)} \quad (C-9)$$

and where $\overline{P_{\ell_0}(E, \mu_0)}$ is identical with the angular distribution coefficients in the L system, $f_{\ell_0}(E)$ (Equation (B-34)). By substituting Equation (C-8) into Equation (C-7) the usual monogroup ℓ_0 type transport approximation is obtained

$$\Sigma_{\ell_0 g} = \Sigma_{\text{el. } g} \overline{P_{\ell_0}(\mu_0)_g} \quad (C-10)$$

The group transport correcting cross section can be postulated as a ℓ_0 flux average of an energy dependent counterpart:

$$\Sigma_{\ell_0 g} = \frac{\int_g dE f_{\ell_0}(E) \Sigma_{\ell_0}(E)}{\int_g dE f_{\ell_0}(E)} \quad (C-11)$$

This indicates that, in the multigroup approximation:

$$\Sigma_{\ell_0}(E) = \frac{\int dE' f_{\ell_0}(E') \Sigma_{\ell_0}(E' \rightarrow E)}{f_{\ell_0}(E)} \quad (C-12)$$

and in the monogroup approximation:

$$\Sigma_{\ell_0}(E) = \Sigma_{el.}(E) \overline{P_{\ell_0}(E, \mu_0)} \quad (C-13)$$

B. THE CORRESPONDING SCATTERING LAW

In the development of the multigroup transport relation, Equation (C-1), the transference function was expressed as an expansion in Legendre polynomials. It is therefore advantageous to determine the resultant form for the transference function after making the transport approximation. This requires working backwards from the pertinent multigroup equations to the energy dependent case.

Now, the multigroup transport equation with transport approximation is equal to Equation (C-2) with $R = 0$. The terms in this relation that correspond to the collision integral, are:

$$I_g = \sum_{\ell=0}^{\ell_0-1} \sum_{g' \leq g} \left(\Sigma_{\ell} \delta_{g' \rightarrow g} - \Sigma_{\ell_0} \delta_{g' \rightarrow g} \right) \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m, g'} + \Sigma_{\ell_0} f_g(\vec{\Omega}) \quad (C-14)$$

which may also be written as

$$I_g = \sum_{\ell=0}^{\ell_0-1} \left[\int dE' \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}(E') \int_g dE \Sigma_{\ell}(E' \rightarrow E) - \int_g dE \Sigma_{\ell_0}(E) \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}(E) \right] \\ + \sum_{\ell=0}^{\infty} \int_g dE \Sigma_{\ell_0}(E) \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}(E) \quad (C-15)$$

where in the first term, the assumptions regarding the spectral averaging of the group transfer cross section has been neglected (see Equations (B-4) and (B-5)). In addition, $\Sigma_{\ell_0}(E)$, as expressed in Equation (C-15), corresponds to this term as previously mentioned in Equation (C-11), but only, if the various ℓ^{th} mode spectra differ from the spectrum of the ℓ_0^{th} mode by constant factors.

The multigroup collision integral is defined by the relation

$$I_g = \int_g dE I(E)$$

Therefore;

$$I(E) = \sum_{\ell=0}^{\ell_0-1} \int dE' \left[\Sigma_{\ell}(E'-E) - \Sigma_{\ell_0}(E') \delta(E'-E) \right] \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}(E') \\ + \sum_{\ell=0}^{\infty} \int dE' \Sigma_{\ell_0}(E') \delta(E'-E) \sum_{m=-\ell}^{+\ell} P_{\ell m}(\vec{\Omega}) f_{\ell m}(E')$$

Next the integral form of the angular flux components (see Equation A-8)) and the addition theorem for the spherical harmonics are used to obtain

$$I(E) = \sum_{\ell=0}^{\ell_0-1} \left(\frac{2\ell+1}{4\pi} \right) \int dE' \left[\Sigma_{\ell}(E'-E) - \Sigma_{\ell_0}(E') \delta(E'-E) \right] \int d\Omega' f(E', \vec{\Omega}') P_{\ell}(\mu_0) \\ + \int dE' \Sigma_{\ell_0}(E') \delta(E'-E) \int d\Omega' f(E', \vec{\Omega}') \sum_{\ell=0}^{\infty} \left(\frac{2\ell+1}{4\pi} \right) P_{\ell}(\mu_0) P_{\ell}(1) \quad (C-16)$$

where the identity, $P_{\ell}(1) = 1$, has been used.

The expansion of the delta function in Legendre polynomials yields

$$\delta_2(\vec{\Omega} \cdot \vec{\Omega}') = \frac{\delta(\mu_0-1)}{2\pi} = \sum_{\ell=0}^{\infty} \left(\frac{2\ell+1}{4\pi} \right) P_{\ell}(1) P_{\ell}(\mu_0)$$

where the angular delta function, $\delta_2(\vec{\Omega} \cdot \vec{\Omega}')$, has the property

$$\int \delta_2(\vec{\Omega} \cdot \vec{\Omega}') f(\vec{\Omega}') d\Omega' = f(\vec{\Omega})$$

If this result is substituted into Equation (C-16) and compared with the collision integral in the energy dependent Boltzmann equation, the expression for the transference function, after use of the transport approximation, is obtained.

$$\begin{aligned} \Sigma(E' \rightarrow E, \vec{\Omega} \rightarrow \vec{\Omega}) &= \sum_{\ell=0}^{\ell_0-1} \frac{2\ell+1}{4\pi} \left[\Sigma_{\ell}(E' \rightarrow E) - \Sigma_{\ell_0}(E') \delta(E' - E) \right] P_{\ell}(\mu_0) \\ &+ \Sigma_{\ell_0}(E') \delta(E' - E) \delta_2(\vec{\Omega} \cdot \vec{\Omega}') \end{aligned} \quad (C-17)$$

The ℓ_0 type transport approximation is thus equivalent to replacing the actual anisotropic scattering distribution by a finite expansion up through ℓ_0-1 , plus a forward directed component. The energy transfer moments are defined by Equation (B-2) in conjunction with the energy dependent form of Equation (B-6), and if the transference function from Equation (C-17) is used in these relations, the following is obtained:

$$\begin{aligned} \Sigma_{\ell}(E' \rightarrow E) &= 2\pi \int_{-1}^{+1} \Sigma(E' \rightarrow E, \vec{\Omega}' \rightarrow \vec{\Omega}) P_{\ell}(\mu_0) d\mu_0 = \Sigma_{\ell}(E' \rightarrow E) \\ \text{trans. approx.} &-1 \end{aligned} \quad (C-18)$$

Thus, all moments up through $\ell = \ell_0-1$ are preserved and used. The inclusion of the ℓ_0^{th} moment is through $\Sigma_{\ell_0}(E)$.

If the scattering distribution is a forward directed delta function, or if the expansion coefficients vanish for $\ell \geq \ell_0$, the ℓ_0 type transport approximation is exact. For the first case; one has $\Sigma_{\ell}(E' \rightarrow E) = \Sigma_s(E') \delta(E' - E)$ and $\Sigma_{\ell_0}(E') = \Sigma_s(E')$. The second case is easily verified in Equation (C-17) since then, $\Sigma_{\ell_0}(E') = 0$.

II. USE OF THE TRANSPORT APPROXIMATION

A. THE MULTIGROUP RELATION AS USED

The transport approximation finds its major use in S_n transport codes (Ref. C-6). The general multigroup S_n type of equation, with the angular description left open as not of interest is

$$\left[\vec{\Omega} \cdot \text{grad}_x + \Sigma_g \right] f_g(\vec{\Omega}) = S_g + \sum_{g' \leq g} S_{s_{g' \rightarrow g}} \quad (C-19)$$

where the scattering source term $\sum_{g' \leq g} S_{s_{g' \rightarrow g}}$ involves the usual finite sum

Legendre expansion.

B. CASES OF IMMEDIATE INTEREST

The cases of immediate interest are those of isotropic and linear anisotropic scattering since these scattering options are available in the LASL family of S_n programs (Ref. C-7). The form of the group cross section, Σ_g , and of the scattering matrices, are primarily of interest.

A comparison of Equation (C-19) with Equation (C-2) gives for the isotropic ($\ell_0 = 1$) transport approximation:

$$\left. \begin{aligned}
 \Sigma_g &= \Sigma_{t_g} - \Sigma_{1_g} \\
 S_{s_{g' \rightarrow g}} &= \Sigma_{0_{g' \rightarrow g}} \varphi_{g'} \quad (g' \neq g) \\
 S_{s_{g \rightarrow g}} &= (\Sigma_{0_{g \rightarrow g}} - \Sigma_{1_g}) \varphi_g
 \end{aligned} \right\} \quad (C-20)$$

Similarly, for the linear anisotropic ($\ell_0 = 2$) case:

$$\left. \begin{aligned}
 \Sigma_g &= \Sigma_{t_g} - \Sigma_{2_g} \\
 S_{s_{g' \rightarrow g}} &= \Sigma_{0_{g' \rightarrow g}} \varphi_{g'} + \Sigma_{1_{g' \rightarrow g}} (3\vec{\Omega} \cdot \vec{J}_{g'}) \quad (g' \neq g) \\
 S_{s_{g \rightarrow g}} &= (\Sigma_{0_{g \rightarrow g}} - \Sigma_{2_g}) \varphi_g + (\Sigma_{1_{g \rightarrow g}} - \Sigma_{2_g}) (3\vec{\Omega} \cdot \vec{J}_g)
 \end{aligned} \right\} \quad (C-21)$$

The transport correcting cross sections are given either by Equation (C-7) in the multigroup approximation or by Equation (C-10) in the monogroup approximation.

REFERENCES - APPENDIX C

- C-1 G. Rakavy and Y. Yeivin, "The Transport Approximation of the Energy-Dependent Boltzmann Equation," Nuclear Science Eng., 15, 158 (1963)

- C-2 G. D. Joanou and A. Halim Kazi, "The Validity of the Transport Approximation in Fast-Reactor Calculations," Trans. Amer. Nuclear Soc., 6, No. 1, p. 17, (1963)

- C-3 E. D. Pendlebury and L. H. Underhill, "The Validity of the Transport Approximation in Critical-Size and Reactivity Calculations," Physics of Fast and Intermediate Reactors, Vol. 2, IAEA, p. 73 (1961)

- C-4 Anisotropic Scattering in the Transport Equation, LAMS-2873, Apr. 1963, K. D. Lathrop

- C-5 Transport Approximation and Anisotropic Sources, Internal LASL Memorandum N-2-1511, Oct. 1959, G. E. Hansen

- C-6 The Discrete S_n Approximation to Transport Theory, LA-2595, March 1962, C. E. Lee

- C-7 The DSN and TDC Neutron Transport Codes, LAMS-2346, Feb 1960, B. Carlson, et al., Also internal LASL documents on the DTK and DDK codes.

APPENDIX DAGN-GAM DATA TAPE #1003

A library data tape has been written for use with the AGN version of the GAM fast cross section code. This appendix explains what data is available on the tape and the source of this information.

The AGN-GAM library tape contains three types of information; the resonance tables which permit calculation of resonance integrals from basic parameters and input geometry; source spectra of neutrons as a function of energy; and material cross section data.

Resonance tables containing approximately 13,500 numbers are provided for spherical, cylindrical and slab geometries.

Ten source spectra are included on the present library tape. These permit the GAM code to calculate fluxes, currents, and the Fermi age for both delayed and prompt U-235; for U-235, Plutonium, and Californium fission; and for Po-Be and Ra-Be sources.

Nuclear cross section data, for a total of 182 different materials, are included on tape number 1003. These data include the microscopic absorption, elastic scattering, inelastic scattering, $n-2n$ reaction, fission, and ν for each of seventy-five groups of one-quarter lethargy unit in width in the energy range from 10 Mev to 0.07 ev. Complete scattering matrices are included for the elastic (both the P_0 and P_1 terms), inelastic, and $(n-2n)$ reactions. Of the materials present on the data tape, 36 are naturally occurring elements, 26 are mixtures (i.e., water and stainless steel), 7 are

fission product groupings, 104 are specific individual isotopes, and 9 are elements which have been added for the special resonance absorption and fission calculations. Room for thirty-one additional entries has been left for future additions.

The microscopic cross sections on this data tape have been obtained from physical measurements of cross sections. They have not been normalized to any specific reactor system, but they do produce good results when used properly.

I. ENERGY GROUPS

The present library tape has been established with 75 fine groups. Each group is one-quarter-lethargy unit wide with the top energy at 10 Mev. Table D-1 lists the energy and lethargy limits of each group.

II. RESONANCE TABLES

The resonance tables on the AGN-GAM data tape were taken from the GAM data tape (101) supplied to AGN by General Atomic. The data from the original tape were transferred to cards by an IBM machine, to eliminate manual keypunching and data transcribing errors, and then added to the AGN tape. Tabular data thus obtained have been compared with published GA documents (Ref. D-1, D-2) to check their validity. No errors were found but the tables included on the data tape are more extensive than those published in the reference documents.

III. SOURCES

Ten sources (listed in Table D-2) are available for use in the AGN-GAM data tape. Eight sources came from the original GA tape while two were added from data generated at AGN. The two added sources, numbers 1 and 3, are for the delayed neutron spectrum from U-235 fission products (Ref. D-3), and the delayed plus prompt U-235 fission spectrum. The latter source is a combination of spectra 2 and 3.

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TABLE D-1

AGN-GAM FAST CROSS SECTION LIBRARY TAPE 1003
FINE GROUP BOUNDRIES

GR	U(LOWER)	E(LOWER)	GR	U(LOWER)	E(LOWER)
1	0.25	7.788E 06	41	10.25	3.536E 02
2	0.50	6.065E 06	42	10.50	2.754E 02
3	0.75	4.724E 06	43	10.75	2.145E 02
4	1.00	3.679E 06	44	11.00	1.670E 02
5	1.25	2.865E 06	45	11.25	1.301E 02
6	1.50	2.231E 06	46	11.50	1.013E 02
7	1.75	1.738E 06	47	11.75	7.889E 01
8	2.00	1.353E 06	48	12.00	6.144E 01
9	2.25	1.054E 06	49	12.25	4.785E 01
10	2.50	8.208E 05	50	12.50	3.727E 01
11	2.75	6.393E 05	51	12.75	2.902E 01
12	3.00	4.979E 05	52	13.00	2.260E 01
13	3.25	3.877E 05	53	13.25	1.760E 01
14	3.50	3.020E 05	54	13.50	1.371E 01
15	3.75	2.352E 05	55	13.75	1.068E 01
16	4.00	1.832E 05	56	14.00	8.315E 00
17	4.25	1.426E 05	57	14.25	6.476E 00
18	4.50	1.111E 05	58	14.50	5.043E 00
19	4.75	8.652E 04	59	14.75	3.928E 00
20	5.00	6.738E 04	60	15.00	3.059E 00
21	5.25	5.248E 04	61	15.25	2.382E 00
22	5.50	4.087E 04	62	15.50	1.855E 00
23	5.75	3.183E 04	63	15.75	1.445E 00
24	6.00	2.479E 04	64	16.00	1.125E 00
25	6.25	1.930E 04	65	16.25	8.764E-01
26	6.50	1.503E 04	66	16.50	6.826E-01
27	6.75	1.171E 04	67	16.75	5.316E-01
28	7.00	9.119E 03	68	17.00	4.140E-01
29	7.25	7.102E 03	69	17.25	3.224E-01
30	7.50	5.531E 03	70	17.50	2.511E-01
31	7.75	4.307E 03	71	17.75	1.956E-01
32	8.00	3.355E 03	72	18.00	1.523E-01
33	8.25	2.613E 03	73	18.25	1.186E-01
34	8.50	2.035E 03	74	18.50	9.237E-02
35	8.75	1.585E 03	75	18.75	7.194E-02
36	9.00	1.234E 03			
37	9.25	9.611E 02			
38	9.50	7.485E 02			
39	9.75	5.829E 02			
40	10.00	4.540E 02			

TABLE D-2
AGN-GAM FAST CROSS SECTION LIBRARY TAPE 1003
1 JULY 1964

SOURCES

1	U-235	PROMPT + DELAYED
2	U-235	PROMPT (CRANBERG)
3	U-235	DELAYED (KEEPIN)
4	U-233	(SMITH)
5	PU-239	(NERESON)
6	PU-241	(SMITH)
7	CF-252	(SMITH)
8	PO-BE	(WHITMORE AND BAKER)
9	PO-BE	(COCHRANE AND HENRY)
10	RA-BE	(HILL)

IV. MATERIAL CONSTANTS

A. GENERAL

The material constants on the AGN-GAM data tape were compiled from a number of different sources. Each of these sources is discussed and sufficient information is provided to describe the data obtained for each material. Complete data for each material is not provided in this document (a complete printout of the tape would take 800 full pages).

The materials on the library tape are listed in alphabetic order in Table D-3 and by numerical and type-of-use arrangement in Table D-4.

B. DATA ORIGINATED AT AGN

The cross section data for 33 elements have been generated at AGN, and thirty-one of these are listed in Table D-5. The other two are free and bound hydrogen.

The inelastic scattering matrix was generated for these materials by the solution of the statistical inelastic scattering model. A full description of this solution is contained in Appendix B. Appendix E explains the use of the INSECT code to calculate the required numerical results. The one input required to these equations, a constant C, is listed for each material in Table D-5.

The P_0 and P_1 elastic scattering matrices were based on the solution of the standard equations as given in the GAM-I report (Ref. D-4, Appendix B). The matrices were calculated and punched directly onto cards, by the POP1 program (Appendix E). Table D-6 lists the values of η ($\eta = \bar{\mu}'$, the average cosine of the scattering angle in the CM system), used for each material. Due to the lack of angular data, for several elements η 's from adjacent materials were used. Thus, for mercury the data of lead were used, for silver those of cadmium, for manganese those of chromium, and for europium, samarium, and gadolinium those of tungsten.

Because of the fact that the $(n,2n)$ reaction in AGN cross sections is treated by a change in the absorption and inelastic cross sections, the absence of a specific $(n,2n)$ cross section does not signify neglect of this reaction.

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TABLE D-4
AGN-GAM FAST CROSS SECTION LIBRARY TAPE 1003
1 JULY 1964

MODERATOR MATERIALS

- 1 HYDROGEN (BOUND)
- 2 DEUTERIUM
- 3 LITHIUM - 7
- 4 BERYLLIUM
- 5 CARBON
- 6 WATER, LIGHT
- 7 WATER, HEAVY
- 8 BERYLLIUM OXIDE
- 9 GRAPHITE (AGOT)
- 10 AMMONIA
- 11 HYDROGEN (FREE)

FUEL MATERIALS

- 13 URANIUM - 233
- 14 URANIUM - 234
- 15 URANIUM - 235 (INF.DIL)
- 16 URANIUM - 236
- 17 URANIUM - 238 (INF. DIL.)
- 18 PROTACTINIUM-233
- 19 NEPTUNIUM - 239
- 20 PLUTONIUM - 239
- 21 PLUTONIUM - 240
- 22 PLUTONIUM - 241
- 23 PLUTONIUM - 242
- 24 THORIUM (INF. DIL)
- 25 URANIUM - NATURAL
- 26 URANIUM-FULLY ENRICHED (ML-1)
- 27 URANIUM DIOXIDE-FULLY ENRICHED

STRUCTURAL MATERIALS
ELEMENTS

- 30 LITHIUM
- 31 NITROGEN
- 32 OXYGEN
- 34 MAGNESIUM
- 35 ALUMINUM
- 36 SILICON
- 40 TITANIUM
- 42 CHROMIUM
- 43 MANGANESE
- 44 IRON
- 45 COBALT
- 46 NICKEL
- 47 COPPER
- 50 YTTRIUM
- 51 ZIRCONIUM
- 52 NIOBIUM (COLUMBIUM)
- 53 MOLYBDENUM (INF. DIL)
- 54 TUNGSTEN (INF DIL)
- 55 CESIUM
- 56 MERCURY
- 57 LEAD
- 58 BISMUTH (NO ABS)

STRUCTURAL MATERIALS
MIXTURES

- 59 STAINLESS STEEL - TYPE 304
- 60 STAINLESS STEEL - TYPE 316
- 61 STAINLESS STEEL - TYPE 321
- 62 STAINLESS STEEL - TYPE 347
- 63 STAINLESS STEEL - TYPE 410
- 64 STAINLESS STEEL - TYPE 440B
- 65 HASTELLOY - X
- 66 INCONEL
- 67 INCONEL - X
- 68 FECRAL
- 69 ALUMINUM - TYPE 6061
- 71 HAYNES - 25
- 72 ALUMINUM OXIDE
- 73 MAGNESIUM OXIDE
- 74 THERMOFLEX (1800)
- 75 REFRASIL

POISON MATERIALS

- 81 BORON
- 82 CADMIUM (INF DIL)
- 83 EUROPIUM (INF DIL)
- 84 SAMARIUM (INF DIL)
- 85 INDIUM (INF DIL)
- 86 SILVER (INF. DIL)
- 89 CONTROL BLADE (AG-IN-CD)
- 90 LITHIUM - 6
- 91 GADOLINIUM

FISSION PRODUCTS

- 93 FISSION PROD. - TOTAL (U-235)
- 94 FISSION PROD. - NON-SAT. (U-235)
- 95 FISSION PROD. - SLOW SAT (U-235)
- 96 FISSION PROD. - GP-155
- 97 FISSION PROD. - XE-135
- 98 FISSION PROD. - SM-149
- 99 FISSION PROD. - SM-151

RESONANCE MATERIALS

- 100 THORIUM
- 101 URANIUM-235
- 102 URANIUM-238
- 103 TUNGSTEN
- 104 MOLYBDENUM
- 105 SILVER
- 106 CADMIUM
- 107 INDIUM
- 108 SAMARIUM

INDIVIDUAL ISOTOPES

- 121 SELENIUM - 82 (ABS)
- 122 BROMINE - 81 (ABS)
- 123 KRYPTON - 83 (ABS)
- 124 KRYPTON - 84 (ABS)
- 125 KRYPTON - 85 (ABS)
- 126 KRYPTON - 86 (ABS)
- 127 RUBIDIUM - 85 (ABS)
- 128 RUBIDIUM - 87 (ABS)
- 129 STRONTIUM - 88 (ABS)
- 130 STRONTIUM - 90 (ABS)
- 131 ZIRCONIUM - 90 (ABS)
- 132 ZIRCONIUM - 91 (ABS)
- 133 ZIRCONIUM - 92 (ABS)
- 134 ZIRCONIUM - 93 (ABS)
- 135 ZIRCONIUM - 94 (ABS)
- 136 ZIRCONIUM - 96 (ABS)
- 137 MOLYBDENUM - 95 (ABS)
- 138 MOLYBDENUM - 96 (ABS)
- 139 MOLYBDENUM - 97 (ABS)
- 140 MOLYBDENUM - 98 (ABS)
- 141 MOLYBDENUM - 100 (ABS)
- 142 TECHNETIUM - 99 (ABS)
- 143 RUTHENIUM - 100 (ABS)
- 144 RUTHENIUM - 101 (ABS)
- 145 RUTHENIUM - 102 (ABS)
- 146 RUTHENIUM - 104 (ABS)
- 147 RHODIUM - 103 (ABS)
- 148 PALLADIUM - 104 (ABS)
- 149 PALLADIUM - 105 (ABS)
- 150 PALLADIUM - 106 (ABS)
- 151 PALLADIUM - 107 (ABS)
- 152 PALLADIUM - 108 (ABS)
- 153 PALLADIUM - 110 (ABS)
- 154 SILVER - 109 (ABS)
- 155 INDIUM - 115 (ABS)
- 156 CADMIUM - 110 (ABS)
- 157 CADMIUM - 111 (ABS)
- 158 CADMIUM - 112 (ABS)
- 159 CADMIUM - 113 (ABS)
- 160 CADMIUM - 114 (ABS)
- 161 TELLURIUM - 126 (ABS)
- 162 TELLURIUM - 128 (ABS)
- 163 TELLURIUM - 130 (ABS)
- 164 IODINE - 127 (ABS)
- 165 IODINE - 129 (ABS)
- 166 XENON - 128 (ABS)
- 167 XENON - 130 (ABS)
- 168 XENON - 131 (ABS)
- 169 XENON - 132 (ABS)
- 170 XENON - 134 (ABS)
- 171 XENON - 136 (ABS)
- 172 CESIUM - 133 (ABS)
- 173 CESIUM - 135 (ABS)
- 174 CESIUM - 137 (ABS)
- 175 BARIUM - 134 (ABS)
- 176 BARIUM - 136 (ABS)
- 177 BARIUM - 137 (ABS)
- 178 BARIUM - 138 (ABS)
- 179 LANTHANUM - 139 (ABS)
- 180 CERIUM - 140 (ABS)
- 181 CERIUM - 142 (ABS)
- 182 PRASEODYMIUM - 141 (ABS)
- 183 NEODYMIUM - 142 (ABS)
- 184 NEODYMIUM - 143 (ABS)
- 185 NEODYMIUM - 144 (ABS)
- 186 NEODYMIUM - 145 (ABS)
- 187 NEODYMIUM - 146 (ABS)
- 188 NEODYMIUM - 148 (ABS)
- 189 NEODYMIUM - 150 (ABS)
- 190 PROMETHIUM - 147 (ABS)
- 191 SAMARIUM - 147 (ABS)
- 192 SAMARIUM - 148 (ABS)
- 193 SAMARIUM - 150 (ABS)
- 194 SAMARIUM - 151 (ABS)
- 195 SAMARIUM - 152 (ABS)
- 196 SAMARIUM - 154 (ABS)
- 197 EUROPIUM - 151 (ABS)
- 198 EUROPIUM - 153 (ABS)
- 199 EUROPIUM - 154 (ABS)
- 200 EUROPIUM - 155 (ABS)
- 201 GADOLINIUM - 154 (ABS)
- 202 GADOLINIUM - 155 (ABS)
- 203 GADOLINIUM - 156 (ABS)
- 204 GADOLINIUM - 157 (ABS)
- 205 GADOLINIUM - 158 (ABS)
- 206 TERBIUM - 159 (ABS)
- 207 GOLD - 197 (ABS)
- 208 YTTRIUM - 89 (ABS)
- 209 SAMARIUM - 149 (ABS)
- 210 1.0/V - 1 BARN AT 2200 M/SEC
- 211 TUNGSTEN - 182 (INF DIL)
- 212 TUNGSTEN - 183 (INF DIL)
- 213 TUNGSTEN - 184 (INF DIL)

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TABLE D-3

AGN-GAM FAST CROSS SECTION LIBRARY TAPE 1003

1 JULY 1964

ALUMINUM	35	OXYGEN	32
ALUMINUM - TYPE 6061	69		
ALUMINUM OXIDE	72	PALLADIUM - 104 (ABS)	148
AMMONIA	10	PALLADIUM - 105 (ABS)	149
		PALLADIUM - 106 (ABS)	150
BARIUM - 134 (ABS)	175	PALLADIUM - 107 (ABS)	151
BARIUM - 136 (ABS)	176	PALLADIUM - 108 (ABS)	152
BARIUM - 137 (ABS)	177	PALLADIUM - 110 (ABS)	153
BARIUM - 138 (ABS)	178	PLUTONIUM - 239	20
BERYLLIUM	4	PLUTONIUM - 240	21
BERYLLIUM OXIDE	8	PLUTONIUM - 241	22
BISMUTH (NO ABS)	58	PLUTONIUM - 242	23
BORON	81	PRASEODYMIUM - 141 (ABS)	182
BROMINE - 81 (ABS)	122	PROTACTINIUM - 233	18
		PROMETHIUM - 147 (ABS)	190
CADMIUM (INF DIL)	82		
CADMIUM	106	REFRASIL	75
CADMIUM - 110 (ABS)	156	RHODIUM - 103 (ABS)	147
CADMIUM - 111 (ABS)	157	RUBIDIUM - 85 (ABS)	127
CADMIUM - 112 (ABS)	158	RUBIDIUM - 87 (ABS)	128
CADMIUM - 113 (ABS)	159	RUTHENIUM - 100 (ABS)	143
CADMIUM - 114 (ABS)	160	RUTHENIUM - 101 (ABS)	144
CARBON	5	RUTHENIUM - 102 (ABS)	145
CERIUM - 140 (ABS)	180	RUTHENIUM - 104 (ABS)	146
CERIUM - 142 (ABS)	181		
CESIUM	55	SAMARIUM (INF DIL)	84
CESIUM - 133 (ABS)	172	SAMARIUM	108
CESIUM - 135 (ABS)	173	SAMARIUM - 147 (ABS)	191
CESIUM - 137 (ABS)	174	SAMARIUM - 148 (ABS)	192
CHROMIUM	42	SAMARIUM - 149 (ABS)	209
COBALT	45	SAMARIUM - 150 (ABS)	193
CONTROL BLADE (AG-IN-CD)	89	SAMARIUM - 151 (ABS)	194
COLUMBIUM	52	SAMARIUM - 152 (ABS)	195
COPPER	47	SAMARIUM - 154 (ABS)	196
		SELENIUM - 82 (ABS)	121
DEUTERIUM	2	SILICON	36
		SILVER (INF. DIL)	86
EUROPIUM (INF DIL)	83	SILVER	105
EUROPIUM - 151 (ABS)	197	SILVER - 109 (ABS)	154
EUROPIUM - 153 (ABS)	198	STAINLESS STEEL - TYPE 304	59
EUROPIUM - 154 (ABS)	199	STAINLESS STEEL - TYPE 316	60
EUROPIUM - 155 (ABS)	200	STAINLESS STEEL - TYPE 321	61
		STAINLESS STEEL - TYPE 347	62
FECRAL	68	STAINLESS STEEL - TYPE 410	63
FISS. PROD. - GD-155	96	STAINLESS STEEL - TYPE 440B	64
FISS. PROD. - NON-SAT. (U-235)	94	STRONTIUM - 88 (ABS)	129
FISS. PROD. - SLOW SAT (U-235)	95	STRONTIUM - 90 (ABS)	130
FISS. PROD. - SM-149	98		
FISS. PROD. - SM-151	99	TECHNETIUM - 99 (ABS)	142
FISS. PROD. - TOTAL (U-235)	93	TELLURIUM - 126 (ABS)	161
FISS. PROD. - XE-135	97	TELLURIUM - 128 (ABS)	162
		TELLURIUM - 130 (ABS)	163
GADOLINIUM	91	TERBIUM - 159 (ABS)	206
GADOLINIUM - 154 (ABS)	201	THERMOFLEX (1800)	74
GADOLINIUM - 155 (ABS)	202	THORIUM (INF. DIL)	24
GADOLINIUM - 156 (ABS)	203	THORIUM	100
GADOLINIUM - 157 (ABS)	204	TITANIUM	40
GADOLINIUM - 158 (ABS)	205	TUNGSTEN (INF DIL)	54
GOLD - 197 (ABS)	207	TUNGSTEN	103
GRAPHITE (AGOT)	9	TUNGSTEN - 182 (INF DIL)	211
		TUNGSTEN - 183 (INF DIL)	212
HASTELLOY - X	65	TUNGSTEN - 184 (INF DIL)	213
HAYNES - 25	71		
HYDROGEN (BOUND)	1	URANIUM - 233	13
HYDROGEN (FREE)	11	URANIUM - 234	14
		URANIUM - 235 (INF DIL)	15
INCONEL	66	URANIUM - 235	101
INCONEL - X	67	URANIUM - 236	16
INDIUM (INF DIL)	85	URANIUM - 238 (INF DIL)	17
INDIUM	107	URANIUM - 238	102
INDIUM - 115 (ABS)	155	URANIUM - NATURAL	25
IODINE - 127 (ABS)	164	URANIUM-FULLY ENRICHED (ML-1)	26
IODINE - 129 (ABS)	165	URANIUM DIOXIDE-FULLY ENRICHED	27
IRON	44		
		WATER, LIGHT	6
KRYPTON - 83 (ABS)	123	WATER, HEAVY	7
KRYPTON - 84 (ABS)	124		
KRYPTON - 85 (ABS)	125	XENON - 128 (ABS)	166
KRYPTON - 86 (ABS)	126	XENON - 130 (ABS)	167
		XENON - 131 (ABS)	168
LANTHANUM - 139 (ABS)	179	XENON - 132 (ABS)	169
LEAD	57	XENON - 134 (ABS)	170
LITHIUM	30	XENON - 136 (ABS)	171
LITHIUM - 6	90		
LITHIUM - 7	3	YTTRIUM	50
		YTTRIUM - 89 (ABS)	208
MAGNESIUM	34		
MAGNESIUM OXIDE	73	ZIRCONIUM	51
MANGANESE	43	ZIRCONIUM - 90 (ABS)	131
MERCURY	56	ZIRCONIUM - 91 (ABS)	132
MOLYBDENUM (INF. DIL)	53	ZIRCONIUM - 92 (ABS)	133
MOLYBDENUM	104	ZIRCONIUM - 93 (ABS)	134
MOLYBDENUM - 95 (ABS)	137	ZIRCONIUM - 94 (ABS)	135
MOLYBDENUM - 96 (ABS)	138	ZIRCONIUM - 96 (ABS)	136
MOLYBDENUM - 97 (ABS)	139		
MOLYBDENUM - 98 (ABS)	140	1.0/V - 1 BARN AT 2200 M/SEC	210
MOLYBDENUM - 100 (ABS)	141		
NEODYMIUM - 142 (ABS)	183		
NEODYMIUM - 143 (ABS)	184		
NEODYMIUM - 144 (ABS)	185		
NEODYMIUM - 145 (ABS)	186		
NEODYMIUM - 146 (ABS)	187		
NEODYMIUM - 148 (ABS)	188		
NEODYMIUM - 150 (ABS)	189		
NEPTUNIUM - 239	19		
NICKEL	46		
NIOBIUM (INF DIL)	52		
NITROGEN	31		

TABLE D-5 - CONSTANT "C"* USED IN CALCULATION OF INELASTIC SCATTERING MATRIX

Number	Material	C	Number	Material	C
			50	Yttrium	0.3421
3	Lithium - 7	1.2177	51	Zirconium	0.3377
4	Beryllium	1.0745	52	Niobium	0.3347
5	Carbon	0.9308	53	Molybdenum	0.3293
15	Uranium-235	0.3750	54	Tungsten	0.2379
17	Uranium-238	0.2090	55	Cesium	0.2798
31	Nitrogen	0.8619	56	Mercury	0.2277
32	Oxygen	0.8065	57	Lead	0.3162
35	Aluminum	0.6210	81	Boron	0.9807
36	Silicon	0.6090	82	Cadmium	0.3043
40	Titanium	0.4661	83	Europium	0.2616
42	Chromium	0.4473	84	Samarium	0.2631
43	Manganese	0.4352	85	Indium	0.3010
44	Iron	0.4316	86	Silver	0.3106
45	Cobalt	0.4202	90	Lithium - 6	1.3151
46	Nickel	0.4210	91	Gadolinium	0.2572

* C is the compound nucleus temperature parameter and is defined by:

$$\theta = C E'^{\frac{1}{2}}$$

where

θ = compound nucleus temperature (Mev)

E' = incident neutron energy (Mev)

TABLE D-6 - VALUES OF η USED IN THE CALCULATION
OF THE ELASTIC SCATTERING MATRICES

Sub-group	H	Li-7	Be	C	U	N	O	Al	Si
1	0.000	0.243	0.640	0.350	0.750	0.390	0.650	0.620	0.578
2		0.224	0.588	0.207	0.798	0.365	0.490	0.590	0.566
3		0.194	0.500	0.110	0.800	0.340	0.300	0.530	0.538
4		0.158	0.470	0.038	0.825	0.295	0.091	0.450	0.450
5		0.120	0.364	-0.009	0.810	0.250	0.079	0.260	0.290
6		0.076	0.214	0.003	0.720	0.200	0.065	0.342	0.326
7		0.038	0.114	0.032	0.635	0.160	0.065	0.378	0.326
8		0.019	0.205	0.060	0.420	0.082	0.158	0.311	0.270
9		-0.007	0.188	0.070	0.400	0.057	0.000	0.254	0.270
10		-0.050	0.131	0.071	0.350	0.043	0.000	0.220	0.308
11		-0.109	0.088	0.064	0.320	0.038	0.109	0.193	0.107
12		-0.200	0.029	0.058	0.300	0.031	0.260	0.182	0.166
13		-0.275	0.031	0.039	0.280	0.025	0.160	0.118	0.089
14		-0.281	0.033	0.032	0.240	0.019	-0.240	0.088	0.071
15		0.015	0.039	0.032	0.180	0.015	-0.170	0.070	0.032
16		0.325	0.021	0.021	0.100	0.011	-0.102	0.077	0.013
17		0.240	0.018	0.010	0.095	0.010	0.006	0.045	0.008
18		0.110	0.012	0.006	0.090	0.008	-0.023	0.020	0.000
19		0.049	0.000	0.002	0.080	0.005	0.000	0.000	
20		0.000	0.014	-0.003	0.074	0.001			
21		-0.025	0.019	-0.005	0.070	0.000			
22		0.060	0.015	-0.003	0.060				
23		0.000	0.010	-0.0025	0.045				
24			0.008	-0.002	0.030				
25			0.005	-0.0015	0.020				
26			0.002	-0.001	0.010				
27			0.001	0.000	0.005				
≈									
75									

TABLE D-6 (Continued)

Sub-group	Cr	Fe	Co	Ni	Y	Zr	Nb	Mo	W
1	0.615	0.820	0.672	0.950	0.600	0.750	0.528	0.700	0.870
2	0.594	0.8125	0.647	0.880	0.550	0.708	0.510	0.610	0.830
3	0.565	0.746	0.597	0.790	0.500	0.603	0.495	0.550	0.790
4	0.530	0.549	0.555	0.578	0.465	0.500	0.475	0.450	0.756
5	0.490	0.500	0.509	0.448	0.338	0.333	0.453	0.480	0.707
6	0.450	0.387	0.447	0.320	0.301	0.370	0.432	0.437	0.598
7	0.395	0.260	0.384	0.230	0.264	0.340	0.406	0.406	0.481
8	0.340	0.220	0.306	0.170	0.205	0.320	0.380	0.381	0.393
9	0.285	0.190	0.193	0.129	0.140	0.300	0.350	0.371	0.342
10	0.219	0.190	0.122	0.095	0.075	0.305	0.315	0.360	0.290
11	0.154	0.145	0.108	0.114	0.000	0.269	0.289	0.346	0.220
12	0.153	0.170	0.095	0.127		0.242	0.264	0.310	0.120
13	0.108	0.124	0.070	0.105		0.194	0.228	0.270	0.055
14	0.096	0.088	0.057	0.082		0.138	0.182	0.230	0.020
15	0.099	0.072	0.049	0.070		0.111	0.152	0.180	0.000
16	0.075	0.058	0.036	0.053		0.103	0.119	0.150	
17	0.051	0.045	0.019	0.034		0.077	0.079	0.120	
18	0.038	0.025	0.008	0.019		0.0475	0.057	0.090	
19	0.031	0.019	0.003	0.011		0.026	0.049	0.070	
20	0.025	0.009	-0.001	0.007		0.013	0.043	0.060	
21	0.022	0.005	-0.004	0.005		0.005	0.020	0.055	
22	0.018	0.000	-0.010	0.000		0.000	0.000	0.050	
23	0.013		-0.017					0.040	
24	0.010		0.000					0.030	
25	0.0075							0.020	
26	0.003							0.010	
27	0.001							0.000	
28	0.000								
≈									
75									

TABLE D-6 (Continued)

Sub-group	Cs	Ph	B	Cd	In	Li-6	Ti
1	0.690	0.626	0.444	0.790	0.690	0.240	0.726
2	0.665	0.607	0.400	0.740	0.665	0.200	0.677
3	0.630	0.559	0.000	0.670	0.630	0.169	0.630
4	0.584	0.577	0.000	0.600	0.584	0.140	0.605
5	0.526	0.466	0.000	0.440	0.526	0.120	0.636
6	0.460	0.480	0.000	0.390	0.460	0.105	0.612
7	0.420	0.350	0.003	0.380	0.420	0.095	0.470
8	0.384	0.261	0.009	0.385	0.384	0.112	0.361
9	0.375	0.191	0.0148	0.394	0.375	0.140	0.320
10	0.358	0.200	0.117	0.395	0.358	0.162	0.248
11	0.380	0.151	0.119	0.380	0.380	0.142	0.168
12	0.382	0.118	0.143	0.360	0.382	0.121	0.176
13	0.322	0.175	0.119	0.340	0.322	0.120	0.125
14	0.294	0.149	0.119	0.300	0.294	0.063	0.099
15	0.272	0.149	0.0076	0.250	0.272	0.040	0.000
16	0.208	0.135	0.0143	0.210	0.208	-0.065	↓
17	0.177	0.104	0.011	0.170	0.177	-0.133	
18	0.152	0.070	0.0105	0.140	0.152	-0.120	
19	0.135	0.058	0.0102	0.120	0.135	-0.117	
20	0.119	0.037	0.010	0.110	0.119	-0.115	
21	0.107	0.028	0.000	0.100	0.107	-0.115	
22	0.092	0.019	↓	0.085	0.092	0.050	
23	0.071	0.010		0.065	0.071	0.000	
24	0.050	0.005		0.050	0.050	↓	
25	0.032	0.000		0.030	0.032		
26	0.016	↓		0.030	0.016		
27	0.005			0.010	0.005		
28	0.000			0.000	0.000		
≈	↓			↓	↓	↓	↓
75							

C. DATA OBTAINED FROM GA TAPE 101

A number of materials, for which cross sections were not available at AGN but which were on the original GAM tape, have been saved and placed on the AGN data tape. A list of these is given in Table D-7. Like the resonance tables, the data on these materials were transferred directly from the old tape to cards to avoid errors. Some of the scattering matrices were reduced in size to eliminate zeros and very small terms.

No references are available on the original sources for these data.

D. DATA OBTAINED BY MIXING MATERIALS

Twenty-six materials on the AGN-GAM library tape were formed by mixing pure elements. This was done to generate data on materials that are most often required such as water, or for materials of specific reference composition such as stainless steel. The cross sections were combined using the SCRIBBLE code (Appendix E), in much the same way as AGN-GAM code functions. Equations were used that calculated the average cross section per atom present. This means that the number density to be used with mixtures is the sum of all atoms present in one cubic centimeter of the mixture. The atomic weight is chosen so that the proper number density results when the physical density of the material is input.

Table D-8 lists the mixtures present, the atomic weights, and the assumed weight as well as the atom percents of the components.

E. INDIVIDUAL ISOTOPE DATA

The data on the individual isotopes (material numbers 121 to 213) were obtained from GA data tape (No. 101) with the exception of yttrium-89 (material 208), tungsten-182, 183, and 184 (materials 211 through 213), and the special $1/v$ cross section addition. These GA materials apparently came from evaluations of the fission product cross sections (Ref. D-5). Except for materials 211 and 213 these constants include only absorption and no other processes.

The original data tape contained only 68 groups of information. To extend this data to 75 groups, it was assumed that a $1/v$ dependence existed. This is a valid assumption for all but a few of the materials considered

TABLE D-7 - MATERIALS FOR WHICH ALL CONSTANTS
WERE OBTAINED FROM GENERAL ATOMICS' DATA

<u>ID NUMBER</u>	<u>MATERIAL</u>
2	Deuterium
13	Uranium-233
14	Uranium-234
16	Uranium-236
18	Protactinium-233
19	Neptunium-239
20	Plutonium-239
21	Plutonium-240
22	Plutonium-241
23	Plutonium-242
24	Thorium (inf dil)
34	Magnesium
47	Copper
58	Bismuth
100	Thorium

TABLE D-8 - COMPOSITION OF MIXED MATERIALS

No.	Name	*	Atomic Weight	Components	Weight Percent	Atom Percent
6	Water, light	a	6.005	Hydrogen Oxygen	11.19 88.81	66.67 33.33
7	Water, heavy	a	6.677	Deuterium Oxygen	20.12 79.88	66.67 33.33
8	Beryllium oxide	a	12.507	Beryllium Oxygen	36.03 63.97	50.00 50.00
9	Graphite (AGOT)	c	12.013	Carbon Iron Boron	99.98 0.02 0.6 ppm	99.99 0.01 - - -
10	Ammonia	a	4.258	Nitrogen Hydrogen	82.25 17.75	25.00 75.00
25	Uranium-natural	b	238.100	U-234 U-235 U-238	0.006 0.72 99.274	0.006 0.729 99.265
26	Uranium-fully enriched (ML-1)	d	235.280	U-235 U-236 U-238	93.15 0.13 5.82	93.22 0.13 5.75
27	UO ₂ -fully enriched	a	89.096	U-fully enriched Oxygen	88.03 11.97	33.33 66.67
30	Lithium	b	6.932	Li-6 Li-7	7.50 92.50	8.64 91.36
59	Stainless Steel-304	e	54.618	Chromium Nickel Silicon Manganese Iron Carbon	19.00 9.50 1.00 2.00 68.42 0.08	19.95 8.84 1.95 1.99 66.91 0.36
60	Stainless Steel-316	e	55.289	Chromium Nickel Silicon Manganese Iron Molybdenum Carbon	17.00 12.00 1.00 2.00 65.40 2.50 0.10	18.07 11.30 1.97 2.01 64.74 1.44 0.46

TABLE D-8 (Continued)

No.	Name	*	Atomic Weight	Components	Weight Percent	Atom Percent
61	Stainless Steel-321	e	54.658	Chromium	18.00	18.92
				Nickel	9.50	8.84
				Silicon	1.00	1.95
				Manganese	2.00	1.99
				Iron	69.42	67.94
				Carbon	0.08	0.36
62	Stainless Steel-347	e	54.684	Chromium	18.00	18.93
				Nickel	10.50	9.78
				Silicon	1.00	1.95
				Manganese	2.00	1.99
				Iron	68.42	66.99
				Carbon	0.08	0.36
63	Stainless Steel-410		54.500	Chromium	12.50	13.10
				Silicon	1.00	1.94
				Manganese	1.00	0.99
				Iron	85.35	83.29
				Carbon	0.15	0.68
64	Stainless Steel-440B		53.165	Chromium	17.00	17.38
				Silicon	1.00	1.90
				Manganese	1.00	0.97
				Iron	79.40	75.58
				Molybdenum	0.75	0.42
				Carbon	0.85	3.76
65	Hastelloy X	f	58.627	Chromium	22.37	25.22
				Manganese	0.75	0.80
				Iron	18.41	19.33
				Nickel	48.0	47.93
				Molybdenum	8.73	5.33
				Tungsten	0.31	0.10
				Cobalt	1.30	1.29
66	Inconel	g	58.461	Chromium	16.34	18.36
				Iron	9.50	9.94
				Nickel	72.00	71.70
67	Inconel-X	g	59.132	Alumium	0.70	1.53
				Chromium	15.50	17.62
				Iron	7.00	7.41
				Nickel	71.81	72.33
				Niobium	0.95	0.61
				Cobalt	0.50	0.50

TABLE D-8 (Continued)

No.	Name	*	Atomic Weight	Components	Weight Percent	Atom Percent
68	FeCrAl	h	52.774	Aluminum	4.00	7.82
				Chromium	25.00	24.37
				Iron	70.20	66.33
				Yttrium	0.80	0.48
69	Aluminum-6061	i	27.180	Silicon	0.60	0.58
				Iron	0.85	0.41
				Copper	0.50	0.21
				Manganese	0.15	0.07
				Chromium	0.25	0.13
				Aluminum	96.75	97.47
71	Haynes-25	j	64.101	Nickel	10.00	10.92
				Cobalt	50.40	54.81
				Chromium	20.00	24.65
				Tungsten	15.00	5.23
				Iron	2.30	2.64
				Manganese	1.50	1.75
72	Aluminum Oxide	a	20.392	Aluminum	52.92	40.00
				Oxygen	47.08	60.00
73	Magnesium Oxide	a	20.160	Magnesium	60.32	50.00
				Oxygen	39.68	50.00
74	Thermoflex	k	20.201	Aluminum	16.78	12.56
				Silicon	31.74	22.85
				Boron	0.02	0.04
				Oxygen	51.13	64.55
75	Refrasil	k	19.963	Silicon	46.22	32.88
				Boron	0.01	0.02
				Oxygen	53.78	67.10
89	Control Blade (ML-1)	l	109.900	Silver	80.00	80.90
				Cadmium	5.00	4.85
				Indium	15.00	14.25

* SOURCE MATERIAL - TABLE D-8

- Fixed Chemical Composition
- Natural occurring analysis taken from W. M. Sullivan's "Trilinear Chart of Nuclides", 1957.
- H. Etherington; Nuclear Engineering Handbook; Mc-Craw Hill, New York; 1958 p. 10-55 (NOTE: Iron was used to represent the impurities for which the fast cross-sections were not available.)

SOURCE MATERIAL (Continued)

- d. Analysis of fuel used in ML-1-I reactor.
- e. H. Etherington; op. crit. p. 10-60.
- f. Analysis of ML-1-I fuel pins performed by Haynes Stellite Company, 3 June 1960. Cobalt content increased to represent average Hastelloy-X content.
- g. Technical Bulletin T-38, Huntington Alloy Products Division, International Nickel Company. Note that several materials were omitted from the mixture since fast cross-sections were not available.
- h. Composition typical of present FeCrAl.
- i. H. Etherington; op crit; p. 10-47.
- j. Data from information sheet published by Haynes Stellite Company, Union Carbide Corporation, June 1962.
- k. Analysis of material used in ML-1 system.
- l. Reference ML-1 control blade composition.

and for those few, 75 groups of data are given in Ref. D-5. This reference also indicates how these data were obtained.

F. FISSION PRODUCTS

Materials 93 through 99 are labeled fission products. The data on these materials was obtained from Ref. D-5. They were not the GA data tape combined fission products. Only absorption is considered. Material 93 is the sum of the cross section data times the yield for all fission products except Xe-135 and Sm-149, expressed in units of barns per fission. Material 94 is the sum of all the "non-saturating" fission products, which build up independent of power or time and are listed in Table D-9. Material 95 is the "slowly saturating" group. Both materials 94 and 95 are also expressed in units of barns per fission. The atomic weights of materials 93, 94, and 95 have been set equal to that of U-235; if the densities of these materials are set equal to the density of U-235 times the fraction burnup, the correct macroscopic cross section will result.

Materials 96, 97, 98 and 99 (Gd-155, Xe-135, Sm-149, and Sm-151) are the principal four of the six "rapidly-saturating" fission products. The atomic weight of each of these materials has been set equal to that of U-235 divided by the yield of the given fission products. A correction term permits calculation of the macroscopic data when this value is used. The cross sections for the four materials are expressed in barns per atom.

The production of U-236 is not considered in the fission product cross section block.

G. RESONANCE MATERIALS

On the current tape the resonance parameters for nine materials are included in a form suitable for the full resonance calculations. The resonance parameters for one of these materials, thorium, were obtained directly from the old GAM data tape. The parameters for each of the other eight were generated from AGN data. It is to be noted that these nine materials are also on the library tape with infinite dilution cross sections. The infinite dilution cross sections should be used, where appropriate, in order to save computational time. Table D-5 lists the nine materials.

H. FUTURE ADDITIONS

There are material numbers in the present AGN-GAM library tape that are not in Tables D-3 and D-4. These represent locations that have been left open for future additions. Table D-10 lists some of these positions and the materials that are expected to occupy them (12, 28, 29 and 76-80). Positions 109 through 120 are available for additional materials with resonance parameters. An almost infinite number of positions is available beyond location 213.

REFERENCES - APPENDIX D

- D-1 Adler, F. T., Hinman, G.W., Nordheim, L.W., "The Quantitative Evaluation of Resonance Integrals," GA-350, 1958.
- D-2 Adler, F.T., Nordheim, L.W., "Tables for the Computation of Resonance Integrals," GA-377, 2 June 1958.
- D-3 Keepin, G.R., "Neutron Data for Reactor Kinetics," Nucleonics, 20, 8, p 152 (1962).
- D-4 Joanou, G.D., Budek, J. W., "CAM-1, A Consistant P-1 Multigroup Code for the Calculation of Fast Neutron Spectra and Multigroup Constants," GA-1850, 28 June 1961.
- D-5 Garrison, J.D., Roose, B.W., "Fission-Product Capture Cross Sections," Nuclear Science and Engineering 12, 115-134 (1962).

TABLE D-9 - FISSION PRODUCTS

NON-SATURATING FISSION PRODUCTS

Br-81, Se-82, Kr-83, Kr-84, Kr-85, Kr-86, Rb-85, Rb-87, Sr-88,
 Sr-90, Y-89, Zr-91, Zr-92, Zr-93, Zr-94, Zr-96, Mo-97, Mo-98,
 Mo-100, Ru-101, Ru-102, Ru-104, Pd-105, Pd-106, Pd-107, Pd-108,
 Pd-110, Ag-109, Cd-111, Cd-112, Cd-114, In-115, Te-126, Te-128,
 Te-130, I-127, I-129, Xe-132, Xe-134, Xe-136, Cs-135, Cs-137,
 Ba-138, La-139, Ce-140, Ce-142, Pr-141, Nd-144, Nd-146, Nd-148,
 Nd-150, Sm-154, Gd-156, Gd-158, Tb-159.

SLOWLY-SATURATING FISSION PRODUCTS

Mo-95, Tc-99, Rh-103, Xe-131, Cs-133, Nd-143, Nd-145, Pm-147,
 Sm-152, Eu-153.

RAPIDLY-SATURATING FISSION PRODUCTS

Cd-113, Sm-149, Sm-151, Gd-155, Gd-157, Xe-135.

TABLE D-10 - PROBABLE FUTURE ASSIGNMENTS
FOR CURRENTLY UNASSIGNED NUMBERS

33	Sodium
37	Sulfur
38	Potassium
39	Calcium
40	Vanadium
48	Zinc
49	Rubidium
70	Zircaloy
87	Hafnium
88	Dysprosium
92	Gold

APPENDIX E

UPDATING THE DATA TAPE

To generate or update an AGN-GAM data tape, it is necessary to perform large amounts of numerical work. The part of this work that is related to the elastic and inelastic scattering matrix and to the mixing of cross sections has largely been automated. This saves computational time and ensures greater accuracy.

The inelastic scattering matrix, as defined by previously stated equations, is generated by the INSECT code. Inputs to, and the use of, this code are described in Paragraph I of this Section. A code entitled POPl (Paragraph II) was written to generate the P_0 and P_1 elastic scattering matrices. The actual updating of the data tape is accomplished by the SCRIBBLE code. This code also mixes element cross sections to form the cross sections for mixed materials (such as the stainless steels) and produces a printed listing of the tape itself. The required inputs to this code are described in Paragraph III.

The listings of the above mentioned codes are not included because of their length and low level of interest. However, they are available, along with the punched Fortran source cards and program binary cards, from the Argonne Code Center.

I. INELASTIC SCATTERING MATRIX - THE INSECT CODE

In order to generate the inelastic scattering matrix, the equations derived in Appendix B were programmed to form the INSECT code. This routine calculates the scattering matrix, $(\Sigma_{g \rightarrow g+n}^0 / \Sigma_g^0)$, for the first twenty-five quarter-lethargy groups. As many down scattering groups are kept as are needed to include all values of the matrix larger than 10^{-5} . Final results

are printed and punched in a form suitable as input to the routines which write the AGN-GAM data tape.

The basic equation solved is (B-30). A Simpson's rule technique is used to evaluate the integral. As a check on the accuracy of the method, the matrix is summed and the result indicated in the print-out. The correct result should be exactly one.

Input data needed for INSECT includes two cards per material.

<u>Card #1</u>	Col. 1-12	Atomic weight of material
	Col. 13-24	Constant "C" of equation (B-27) in Mev. ^{1/2} If input as zero, "C" will be calculated from equation (B-28).
<u>Card #2</u>	Col. 1-46	Hollerith description of the material
	Col. 47-48	Two letter Hollerith symbol for the material. This will be used to identify the punched cards.

Problems may be stacked. Operation is standard under the MONITOR program.

II. ELASTIC SCATTERING MATRIX - THE POP1 CODE

The elastic scattering matrices needed for the AGN-GAM data tape are generated from the general equations presented in Appendix B, Section III. For these calculations, the exact integrations were performed and programmed into the POP1 code. This code, like its counterpart for inelastic scattering, prints the calculated values and punches them in a form suitable for addition to the data tape. Scattering values from all 75 fine groups are calculated. All scattering to energies below the 75th group are combined into a 76th group.

A list of the exact equations solved is not given in this document. The equations are straight-forward, although somewhat involved. (The tabulation of these equations in the original version of the GAM code (Reference E-1) contains typographical errors.)

Input Requirements are

<u>Card #1</u>	Col. 1-12	Atomic weight of material
	Col. 13-24	Number of groups for which values of $\overline{\eta}_0$ are input (see below).
<u>Card #2</u>	Col. 1-54	Hollerith description of material
	Col. 55-56	Two letter Hollerith description of material to be used to identify punched cards.
<u>Cards #3,4</u>	Col. 1-12	As many values of $\overline{\eta}_0$, the average cosine of the scattering angle in the CM system, as specified above. Start with the highest energy fine group and specify for each succeeding lower group. The last value specified will automatically be used in all lower groups (to the 75th)
	Col. 13-24	
	Etc.	

Problems may be stacked. Operation is under MONITOR control.

III. THE SCRIBBLE PROGRAM

A. INTRODUCTION

The SCRIBBLE program was written to update the AGN-GAM data tape. Besides correcting the existing cross-section data, it is able to add new materials to the tape and to prepare lists of the data on the library tape.

As an added feature, this program was designed to also mix cross-section data to form mixed materials. This permits the data tape to include materials which would normally have to be specified in any one AGN-GAM problem as several separate elements. Water is the most frequently required mixed material and is fairly simple to include; the various kinds of stainless steels require more work because of the larger number of constituent elements. By placing mixtures on the library tape, a saving in the running time per problem is obtained, since fewer materials need be read from this tape. In addition, consistency is secured in the properties of the various mixtures because a reference composition is defined.

The mixing relationships are used to find the cross-section and the atomic weight of an "average" atom of the mixture. The cross-section for water, obtained by this method, is one third of the (commonly-thought-of) value based on the cross-section per molecule. The water mixture atomic weight by this definition is 6.

Materials using the special resonance treatment can not be mixed with this routine.

The description of the input to this code will describe its operation more fully.

B. SCRIBBLE INPUT

FIGURE E-1. SCRIBBLE INPUT

The input to the SCRIBBLE code consists of five major groups of data as illustrated in Figure E-1. The first of these, the basic input parameters, must always be present. Any of the following four groups may be omitted if the basic parameters do not indicate a need for the data contained within them. Each of these groups is described in detail below.

GROUP I, BASIC INPUT PARAMETERS

These two cards must be supplied in all problems.

Card #1001 Col. 1-12

Number of materials for which cross section data are supplied. These can be either new materials to be added to the tape (either at the end of the present data or in one of the "blank" positions) or revisions of data existing on the present tape. Revisions are made by adding the corrected material to the tape in the same position as the old material. If this number is zero, no materials will be supplied in the Section II input.

Col. 13-24	Number of materials to be formed by mixing together cross-sections. These mixed materials are formed by specifying the material composition of the mixture. Both the cross-section data already on an existing data tape and those added in Section II can be used. If this number is zero, omit the Section III input.
Col. 25-36	The new ID number for the tape which is to be written. If this number is set equal to zero, no new tape will be written. This would be done only if it is desired to have SCRIBBLE just print an existing tape.
Col. 37-48	Total number of materials to be on the new data tape.
Col. 49-60	Total number of sources to be on the new data tape.
Col. 61-72	Set equal to zero if the new data tape is to include the same sources as the old data tape (omit Section IV input). Otherwise set equal to + 1.0 and supply all sources as defined in Section IV.
<u>Card #1002</u> Col. 1-72	Hollerith description of data tape. Give tape name, date, source of data, etc.

GROUP II, NEW OR REVISED MATERIAL CROSS-SECTIONS

The input discussed in this section consists of a number of sets of cross-section data. Each input material will have its own set of data. As many sets must be supplied as are specified in Col. 1-12 of Card #1001. Whether the material is a revision of existing data or the addition of an entirely new material, there is no difference in the composition of these sets. (The only difference would be the ID number assigned to the material). The sets of data are stacked one behind the other without any particular order or sequence.

Each set of data consists of four basic parameter cards followed by the required cross-sections and scattering matrices. An end card (containing a +99999.0 in the first field) is included after each material as a check to ensure the proper input.

Figure E-2 indicates the composition of the four parameter cards. The ID designations in columns 73 through 79 are for identification only and have no input significance. Included in this same figure is a check list which indicates the order in which cross-sections must be supplied. If certain data are not required for a specific material, no special cards need be substituted for those that would have given this information; the cards can simply be omitted. Lines are drawn between the key blocks and the check list summary to indicate the placement of the check list items. Definition of a scattering matrix with zero length automatically indicates that that process is not appropriate and that all input can be neglected. When the basic parameter cards are filled out to indicate the absence of a particular set of input cards, the corresponding blocks in the check list should be crossed out. Figure E-3 shows a typical form when filled out.

Each cross section block (i.e., σ_a , σ_f , ν , etc) includes 75 values, one for each of the fine groups. Because six values are given per card starting with the highest energy group (#1), thirteen cards are needed per block. All values of cross-sections are expressed in barns.

The scattering matrices are provided in a compressed form. If each element in these matrices is designated as $A_{i \rightarrow j}$, which means the scattering value from group i to group j , the input takes the form of:

$$A_{1 \rightarrow 1}, A_{1 \rightarrow 2}, A_{1 \rightarrow 3}, \dots, A_{1 \rightarrow 1+J}, A_{2 \rightarrow 2},$$

$$A_{2 \rightarrow 3}, \dots, A_{2 \rightarrow 2+J}, \dots, A_{I \rightarrow I+J}$$

In this example, J is the number of groups downscatter and I is the total number of groups considered. Values representing scattering to any group with a higher number than 76, are omitted from the list. The length of the matrix is defined as the total number of values in the matrix. Because six numbers are punched on each input card and since the matrix is input exactly as shown

1													
NAME OF MATERIAL					SOURCE OF DATA					DATE			ID
2													
MATERIAL ID			ATOMIC wt		ABSORPTION?		FISSION?		RESON A35?		RESON FIS?		ID
3													
LENGTH			# GROUPS		GRS DWN SCAT		LENGTH			# GROUPS		ID	
INELASTIC SCATTER MATRIX					n-2n MATRIX								
4													
LENGTH			# GROUPS		GRS DWN SCAT		TRANSPORT?		75 gr DATA?		ID		
P ₀ AND P ₁ SCATTERING MATRICES													

CHECK LIST		
ITEM	NO.	OK
PARAMETER CARDS	4	
σ_o	13	
σ_f	13	
ν	13	
σ_{ie}	13	
INELASTIC MATRIX		
σ_{n-2n}	13	
n-2n MATRIX		
σ_s	13	
P ₀ MATRIX		
P ₁ MATRIX		
TRANSPORT L-1	13	
TRANSPORT L-2	13	
RESONANCE PARAMETERS	2	
RESONANCE VALUES		
END CARD	1	
TOTAL CARDS		
IS THIS MATERIAL IN THE PROPER SEQUENCE		
ARE THE CARDS IN THE ABOVE ORDER?		

FIGURE E-2. PARAMETER CARD

FOR QUESTIONS; YES = 1.0, NO = 0.0 (IF NO, STRIKE OUT CORRESPONDING BLOCK IN CHECK LIST).

IRON			AGN - AN - COM - 47 (DEC 60)			1 JULY 1964		FE	1	
NAME OF MATERIAL			SOURCE OF DATA			DATA		ID	80	
+44.0			+55.85			+1.0		+0.0		
+0.0			+0.0			+0.0		+0.0		
FE			2							
MATERIAL ID 13			ATOMIC wt 25			ABSORPTION? 37			FISSION? 49	
RESON ABS? 61			RESON FIS? 73			ID			80	
+280.0			+10.0			+27.0		+0.0		
+0.0			+0.0			+0.0		+0.0		
FE			3							
LENGTH 13			# GROUPS 25			GRS DWNSCAT 37			LENGTH 49	
# GROUPS 61			GRS DWNSCAT 73			ID			80	
INELASTIC SCATTER MATRIX					n-2n MATRIX					
+150.0			+75.0			+1.0		+1.0		
+1.0			+1.0			+1.0		+1.0		
FE			4							
LENGTH 13			# GROUPS 25			GRS DWNSCAT 37			TRANSPORT? 49	
75 gr DATA? 61			73			ID			80	
P ₀ AND P ₁ SCATTERING MATRICES										

ITEM	NO. OK CARDS	
PARAMETER CARDS	4	
σ_a	13	
σ_f	13	
ν	13	
σ_{ie}	13	
INELASTIC MATRIX	47	
σ_{n-2n}	13	
σ_s	13	
P ₀ MATRIX	25	
P ₁ MATRIX	25	
TRANSPORT L-1	13	
TRANSPORT L-2	13	
RESONANCE PARAMETERS	2	
RESONANCE VALUES	1	
END CARDS	1	
TOTAL CARDS	167	
IS THIS MATERIAL IN THE PROPER SEQUENCE	---	
ARE THE CARDS IN THE ABOVE ORDER?	---	

FIGURE E-3. FILLED-OUT PARAMETER CARD

without blanks or spacing between groups, the total number of input cards for the matrix is equal to its length divided by six and rounded off to the next highest integer. Note that the terms to be input are the probabilities of scattering, not the product of cross-section and probability. If a scattering matrix is specified for groups in which a zero cross-section is then given, the SCRIBBLE program will disregard the zero values and shorten the stored matrix.

If the material has resonance absorption and/or resonance fission and the special resonance treatment is to be performed, additional input is necessary. First, two cards containing basic parameters and unresolved region data are required. These contain:

<u>1st Card</u>	Col. 1-12	Total number of resonances
	Col. 13-24	Atomic mass
	Col. 25-36	Unresolved region's lower cut-off energy, ev.
	Col. 37-48	D, Unresolved region energy level spacing, ev.
	Col. 49-60	$\langle \Gamma_n^0 \rangle$ average reduced neutron width, ev
	Col. 61-72	Γ_γ , average radiative width, $\sqrt{ev}$.
<u>2nd Card</u>	Col. 1-12	$\sigma_{(potential)}$, barns
	Col. 13-24	Statistical weight factor, g
	Col. 25-36	Γ_f , average fission width ev.

Following these cards are a series of cards describing the parameters for each resonance. Two cards per resonance are required.

<u>1st Card</u>	Col. 1-12	Energy of resonance, ev.
	Col. 13-24	Γ_n , neutron width of resonance, ev.
	Col. 25-36	Γ_γ , radiative width of resonance, ev.
	Col. 37-48	Γ_f , fission width of resonance, ev.
	Col. 49-60	1.0 if narrow resonance infinite absorption approximation used (NR1A); 2.0 if narrow resonance approximation to be used, (NR)

Col. 61-72	Isotopic abundance of the isotope having this resonance (if a pure material, set equal to one).
------------	---

<u>2nd Card</u>	Col. 1-12	Statistical weight factor, g.
-----------------	-----------	-------------------------------

The inputs for the material specified on Figure E-4 are shown in Figure E-5, as an example of the format used to input cross-sections but not to specify particular cross-section data.

GROUP III, MIXED MATERIAL DEFINITIONS

One set of cards must be supplied for each material which is to be formed by mixing together materials already on the AGN-GAM library tape or materials that have been added as part of the Group II input. A mixed material is added to the tape either as a new material or an up-dated material. The number of mixed materials is given in Col. 13-24 of Card #1001 and one set of cards must be present for each of these. Omit all cards if no mixing is to be done.

<u>Card #1</u>	Col. 1-30	Name of material
	Col. 31-60	Source of cross-section data
	Col. 61-72	Date material added to tape
<u>Card #2</u>	Col. 1-12	Library tape ID number assigned to mixed material. Must be equal to or less than the maximum number of materials on this tape.
	Col. 13-24	Number of materials to be used to make the mixture.
	Col. 25-36	+ 1.0 if the mixed cross-section data is to be considered valid for use in transport codes; 0.0 otherwise.
	Col. 37-48	+ 1.0 if the mixed data is to be considered to have valid data in all 75 groups. Set equal to zero if only 68 groups are valid.
<u>Cards # 3, 4, etc.</u>	Col. 1-12	Tape ID number of the first material in the mixture. If this material has just been

	read into the program (in Group II) for addition to the library, place a negative sign before the normal ID number.
Col. 13-24	The weight fraction of the first material in the mixture.
Col. 25-36	ID number of the second material.
Col. 37-48	Weight fraction of the second material, etc.

GROUP IV, SOURCES

If the sources are to be read into the program and added to the library tape (option in Col. 61-72 of Card #1001), they will be placed into the input at this location. Since the total group of sources represents only a very small number of cards, it is necessary to input the complete set of sources in order to change one source or to add a new source. The total number of sources is given in Col. 49-60 of Card #1001. For each of these, the following set of cards must be supplied.

<u>Card #1</u>	Col. 1-72	Hollerith description of source
<u>Cards #2-14</u>		Seventy-five values of the source in each group, starting with the first (highest energy) group. Since the AGN-GAM program automatically normalizes the input source, no special normalization is necessary.
<u>Card #15</u>		End Card, +99999.0 in Col. 1-12

GROUP V, PRINTOUT OPTIONS

This group of cards defines the extent of the printout of the new AGN-GAM library tape. It is possible to obtain as little as the listing of one material or as much as all data on the entire tape. Special summary lists are available.

The first card describes the information wanted on general terms:

Col. 1-12	A + 1.0 if the resonance tables are to be printed. (These lists are finished tables with the proper description and coordinates. They are not just pages of unlabeled numbers.)
-----------	---

Col. 13-24	A + 1.0 if the sources are to be printed.
Col. 25-36	A + 1.0 if there is to be a printout of a summary table of materials on the library tape. This table includes, in numerical order of the ID numbers, the name, atomic weight, date added, and source of the materials and an indication of what cross-section blocks are included.
Col. 37-48	A + 1.0 if summary cards are to be punched for each material in the library. These cards are identical to the first card of the material input parameter cards (name, source, data added) with the material ID number punched into Col. 72-80.

The following cards describe which materials on the library tape are to be printed. Each of these cards contains two numbers (in the first two fields). As many cards as necessary can be used. Each of the two numbers represents an ID number of a material on the tape. Printing will start at the first of these numbers and all materials up to and including the second of the ID numbers will be printed. The cards must be placed so that the ID numbers are in ascending order.

For example, if the information for materials 2, 7, 8, 15, 75 through 90, and 107 must be printed, the input cards to accomplish this would look as shown below:

+ 2.0	+ 2.0
+ 7.0	+ 8.0
+ 15.0	+ 15.0
+ 75.0	+ 90.0
+ 107.0	+ 107.0

At the end of this description, an end card (with a +99999.0 in the first field) will be added.

Figure E-5 gives a sample of the printout obtained from SCRIBBLE.

C. OPERATING INSTRUCTIONS

SCRIBBLE is operated under MONITOR control. It is necessary to place the old AGN-GAM tape on logical tape number 1, the new AGN-GAM tape (to be written) on tape number 6, and erasable tapes on number 5 and 7.

If an existing tape is just to be printed, it should be placed on tape number 6 with an erasable tape on number 1.

There are a number of internal checks of input data. When appropriate, these checks result in error statements in the off-line printout and an automatic exit from the program.

IRON
+44.0 +55.85 +1.0 +0.0 +0.0 +0.0 +0.0 FE 1
+280.0 +10.0 +27.0 +0.0 +0.0 +0.0 FE 2
+150.0 +75.0 +1.0 +1.0 +1.0 +1.0 FE 3
+1.00000E-02 2.00000E-02 10.00000E-03 1.50000E-03 10.00000E-04 10.00000E-04FE 4
10.00000E-04 10.00000E-04 10.00000E-04 10.00000E-04 10.00000E-04 10.00000E-04FE 5
2.00000E-03 3.00000E-03 4.00000E-03 4.50000E-03 5.00000E-03 5.00000E-03FE 6
5.10000E-03 5.20000E-03 7.00000E-03 3.00000E-03 2.00000E-03 2.00000E-03FE 7
5.20000E-03 6.60000E-03 6.70000E-03 6.80000E-03 6.80000E-03 6.80000E-03FE 8
1.32000E-01 1.32000E-01 1.40000E-01 1.41000E-01 1.42000E-01 1.43000E-01FE 9
1.44000E-01 1.45000E-01 1.46000E-01 1.48000E-01 1.49000E-01 1.50000E-01FE 10
1.51000E-01 1.53000E-01 1.54000E-01 1.56000E-01 1.58000E-01 1.60000E-01FE 11
1.70000E-01 1.76000E-01 1.84000E-01 1.93000E-01 2.03000E-01 1.70000E-01FE 12
1.19800E-01 1.13700E-01 1.53800E-01 1.74300E-01 1.97500E-01 2.23800E-01FE 13
2.53600E-01 2.87400E-01 3.25600E-01 3.69000E-01 4.18100E-01 4.73800E-01FE 14
5.36900E-01 6.08400E-01 6.89400E-01 7.81200E-01 8.85200E-01 1.00300E-01FE 15
1.13700E-01 1.28800E-01 1.45900E-01 1.60000E-01 1.79900E-01 2.00900E-01FE 16
1.35000E-01 1.38000E-01 1.39000E-01 1.34000E-01 1.19900E-01 1.00900E-01FE 17
8.20000E-01 6.99000E-01 5.00000E-01 1.00000E-01 0. 0. 0. FE 18
0. 0. 0. 0. 0. 0. FE 19
0. 0. 0. 0. 0. 0. FE 20
0. 0. 0. 0. 0. 0. FE 21
0. 0. 0. 0. 0. 0. FE 22
0. 0. 0. 0. 0. 0. FE 23
0. 0. 0. 0. 0. 0. FE 24
0. 0. 0. 0. 0. 0. FE 25
0. 0. 0. 0. 0. 0. FE 26
0. 0. 0. 0. 0. 0. FE 27
0. 0. 0. 0. 0. 0. FE 28
0. 0. 0. 0. 0. 0. FE 29
0. 0. 0. 0. 0. 0. FE 30
0. 0. 0. 0. 0. 0. FE 31
0. 0. 0. 0. 0. 0. FE 32
0. 0. 0. 0. 0. 0. FE 33
0. 0. 0. 0. 0. 0. FE 34
0. 0. 0. 0. 0. 0. FE 35
0. 0. 0. 0. 0. 0. FE 36
0. 0. 0. 0. 0. 0. FE 37
0. 0. 0. 0. 0. 0. FE 38
0. 0. 0. 0. 0. 0. FE 39
0. 0. 0. 0. 0. 0. FE 40
0. 0. 0. 0. 0. 0. FE 41
0. 0. 0. 0. 0. 0. FE 42
0. 0. 0. 0. 0. 0. FE 43
0. 0. 0. 0. 0. 0. FE 44
0. 0. 0. 0. 0. 0. FE 45
0. 0. 0. 0. 0. 0. FE 46
0. 0. 0. 0. 0. 0. FE 47
0. 0. 0. 0. 0. 0. FE 48
0. 0. 0. 0. 0. 0. FE 49
0. 0. 0. 0. 0. 0. FE 50
0. 0. 0. 0. 0. 0. FE 51
0. 0. 0. 0. 0. 0. FE 52
0. 0. 0. 0. 0. 0. FE 53
0. 0. 0. 0. 0. 0. FE 54
0. 0. 0. 0. 0. 0. FE 55
0. 0. 0. 0. 0. 0. FE 56
0. 0. 0. 0. 0. 0. FE 57
0. 0. 0. 0. 0. 0. FE 58
0. 0. 0. 0. 0. 0. FE 59
0. 0. 0. 0. 0. 0. FE 60
0. 0. 0. 0. 0. 0. FE 61
0. 0. 0. 0. 0. 0. FE 62
0. 0. 0. 0. 0. 0. FE 63
0. 0. 0. 0. 0. 0. FE 64
0. 0. 0. 0. 0. 0. FE 65
0. 0. 0. 0. 0. 0. FE 66
0. 0. 0. 0. 0. 0. FE 67
0. 0. 0. 0. 0. 0. FE 68
0. 0. 0. 0. 0. 0. FE 69
0. 0. 0. 0. 0. 0. FE 70
0. 0. 0. 0. 0. 0. FE 71
0. 0. 0. 0. 0. 0. FE 72
0. 0. 0. 0. 0. 0. FE 73
0. 0. 0. 0. 0. 0. FE 74
0. 0. 0. 0. 0. 0. FE 75
0. 0. 0. 0. 0. 0. FE 76
0. 0. 0. 0. 0. 0. FE 77
0. 0. 0. 0. 0. 0. FE 78
0. 0. 0. 0. 0. 0. FE 79
0. 0. 0. 0. 0. 0. FE 80
0. 0. 0. 0. 0. 0. FE 81
0. 0. 0. 0. 0. 0. FE 82
0. 0. 0. 0. 0. 0. FE 83
0. 0. 0. 0. 0. 0. FE 84
0. 0. 0. 0. 0. 0. FE 85
0. 0. 0. 0. 0. 0. FE 86
0. 0. 0. 0. 0. 0. FE 87
0. 0. 0. 0. 0. 0. FE 88
0. 0. 0. 0. 0. 0. FE 89
0. 0. 0. 0. 0. 0. FE 90
0. 0. 0. 0. 0. 0. FE 91
0. 0. 0. 0. 0. 0. FE 92
0. 0. 0. 0. 0. 0. FE 93
0. 0. 0. 0. 0. 0. FE 94
0. 0. 0. 0. 0. 0. FE 95
0. 0. 0. 0. 0. 0. FE 96
0. 0. 0. 0. 0. 0. FE 97
0. 0. 0. 0. 0. 0. FE 98
0. 0. 0. 0. 0. 0. FE 99
0. 0. 0. 0. 0. 0. FE 100
0. 0. 0. 0. 0. 0. FE 101
0. 0. 0. 0. 0. 0. FE 102
0. 0. 0. 0. 0. 0. FE 103
0. 0. 0. 0. 0. 0. FE 104
0. 0. 0. 0. 0. 0. FE 105
0. 0. 0. 0. 0. 0. FE 106
0. 0. 0. 0. 0. 0. FE 107
0. 0. 0. 0. 0. 0. FE 108
0. 0. 0. 0. 0. 0. FE 109
0. 0. 0. 0. 0. 0. FE 110
0. 0. 0. 0. 0. 0. FE 111
0. 0. 0. 0. 0. 0. FE 112
0. 0. 0. 0. 0. 0. FE 113
0. 0. 0. 0. 0. 0. FE 114
0. 0. 0. 0. 0. 0. FE 115
0. 0. 0. 0. 0. 0. FE 116
0. 0. 0. 0. 0. 0. FE 117
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0. 0. 0. 0. 0. 0. FE 126
0. 0. 0. 0. 0. 0. FE 127
0. 0. 0. 0. 0. 0. FE 128
0. 0. 0. 0. 0. 0. FE 129
0. 0. 0. 0. 0. 0. FE 130
0. 0. 0. 0. 0. 0. FE 131
0. 0. 0. 0. 0. 0. FE 132
0. 0. 0. 0. 0. 0. FE 133
0. 0. 0. 0. 0. 0. FE 134
0. 0. 0. 0. 0. 0. FE 135
0. 0. 0. 0. 0. 0. FE 136
0. 0. 0. 0. 0. 0. FE 137
0. 0. 0. 0. 0. 0. FE 138
0. 0. 0. 0. 0. 0. FE 1

FIGURE E-5. SAMPLE PRINTOUT OF SCRIBBLE CODE

AGN-GAM DATA TAPE NUMBER 1003							
1 JUL 1964							
SURFACE RESONANCE TABLE FOR SLAB -- L(2,XI,K) -- Z = 0.10							
K/XI	0.020	0.030	0.040	0.050	0.100	0.150	0.200
4.0	1.1400E-01	4.6800E-02	7.7000E-02	6.5430E-02	4.2500E-02	3.6300E-02	3.4020E-02
4.5	1.7640E-01	1.2840E-01	1.0230E-01	8.6680E-02	5.4830E-02	4.5480E-02	4.1810E-02
5.0	2.2470E-01	1.6910E-01	1.3540E-01	1.1450E-01	7.1220E-02	5.7530E-02	5.1840E-02
5.5	2.7420E-01	2.2050E-01	1.7780E-01	1.5050E-01	9.2880E-02	7.3430E-02	6.4880E-02
6.0	3.2450E-01	2.7320E-01	2.3110E-01	1.9600E-01	1.2120E-01	7.4350E-02	6.1900E-02
6.5	4.4420E-01	3.5600E-01	2.9560E-01	2.5210E-01	1.5780E-01	1.2170E-01	1.0420E-01
7.0	5.2600E-01	4.3510E-01	3.5990E-01	3.1820E-01	2.0420E-01	1.5710E-01	1.3310E-01
7.5	5.9340E-01	5.1370E-01	4.4930E-01	3.9180E-01	2.6150E-01	2.0210E-01	1.7030E-01
8.0	6.4240E-01	5.9320E-01	5.2660E-01	4.6780E-01	3.2930E-01	2.5770E-01	2.1730E-01
8.5	6.4680E-01	6.3530E-01	5.9340E-01	5.3880E-01	4.0480E-01	3.2380E-01	2.7500E-01
9.0	6.6290E-01	6.6380E-01	6.4160E-01	5.9710E-01	4.8230E-01	3.9780E-01	3.4260E-01
9.5	6.1420E-01	6.6530E-01	6.5530E-01	6.3560E-01	5.5390E-01	4.7410E-01	4.1700E-01
10.0	5.9150E-01	6.3960E-01	6.5170E-01	6.4980E-01	6.1150E-01	5.4530E-01	4.9190E-01
10.5	5.1240E-01	5.7020E-01	6.3140E-01	6.3790E-01	6.4780E-01	5.0290E-01	5.5960E-01
11.0	4.3460E-01	5.7320E-01	5.7840E-01	6.0160E-01	6.5840E-01	5.4010E-01	6.1200E-01
11.5	3.5610E-01	4.4640E-01	5.0910E-01	5.4550E-01	6.4220E-01	5.5210E-01	6.4270E-01
12.0	2.8280E-01	3.6760E-01	4.3140E-01	4.7600E-01	6.0120E-01	5.3750E-01	6.4760E-01
12.5	2.1870E-01	2.7330E-01	3.5310E-01	4.0060E-01	5.4060E-01	5.9830E-01	6.2640E-01
13.0	1.6550E-01	2.2770E-01	2.8020E-01	3.2610E-01	4.6750E-01	5.3940E-01	5.8180E-01
13.5	1.2310E-01	1.7240E-01	2.1660E-01	2.5770E-01	3.8980E-01	4.6770E-01	5.1920E-01
14.0	9.0250E-02	1.2870E-01	1.6380E-01	1.9870E-01	3.1440E-01	3.9090E-01	4.4580E-01
14.5	6.5630E-02	9.4770E-02	1.2180E-01	1.5000E-01	2.4640E-01	3.1600E-01	3.6930E-01
15.0	4.7530E-02	6.8940E-02	9.9360E-02	1.1130E-01	1.8850E-01	2.4820E-01	2.9620E-01
15.5	3.3540E-02	4.9760E-02	5.4900E-02	8.1610E-02	1.4140E-01	1.9010E-01	2.3110E-01
16.0	2.4240E-02	3.5710E-02	4.5790E-02	5.9240E-02	1.0440E-01	1.4280E-01	1.7610E-01
16.5	1.7260E-02	2.5520E-02	3.3550E-02	4.2690E-02	7.6250E-02	1.0560E-01	1.3170E-01
17.0	1.2270E-02	1.8180E-02	2.3960E-02	3.0500E-02	5.5180E-02	7.7150E-02	9.7040E-02
17.5	8.7670E-03	1.2930E-02	1.7060E-02	2.1850E-02	3.9680E-02	5.5870E-02	7.0720E-02
18.0	6.1720E-03	9.1740E-03	1.2130E-02	1.5560E-02	2.8390E-02	4.0180E-02	5.1110E-02
18.5	4.3720E-03	6.5050E-03	9.5050E-03	1.1060E-02	2.0250E-02	2.8760E-02	3.6720E-02
19.0	3.0560E-03	4.6080E-03	6.1000E-03	7.8450E-03	1.4400E-02	2.0520E-02	2.6260E-02
19.5	2.1910E-03	3.2680E-03	4.3210E-03	5.5610E-03	1.0230E-02	1.4600E-02	1.8720E-02
20.0	1.5500E-03	2.3100E-03	3.0590E-03	3.9390E-03	7.2560E-03	1.0370E-02	1.3310E-02

AGN-GAM DATA TAPE NUMBER 1003							
1 JUL 1964							
SURFACE RESONANCE TABLE FOR SLAB -- L-PRIME(K,XI)							
K/XI	0.050	0.100	0.150	0.200	0.250	0.300	0.350
-2.0	3.9410E-03	2.9150E-03	2.9100E-03	2.9090E-03	2.9080E-03	2.9080E-03	2.9070E-03
-1.5	3.9340E-03	3.8780E-03	3.8690E-03	3.8660E-03	3.8640E-03	3.8630E-03	3.8630E-03
-1.0	4.1580E-03	5.0840E-03	5.0660E-03	5.0600E-03	5.0580E-03	5.0560E-03	5.0550E-03
-0.5	4.3040E-03	5.5760E-03	5.5440E-03	5.5330E-03	5.5280E-03	5.5250E-03	5.5230E-03
0.0	4.4480E-03	6.0700E-03	6.0340E-03	6.0300E-03	6.03210E-03	6.03160E-03	6.03130E-03
0.5	4.1470E-02	1.0650E-02	1.0540E-02	1.0510E-02	1.0490E-02	1.0480E-02	1.0480E-02
1.0	4.4660E-02	1.3390E-02	1.3200E-02	1.3140E-02	1.3110E-02	1.3100E-02	1.3090E-02
1.5	4.9200E-02	1.6780E-02	1.6410E-02	1.6310E-02	1.6260E-02	1.6230E-02	1.6220E-02
2.0	5.5140E-02	2.0980E-02	2.0310E-02	2.0120E-02	2.0040E-02	2.0000E-02	1.9970E-02
2.5	6.2870E-02	2.6260E-02	2.5070E-02	2.4720E-02	2.4580E-02	2.4510E-02	2.4460E-02
3.0	7.3160E-02	3.2990E-02	3.0930E-02	3.0300E-02	3.0040E-02	2.9910E-02	2.9840E-02
3.5	8.6660E-02	4.1660E-02	3.8220E-02	3.7100E-02	3.6640E-02	3.6410E-02	3.6290E-02
4.0	9.5110E-02	5.2930E-02	4.7410E-02	4.5490E-02	4.4670E-02	4.4260E-02	4.4030E-02
4.5	9.9260E-02	6.1700E-02	5.9120E-02	5.5930E-02	5.4510E-02	5.3780E-02	5.3370E-02
5.0	1.03140E-01	7.1110E-02	7.4200E-02	6.9080E-02	6.6700E-02	6.5440E-02	6.4730E-02
5.5	1.1240E-01	1.1260E-01	9.3730E-02	8.5820E-02	8.1950E-02	7.9850E-02	7.8610E-02
6.0	1.2760E-01	1.4610E-01	1.1910E-01	1.0730E-01	1.0120E-01	9.7820E-02	9.5770E-02
6.5	1.4640E-01	1.8960E-01	1.5220E-01	1.3500E-01	1.2580E-01	1.2050E-01	1.1720E-01
7.0	1.6070E-01	2.4570E-01	1.9510E-01	1.7070E-01	1.5730E-01	1.4920E-01	1.4400E-01
7.5	1.8010E-01	3.1660E-01	2.5020E-01	2.1670E-01	1.9760E-01	1.8580E-01	1.7800E-01
8.0	2.0150E-01	4.0390E-01	3.1990E-01	2.7550E-01	2.4910E-01	2.3230E-01	2.2100E-01
8.5	2.0580E-01	5.0660E-01	4.0550E-01	3.4900E-01	3.1410E-01	2.9120E-01	2.7530E-01
9.0	3.2400E-01	6.2120E-01	5.0640E-01	4.3850E-01	3.9440E-01	3.6450E-01	3.4320E-01

K/XI	0.400	0.450	0.500	0.550
-2.0	2.9070E-03	2.9070E-03	2.9070E-03	2.9070E-03
-1.5	3.8620E-03	3.8620E-03	3.8620E-03	3.8620E-03
-1.0	5.0530E-03	5.0540E-03	5.0540E-03	5.0530E-03
-0.5	6.5190E-03	6.5220E-03	6.5210E-03	6.5190E-03
0.0	8.3050E-03	8.3100E-03	8.3090E-03	8.3050E-03
0.5	1.0470E-02	1.0470E-02	1.0470E-02	1.0470E-02
1.0	1.3060E-02	1.3080E-02	1.3080E-02	1.3060E-02
1.5	1.6180E-02	1.6200E-02	1.6200E-02	1.6180E-02
2.0	1.9900E-02	1.9940E-02	1.9940E-02	1.9900E-02
2.5	2.4340E-02	2.4410E-02	2.4400E-02	2.4340E-02
3.0	2.9640E-02	2.9760E-02	2.9730E-02	2.9640E-02
3.5	3.5940E-02	3.6150E-02	3.6100E-02	3.5940E-02
4.0	4.3450E-02	4.3790E-02	4.3720E-02	4.3450E-02
4.5	5.2370E-02	5.2960E-02	5.2840E-02	5.2370E-02
5.0	6.2990E-02	6.3990E-02	6.3790E-02	6.2990E-02
5.5	7.5610E-02	7.7330E-02	7.5990E-02	7.5610E-02
6.0	9.0610E-02	9.2970E-02	9.0610E-02	9.0610E-02
6.5	1.0840E-01	1.1350E-01	1.1250E-01	1.0840E-01
7.0	1.2960E-01	1.3820E-01	1.3650E-01	1.2960E-01
7.5	1.5470E-01	1.6890E-01	1.6610E-01	1.5470E-01
8.0	1.8450E-01	2.0730E-01	2.0310E-01	1.8450E-01
8.5	2.1980E-01	2.5600E-01	2.4930E-01	2.1980E-01
9.0	2.6150E-01	3.1590E-01	3.0680E-01	2.6150E-01

AGN-GAM DATA TAPE NUMBER 1003							
1 JUL 1964							
SOURCE SPECTRUM NUMBER 1							
THE	U-235	SPECTRUM	- PROMPT	+ DELAYED			
1	5.92600E-03	16	1.47040E-02	21	-0.	46	-0.
2	1.69510E-02	17	1.411590E-02	22	-0.	47	-0.
3	3.92170E-02	18	7.655500E-03	23	-0.	48	-0.
4	6.83300E-02	19	5.451200E-03	24	-0.	49	-0.
5	9.57040E-02	20	3.490600E-03	25	-0.	50	-0.
6	1.13380E-01	21	2.373700E-03	26	-0.	51	-0.
7	1.18208E-01	22	1.909900E-03	27	-0.	52	-0.
8	1.11753E-01	23	1.30200E-03	28	-0.	53	-0.
9	9.81090E-02	24	8.86000E-04	29	-0.	54	-0.
10	8.14510E-02	25	5.98000E-04	30	-0.	55	-0.
11	6.48210E-02	26	4.407000E-04	31	-0.	56	-0.
12	4.99930E-02	27	2.81000E-04	32	-0.	57	-0.
13	3.76330E-02	28	-0.	33	-0.	58	-0.
14	2.78120E-02	29	-0.	34	-0.	59	-0.
15	2.03060E-02	30	-0.	35	-0.	60	-0.

SOURCE SPECTRUM NUMBER 2							
THE	U-235	SPECTRUM	- PROMPT	(CRANBERG)			
1	5.96420E-03	16	1.441940E-02	31	0.	51	0.
2	1.70590E-02	17	1.400610E-02	32	0.	52	0.
3	3.94680E-02	18	7.08220E-03	33	0.	53	0.
4	6.87700E-02	19	4.95880E-03	34	0.	54	0.
5	9.63240E-02	20	3.45780E-03	35	0.	55	0.
6	1.14110E-01	21	2.440330E-03	36	0.	56	0.
7	1.18950E-01	22	1.66630E-03	37	0.	57	0.
8	1.12440E-01	23	1.15300E-03	38	0.	58	0.
9	9.86710E-02	24	7.96670E-04	39	0.	59	0.
10	8.18060E-02	25	5.49810E-04	40	0.	60	0.
11	6.49490E-02	26	3.79090E-04	41	0.	61	0.
12	4.98850E-02	27	2.61190E-04	42	0.	62	0.
13	3.73550E-02	28	0.	43	0.	63	0.
14	2.74330E-02	29	0.	44	0.	64	0.
15	1.98470E-02	30	0.	45	0.	65	0.

SOURCE SPECTRUM NUMBER 3							
THE	U-235	SPECTRUM	- DELAYED	(KEEPIN)			
1	0.	16	9.20500E-02	21	-0.	46	-0.
2	0.	17	9.48800E-02	22	-0.	47	-0.
3	0.	18	9.51500E-02	23	-0.	48	-0.
4	0.	19	8.99300E-02	24	-0.	49	-

AGN-GAM DATA TAPE NUMBER 1003

1 JUL 1964

MATERIAL NUMBER 44 IRON

SOURCE - AGN

DATE ADDED - 1 JULY 1964

ATOMIC WEIGHT = 5.5850F 01

GRP. NO.	SIGMA TOTAL	SIGMA ABSORPTION	SIGMA ELASTIC	SIGMA INELASTIC	SIGMA N-2N	SIGMA FISSION	NU	L-1	L-2
1	3.2595F 00	5.0000E-02	1.9000E 00	1.3500E 00	0.	0.	0.	8.2701E-01	5.2131E-01
2	3.6000F 00	5.0000E-02	2.2000E 00	1.3800E 00	0.	0.	0.	8.2501E-01	6.1531E-01
3	3.5595F 00	10.0000E-03	2.2000E 00	1.3900E 00	0.	0.	0.	7.6000E-01	5.5730E-01
4	3.4765F 00	1.5000E-03	2.1350E 00	1.3400E 00	0.	0.	0.	6.6000E-01	5.2700E-01
5	3.3000F 00	10.0000E-04	2.1000E 00	1.1990E 00	0.	0.	0.	5.2500E-01	3.9200E-01
6	3.1000F 00	10.0000E-04	2.0900E 00	1.0990E 00	0.	0.	0.	4.0000E-01	3.3030E-01
7	2.9000F 00	10.0000E-04	1.9790E 00	8.1999E-01	0.	0.	0.	3.0000E-01	2.6030E-01
8	2.7000F 00	10.0000E-04	2.0000E 00	6.9898E-01	0.	0.	0.	2.4000E-01	2.0030E-01
9	2.5000F 00	10.0000E-04	1.9990E 00	4.9999E-01	0.	0.	0.	2.1000E-01	1.6030E-01
10	2.4500F 00	10.0000E-04	2.3490E 00	10.0000E-02	0.	0.	0.	2.0000E-01	1.5030E-01
11	3.0000F 00	10.0000E-04	2.9990E 00	0.	0.	0.	0.	1.4500E-01	1.2000E-01
12	2.6000F 00	10.0000E-04	2.5990E 00	0.	0.	0.	0.	2.3300E-01	1.0000E-01
13	2.5000F 00	2.0000E-03	2.4980E 00	0.	0.	0.	0.	1.5000E-01	5.3330E-02
14	3.0000F 00	3.0000E-03	2.9970E 00	0.	0.	0.	0.	9.0000E-02	2.8000E-02
15	3.0000F 00	4.0000E-03	2.9960E 00	0.	0.	0.	0.	8.0000E-02	9.0000E-03
16	3.0000F 00	4.5000E-03	2.9955E 00	0.	0.	0.	0.	7.0000E-02	5.0030E-03
17	3.0000F 00	5.0000E-03	2.9950E 00	0.	0.	0.	0.	5.0000E-02	6.0000E-03
18	3.0000F 00	5.5000E-03	2.9950E 00	0.	0.	0.	0.	2.7000E-02	6.0000E-03
19	3.5000F 00	5.1000E-03	3.4949E 00	0.	0.	0.	0.	2.0000E-02	7.0000E-03
20	3.0000F 00	5.7000E-03	2.9948E 00	0.	0.	0.	0.	1.1900E-02	7.3000E-03
21	3.1000F 00	7.0000E-03	3.0930E 00	0.	0.	0.	0.	1.1900E-02	5.0000E-03
22	4.6000F 00	3.0000E-03	4.5970E 00	0.	0.	0.	0.	1.1900E-02	5.0030E-03
23	7.0000F 00	2.0000E-03	6.9980E 00	0.	0.	0.	0.	1.1900E-02	3.3330E-03
24	1.5000F 01	2.0000E-03	1.5798E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-03
25	1.1000F 01	5.2000E-02	1.0948E 01	0.	0.	0.	0.	1.1900E-02	2.0000E-03
26	2.6000F 00	6.0000E-02	2.5340E 00	0.	0.	0.	0.	1.1900E-02	1.3030E-03
27	4.5000F 00	6.7000E-02	4.4330E 00	0.	0.	0.	0.	1.1900E-02	3.0030E-04
28	6.4000F 00	6.3000E-02	6.3320E 00	0.	0.	0.	0.	1.1900E-02	3.0000E-04
29	1.5000F 01	6.0000E-02	1.4932E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
30	1.9000F 01	7.0000E-02	1.7930E 01	0.	0.	0.	0.	1.1900E-02	3.3330E-04
31	4.0000F 00	1.2500E-01	7.8610E 00	0.	0.	0.	0.	1.1900E-02	3.0000E-04
32	5.5000F 00	1.3500E-01	5.3610E 00	0.	0.	0.	0.	1.1900E-02	3.0030E-04
33	5.1000F 00	1.4000E-01	4.9600E 00	0.	0.	0.	0.	1.1900E-02	3.3330E-04
34	6.1000F 00	1.4100E-01	5.9590E 00	0.	0.	0.	0.	1.1900E-02	3.0000E-04
35	7.0000F 00	1.4200E-01	6.8580E 00	0.	0.	0.	0.	1.1900E-02	3.0000E-04
36	8.0000F 00	1.4300E-01	7.8570E 00	0.	0.	0.	0.	1.1900E-02	3.0030E-04
37	8.9000F 00	1.4400E-01	8.6560E 00	0.	0.	0.	0.	1.1900E-02	3.3030E-04
38	9.4000F 00	1.4500E-01	9.2550E 00	0.	0.	0.	0.	1.1900E-02	3.0030E-04
39	10.0000F 00	1.4600E-01	9.8540E 00	0.	0.	0.	0.	1.1900E-02	3.0030E-04
40	1.0500F 01	1.4900E-01	1.0752E 01	0.	0.	0.	0.	1.1900E-02	3.3330E-04

AGN-GAM DATA TAPE NUMBER 1003

1 JUL 1964

MATERIAL NUMBER 44 IRON

SOURCE - AGN

DATE ADDED - 1 JULY 1964

ATOMIC WEIGHT = 5.5850F 01

GRP. NO.	SIGMA TOTAL	SIGMA ABSORPTION	SIGMA ELASTIC	SIGMA INELASTIC	SIGMA N-2N	SIGMA FISSION	NU	L-1	L-2
41	1.0000E 01	1.4500E-01	1.0651E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
42	1.1000F 01	1.5000E-01	1.0850E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
43	1.1300F 01	1.5100E-01	1.1149E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
44	1.1500F 01	1.5300E-01	1.1347E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
45	1.1500F 01	1.5400E-01	1.1346E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
46	1.1495F 01	1.5600E-01	1.1343E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
47	1.1500F 01	1.5800E-01	1.1342E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
48	1.1500F 01	1.6000E-01	1.1340E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
49	1.1500F 01	1.7000E-01	1.1330E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
50	1.1500F 01	1.7600E-01	1.1324E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
51	1.1500F 01	1.8400E-01	1.1316E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
52	1.1495F 01	1.9300E-01	1.1306E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
53	1.1500F 01	2.0300E-01	1.1297E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
54	1.1500F 01	1.7000E-01	1.1330E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
55	1.1500F 01	1.1580E-01	1.1380E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
56	1.1495F 01	1.2570E-01	1.1360E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
57	1.1504E 01	1.5380E-01	1.1350E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
58	1.1504E 01	1.7430E-01	1.1330E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
59	1.1497E 01	1.9750E-01	1.1300E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
60	1.1504E 01	2.2380E-01	1.1280F 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
61	1.1504E 01	2.5360E-01	1.1250E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
62	1.1497E 01	2.8740E-01	1.1210E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
63	1.1496F 01	3.2560E-01	1.1170E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
64	1.1495E 01	3.6500E-01	1.1130E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
65	1.1496E 01	4.1810E-01	1.1080E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
66	1.1504E 01	4.7280E-01	1.1030E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
67	1.1497E 01	5.3690E-01	1.0960E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
68	1.1498E 01	6.0840E-01	1.0890E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
69	1.1549E 01	6.8940E-01	1.0840E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
70	1.1601E 01	7.8120E-01	1.0820E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
71	1.1495E 01	8.8520E-01	1.0810E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
72	1.1603E 01	1.0030E 00	1.0800E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04
73	1.1577E 01	1.1370E 00	1.0840E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
74	1.1599E 01	1.2880E 00	1.0710E 01	0.	0.	0.	0.	1.1900E-02	3.0030E-04
75	1.1595F 01	1.4590E 00	1.0540E 01	0.	0.	0.	0.	1.1900E-02	3.0000E-04

AGN-GAM DATA TAPE NUMBER 1003

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INELASTIC SCATTERING MATRIX FOR MATERIAL NUMBER 44 IRON

FROM 1 TO 1	6.3352E-03	FROM 2 TO 24	1.5475E-04	FROM 4 TO 20	1.8352E-03	FROM 6 TO 16	1.9338E-02
FROM 1 TO 2	3.4687E-02	FROM 2 TO 25	9.4383E-05	FROM 4 TO 21	1.1350E-03	FROM 6 TO 17	1.2552E-02
FROM 1 TO 3	6.7693E-02	FROM 2 TO 26	5.7496E-05	FROM 4 TO 22	6.9895E-04	FROM 6 TO 18	8.272E-03
FROM 1 TO 4	1.0263E-01	FROM 2 TO 27	3.4989E-05	FROM 4 TO 23	4.2897E-04	FROM 6 TO 19	5.3736E-03
FROM 1 TO 5	1.2755E-01	FROM 2 TO 28	2.1277E-05	FROM 4 TO 24	2.6258E-04	FROM 6 TO 20	3.1777E-03
FROM 1 TO 6	1.3556E-01	FROM 2 TO 29	1.2935E-05	FROM 4 TO 25	1.6041E-04	FROM 6 TO 21	1.762E-03
FROM 1 TO 7	1.2745E-01	FROM 3 TO 3	2.1311E-02	FROM 4 TO 26	9.7844E-05	FROM 6 TO 22	1.2221E-03
FROM 1 TO 8	1.0884E-01	FROM 3 TO 4	6.9209E-02	FROM 4 TO 27	5.9600E-05	FROM 6 TO 23	7.5261E-04
FROM 1 TO 9	6.6227E-02	FROM 3 TO 5	1.0494E-01	FROM 4 TO 28	3.6273E-05	FROM 6 TO 24	4.5190E-04
FROM 1 TO 10	6.4409E-02	FROM 3 TO 6	1.3043E-01	FROM 4 TO 29	2.2056E-05	FROM 6 TO 25	2.8275E-04
FROM 1 TO 11	4.5954E-02	FROM 3 TO 7	1.3863E-01	FROM 4 TO 30	1.3408E-05	FROM 6 TO 26	1.7274E-04
FROM 1 TO 12	3.1635E-02	FROM 3 TO 8	1.3034E-01	FROM 4 TO 31	0.	FROM 6 TO 27	1.3535E-04
FROM 1 TO 13	2.1177E-02	FROM 3 TO 9	1.1132E-01	FROM 5 TO 5	4.1139E-02	FROM 6 TO 28	6.6178E-05
FROM 1 TO 14	1.3871E-02	FROM 3 TO 10	8.8192E-02	FROM 5 TO 6	1.1061E-01	FROM 6 TO 29	3.3057E-05
FROM 1 TO 15	8.4326E-03	FROM 3 TO 11	6.5878E-02	FROM 5 TO 7	1.3748E-01	FROM 6 TO 30	2.3751E-05
FROM 1 TO 16	5.6767E-03	FROM 3 TO 12	4.7004E-02	FROM 5 TO 8	1.4615E-01	FROM 6 TO 31	1.4438E-05
FROM 1 TO 17	3.5706E-03	FROM 3 TO 13	3.2357E-02	FROM 5 TO 9	1.3742E-01	FROM 6 TO 32	0.
FROM 1 TO 18	2.2279E-03	FROM 3 TO 14	2.1661E-02	FROM 5 TO 10	1.1737E-01	FROM 6 TO 33	0.
FROM 1 TO 19	1.3814E-03	FROM 3 TO 15	1.4188E-02	FROM 5 TO 11	9.2992E-02	FROM 7 TO 7	6.5347E-02
FROM 1 TO 20	3.5238E-04	FROM 3 TO 16	9.1369E-03	FROM 5 TO 12	6.9467E-02	FROM 7 TO 8	1.5149E-01
FROM 1 TO 21	5.2397E-04	FROM 3 TO 17	5.8066E-03	FROM 5 TO 13	4.9566E-02	FROM 7 TO 9	1.5107E-01
FROM 1 TO 22	3.7113E-04	FROM 3 TO 18	3.6523E-03	FROM 5 TO 14	3.4122E-02	FROM 7 TO 10	1.5145E-01
FROM 1 TO 23	1.5636E-04	FROM 3 TO 19	2.2789E-03	FROM 5 TO 15	2.2843E-02	FROM 7 TO 11	1.2339E-01
FROM 1 TO 24	1.1965E-04	FROM 3 TO 20	1.4130E-03	FROM 5 TO 16	1.4962E-02	FROM 7 TO 12	1.3251E-01
FROM 1 TO 25	7.3054E-05	FROM 3 TO 21	8.7190E-04	FROM 5 TO 17	9.6356E-03	FROM 7 TO 13	7.5579E-02
FROM 1 TO 26	4.4479E-05	FROM 3 TO 22	5.3596E-04	FROM 5 TO 18	6.1236E-03	FROM 7 TO 14	5.6643E-02
FROM 1 TO 27	2.7059E-05	FROM 3 TO 23	3.2848E-04	FROM 5 TO 19	3.8517E-03	FROM 7 TO 15	3.7519E-02
FROM 1 TO 28	1.6452E-05	FROM 3 TO 24	2.0086E-04	FROM 5 TO 20	2.4033E-03	FROM 7 TO 16	2.5184E-

AGN-GAM DATA TAPE NUMBER 1003 1 JUL 1964

INELASTIC SCATTERING MATRIX FOR MATERIAL NUMBER 44 IRON

FROM 8 TO 12	1.2432E-01	FROM 9 TO 35	0.
FROM 8 TO 13	9.5477E-02	FROM 9 TO 36	0.
FROM 8 TO 14	6.9612E-02	FROM 10 TO 10	1.0134E-01
FROM 8 TO 15	4.8736E-02	FROM 10 TO 11	2.0238E-01
FROM 8 TO 16	3.3058E-02	FROM 10 TO 12	1.8088E-01
FROM 8 TO 17	2.1877E-02	FROM 10 TO 13	1.4848E-01
FROM 8 TO 18	1.4201E-02	FROM 10 TO 14	1.1404E-01
FROM 8 TO 19	9.0817E-03	FROM 10 TO 15	8.3147E-02
FROM 8 TO 20	5.7401E-03	FROM 10 TO 16	5.8215E-02
FROM 8 TO 21	3.5951E-03	FROM 10 TO 17	3.9489E-02
FROM 8 TO 22	2.2358E-03	FROM 10 TO 18	2.6133E-02
FROM 8 TO 23	1.3827E-03	FROM 10 TO 19	1.6968E-02
FROM 8 TO 24	8.5151E-04	FROM 10 TO 20	1.0849E-02
FROM 8 TO 25	5.2261E-04	FROM 10 TO 21	6.8572E-03
FROM 8 TO 26	3.1590E-04	FROM 10 TO 22	4.2948E-03
FROM 8 TO 27	1.9544E-04	FROM 10 TO 23	2.6709E-03
FROM 8 TO 28	1.1919E-04	FROM 10 TO 24	1.6519E-03
FROM 8 TO 29	7.2615E-05	FROM 10 TO 25	1.0172E-03
FROM 8 TO 30	4.4190E-05	FROM 10 TO 26	6.2432E-04
FROM 8 TO 31	2.6872E-05	FROM 10 TO 27	3.8217E-04
FROM 8 TO 32	1.6335E-05	FROM 10 TO 28	2.3347E-04
FROM 8 TO 33	0.	FROM 10 TO 29	1.4240E-04
FROM 8 TO 34	0.	FROM 10 TO 30	8.6744E-05
FROM 8 TO 35	0.	FROM 10 TO 31	5.2792E-05
FROM 9 TO 9	9.4620E-02	FROM 10 TO 32	3.2102E-05
FROM 9 TO 10	1.8712E-01	FROM 10 TO 33	1.9515E-05
FROM 9 TO 11	1.7598E-01	FROM 10 TO 34	1.1853E-05
FROM 9 TO 12	1.5034E-01	FROM 10 TO 35	0.
FROM 9 TO 13	1.1912E-01	FROM 10 TO 36	0.
FROM 9 TO 14	8.8966E-02	FROM 10 TO 37	0.
FROM 9 TO 15	6.2506E-02		
FROM 9 TO 16	4.2722E-02		
FROM 9 TO 17	2.6270E-02		
FROM 9 TO 18	1.9173E-02		
FROM 9 TO 19	1.2348E-02		
FROM 9 TO 20	7.8475E-03		
FROM 9 TO 21	4.9362E-03		
FROM 9 TO 22	3.0800E-03		
FROM 9 TO 23	1.9098E-03		
FROM 9 TO 24	1.1784E-03		
FROM 9 TO 25	7.2451E-04		
FROM 9 TO 26	4.4399E-04		
FROM 9 TO 27	2.7147E-04		
FROM 9 TO 28	1.6571E-04		
FROM 9 TO 29	1.0100E-04		
FROM 9 TO 30	6.1499E-05		
FROM 9 TO 31	3.7411E-05		
FROM 9 TO 32	2.2745E-05		
FROM 9 TO 33	1.3819E-05		
FROM 9 TO 34	0.		

AGN-GAM DATA TAPE NUMBER 1003 1 JUL 1964

P-Q SCATTERING MATRIX FOR MATERIAL NUMBER 44 IRON

FROM 1 TO 1	9.7589E+01	FROM 26 TO 26	8.5845E-01	FROM 51 TO 51	8.5845E-01
FROM 1 TO 2	2.4106E+02	FROM 26 TO 27	1.4155E-01	FROM 51 TO 52	1.4155E-01
FROM 2 TO 2	9.7482E+01	FROM 27 TO 27	8.5845E-01	FROM 52 TO 52	8.5845E-01
FROM 2 TO 3	2.5180E+02	FROM 27 TO 28	1.4155E-01	FROM 52 TO 53	1.4155E-01
FROM 3 TO 3	9.5530E+01	FROM 28 TO 28	8.5845E-01	FROM 53 TO 53	8.5845E-01
FROM 3 TO 4	3.4704E+02	FROM 28 TO 29	1.4155E-01	FROM 53 TO 54	1.4155E-01
FROM 4 TO 4	9.3708E+01	FROM 29 TO 29	8.5845E-01	FROM 54 TO 54	8.5845E-01
FROM 4 TO 5	6.2918E+02	FROM 29 TO 30	1.4155E-01	FROM 54 TO 55	1.4155E-01
FROM 5 TO 5	9.3006E+01	FROM 30 TO 30	8.5845E-01	FROM 55 TO 55	8.5845E-01
FROM 5 TO 6	6.3936E+02	FROM 30 TO 31	1.4155E-01	FROM 55 TO 56	1.4155E-01
FROM 6 TO 6	9.1388E+01	FROM 31 TO 31	8.5845E-01	FROM 56 TO 56	8.5845E-01
FROM 6 TO 7	8.5120E+02	FROM 31 TO 32	1.4155E-01	FROM 56 TO 57	1.4155E-01
FROM 7 TO 7	8.3569E+01	FROM 32 TO 32	8.5845E-01	FROM 57 TO 57	8.5845E-01
FROM 7 TO 8	1.2431E+01	FROM 32 TO 33	1.4155E-01	FROM 57 TO 58	1.4155E-01
FROM 8 TO 8	8.3996E+01	FROM 33 TO 33	8.5845E-01	FROM 58 TO 58	8.5845E-01
FROM 8 TO 9	1.1004E+01	FROM 33 TO 34	1.4155E-01	FROM 58 TO 59	1.4155E-01
FROM 9 TO 9	8.3567E+01	FROM 34 TO 34	8.5845E-01	FROM 59 TO 59	8.5845E-01
FROM 9 TO 10	1.1433E+01	FROM 34 TO 35	1.4155E-01	FROM 59 TO 60	1.4155E-01
FROM 10 TO 10	8.3567E+01	FROM 35 TO 35	8.5845E-01	FROM 60 TO 60	8.5845E-01
FROM 10 TO 11	1.1433E+01	FROM 35 TO 36	1.4155E-01	FROM 60 TO 61	1.4155E-01
FROM 11 TO 11	8.1922E+01	FROM 36 TO 36	8.5845E-01	FROM 61 TO 61	8.5845E-01
FROM 11 TO 12	1.2078E+01	FROM 36 TO 37	1.4155E-01	FROM 61 TO 62	1.4155E-01
FROM 12 TO 12	8.3280E+01	FROM 37 TO 37	8.5845E-01	FROM 62 TO 62	8.5845E-01
FROM 12 TO 13	1.1720E+01	FROM 37 TO 38	1.4155E-01	FROM 62 TO 63	1.4155E-01
FROM 13 TO 13	8.7621E+01	FROM 38 TO 38	8.5845E-01	FROM 63 TO 63	8.5845E-01
FROM 13 TO 14	1.2379E+01	FROM 38 TO 39	1.4155E-01	FROM 63 TO 64	1.4155E-01
FROM 14 TO 14	8.7106E+01	FROM 39 TO 39	8.5845E-01	FROM 64 TO 64	8.5845E-01
FROM 14 TO 15	1.2894E+01	FROM 39 TO 40	1.4155E-01	FROM 64 TO 65	1.4155E-01
FROM 15 TO 15	8.8877E+01	FROM 40 TO 40	8.5845E-01	FROM 65 TO 65	8.5845E-01
FROM 15 TO 16	1.3123E+01	FROM 40 TO 41	1.4155E-01	FROM 65 TO 66	1.4155E-01
FROM 16 TO 16	8.8676E+01	FROM 41 TO 41	8.5845E-01	FROM 66 TO 66	8.5845E-01
FROM 16 TO 17	1.3324E+01	FROM 41 TO 42	1.4155E-01	FROM 66 TO 67	1.4155E-01
FROM 17 TO 17	8.8490E+01	FROM 42 TO 42	8.5845E-01	FROM 67 TO 67	8.5845E-01
FROM 17 TO 18	1.3510E+01	FROM 42 TO 43	1.4155E-01	FROM 67 TO 68	1.4155E-01
FROM 18 TO 18	8.8203E+01	FROM 43 TO 43	8.5845E-01	FROM 68 TO 68	8.5845E-01
FROM 18 TO 19	1.3707E+01	FROM 43 TO 44	1.4155E-01	FROM 68 TO 69	1.4155E-01
FROM 19 TO 19	8.8118E+01	FROM 44 TO 44	8.5845E-01	FROM 69 TO 69	8.5845E-01
FROM 19 TO 20	1.3882E+01	FROM 44 TO 45	1.4155E-01	FROM 69 TO 70	1.4155E-01
FROM 20 TO 20	8.5974E+01	FROM 45 TO 45	8.5845E-01	FROM 70 TO 70	8.5845E-01
FROM 20 TO 21	1.4026E+01	FROM 45 TO 46	1.4155E-01	FROM 70 TO 71	1.4155E-01
FROM 21 TO 21	8.5917E+01	FROM 46 TO 46	8.5845E-01	FROM 71 TO 71	8.5845E-01
FROM 21 TO 22	1.4083E+01	FROM 46 TO 47	1.4155E-01	FROM 71 TO 72	1.4155E-01
FROM 22 TO 22	8.5845E+01	FROM 47 TO 47	8.5845E-01	FROM 72 TO 72	8.5845E-01
FROM 22 TO 23	1.4155E+01	FROM 47 TO 48	1.4155E-01	FROM 72 TO 73	1.4155E-01
FROM 23 TO 23	8.5845E+01	FROM 48 TO 48	8.5845E-01	FROM 73 TO 73	8.5845E-01
FROM 23 TO 24	1.4155E+01	FROM 48 TO 49	1.4155E-01	FROM 73 TO 74	1.4155E-01
FROM 24 TO 24	8.5845E+01	FROM 49 TO 49	8.5845E-01	FROM 74 TO 74	8.5845E-01
FROM 24 TO 25	1.4155E+01	FROM 49 TO 50	1.4155E-01	FROM 74 TO 75	1.4155E-01
FROM 25 TO 25	8.5845E+01	FROM 50 TO 50	8.5845E-01	FROM 75 TO 75	8.5845E-01
FROM 25 TO 26	1.4155E+01	FROM 50 TO 51	1.4155E-01	FROM 75 TO 76	1.4155E-01

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P-1 SCATTERING MATRIX FOR MATERIAL NUMBER 44 IRON

FROM 1 TO 1	2.3045E 00	FROM 26 TO 26	1.7367E-01	FROM 51 TO 51	1.7367E-01
FROM 1 TO 2	1.5082E-01	FROM 26 TO 27	-1.3786E-01	FROM 51 TO 52	-1.3786E-01
FROM 2 TO 2	2.2850E 00	FROM 27 TO 27	1.7367E-01	FROM 52 TO 52	1.7367E-01
FROM 2 TO 3	1.8791E-01	FROM 27 TO 28	-1.3786E-01	FROM 52 TO 53	-1.3786E-01
FROM 3 TO 3	2.1122E 00	FROM 28 TO 28	1.7367E-01	FROM 53 TO 53	1.7367E-01
FROM 3 TO 4	1.6115E-01	FROM 28 TO 29	-1.3786E-01	FROM 53 TO 54	-1.3786E-01
FROM 4 TO 4	1.6003E 00	FROM 29 TO 29	1.7367E-01	FROM 54 TO 54	1.7367E-01
FROM 4 TO 5	8.2192E-02	FROM 29 TO 30	-1.3786E-01	FROM 54 TO 55	-1.3786E-01
FROM 5 TO 5	1.4730E 00	FROM 30 TO 30	1.7367E-01	FROM 55 TO 55	1.7367E-01
FROM 5 TO 6	6.2552E-02	FROM 30 TO 31	-1.3786E-01	FROM 55 TO 56	-1.3786E-01
FROM 6 TO 6	1.1793E 00	FROM 31 TO 31	1.7367E-01	FROM 56 TO 56	1.7367E-01
FROM 6 TO 7	1.7259E-02	FROM 31 TO 32	-1.3786E-01	FROM 56 TO 57	-1.3786E-01
FROM 7 TO 7	8.4931E-01	FROM 32 TO 32	1.7367E-01	FROM 57 TO 57	1.7367E-01
FROM 7 TO 8	-3.3646E-02	FROM 32 TO 33	-1.3786E-01	FROM 57 TO 58	-1.3786E-01
FROM 8 TO 8	7.4536E-01	FROM 33 TO 33	1.7367E-01	FROM 58 TO 58	1.7367E-01
FROM 8 TO 9	-4.9679E-02	FROM 33 TO 34	-1.3786E-01	FROM 58 TO 59	-1.3786E-01
FROM 9 TO 9	6.6797E-01	FROM 34 TO 34	1.7367E-01	FROM 59 TO 59	1.7367E-01
FROM 9 TO 10	-6.1705E-02	FROM 34 TO 35	-1.3786E-01	FROM 59 TO 60	-1.3786E-01
FROM 10 TO 10	6.6741E-01	FROM 35 TO 35	1.7367E-01	FROM 60 TO 60	1.7367E-01
FROM 10 TO 11	-6.1705E-02	FROM 35 TO 36	-1.3786E-01	FROM 60 TO 61	-1.3786E-01
FROM 11 TO 11	5.5047E-01	FROM 36 TO 36	1.7367E-01	FROM 61 TO 61	1.7367E-01
FROM 11 TO 12	-7.6741E-02	FROM 36 TO 37	-1.3786E-01	FROM 61 TO 62	-1.3786E-01
FROM 12 TO 12	6.1543E-01	FROM 37 TO 37	1.7367E-01	FROM 62 TO 62	1.7367E-01
FROM 12 TO 13	-6.4720E-02	FROM 37 TO 38	-1.3786E-01	FROM 62 TO 63	-1.3786E-01
FROM 13 TO 13	4.9590E-01	FROM 38 TO 38	1.7367E-01	FROM 63 TO 63	1.7367E-01
FROM 13 TO 14	-8.8158E-02	FROM 38 TO 39	-1.3786E-01	FROM 63 TO 64	-1.3786E-01
FROM 14 TO 14	4.0235E-01	FROM 39 TO 39	1.7367E-01	FROM 64 TO 64	1.7367E-01
FROM 14 TO 15	-1.0259E-01	FROM 39 TO 40	-1.3786E-01	FROM 64 TO 65	-1.3786E-01
FROM 15 TO 15	3.6077E-01	FROM 40 TO 40	1.7367E-01	FROM 65 TO 65	1.7367E-01
FROM 15 TO 16	-1.0900E-01	FROM 40 TO 41	-1.3786E-01	FROM 65 TO 66	-1.3786E-01
FROM 16 TO 16	3.2439E-01	FROM 41 TO 41	1.7367E-01	FROM 66 TO 66	1.7367E-01
FROM 16 TO 17	-1.1461E-01	FROM 41 TO 42	-1.3786E-01	FROM 66 TO 67	-1.3786E-01
FROM 17 TO 17	2.9061E-01	FROM 42 TO 42	1.7367E-01	FROM 67 TO 67	1.7367E-01
FROM 17 TO 18	-1.1982E-01	FROM 42 TO 43	-1.3786E-01	FROM 67 TO 68	-1.3786E-01
FROM 18 TO 18	2.3864E-01	FROM 43 TO 43	1.7367E-01	FROM 68 TO 68	1.7367E-01
FROM 18 TO 19	-1.2784E-01	FROM 43 TO 44	-1.3786E-01	FROM 68 TO 69	-1.3786E-01
FROM 19 TO 19	2.2304E-01	FROM 44 TO 44	1.7367E-01	FROM 69 TO 69	1.7367E-01
FROM 19 TO 20	-1.3024E-01	FROM 44 TO 45	-1.3786E-01	FROM 69 TO 70	-1.3786E-01
FROM 20 TO 20	1.6706E-01	FROM 45 TO 45	1.7367E-01	FROM 70 TO 70	1.7367E-01
FROM 20 TO 21	-1.3425E-01	FROM 45 TO 46	-1.3786E-01	FROM 70 TO 71	-1.3786E-01
FROM 21 TO 21	1.8666E-01	FROM 46 TO 46	1.7367E-01	FROM 71 TO 71	1.7367E-01
FROM 21 TO 22	-1.3586E-01	FROM 46 TO 47	-1.3786E-01	FROM 71 TO 72	-1.3786E-01
FROM 22 TO 22	1.7367E-01	FROM 47 TO 47	1.7367E-01	FROM 72 TO 72	1.7367E-01
FROM 22 TO 23	-1.3786E-01	FROM 47 TO 48	-1.3786E-01	FROM 72 TO 73	-1.3786E-01
FROM 23 TO 23	1.7367E-01	FROM 48 TO 48	1.7367E-01	FROM 73 TO 73	1.7367E-01
FROM 23 TO 24	-1.3786E-01	FROM 48 TO 49	-1.3786E-01	FROM 73 TO 74	-1.3786E-01
FROM 24 TO 24	1.7367E-01	FROM 49 TO 49	1.7367E-01	FROM 74 TO 74	1.7367E-01
FROM 24 TO 25	-1.3786E-01	FROM 49 TO 50	-1.3786E-01	FROM 74 TO 75	-1.3786E-01
FROM 25 TO 25	1.7367E-01	FROM 50 TO 50	1.7367E-01	FROM 75 TO 75	1.7367E-01
FROM 25 TO 26	-1.3786E-01	FROM 50 TO 51	-1.3786E-01	FROM 75 TO 76	-1.3786E-01

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RESONANCE PARAMETERS FOR MATERIAL NUMBER 101 URANIUM-235

UNRESOLVED REGION
CUT-OFF ENERGY = 6.6000E-01
ENERGY LEVEL SPACING = 9.9400E-01
GAMMA-N(0) = 8.4000E-05
GAMMA-GAMMA = 3.3000E-02
GAMMA-FISSION = 3.7500E-02
POTENTIAL SCATTERING = 1.0390E-01
STATISTICAL WEIGHT = 5.0000E-01

RESOLVED REGION

ENERGY	SUB-GROUP	GAMMA-N	GAMMA-G	GAMMA-F	TYPE	ABUNDANCE	G
2.0350E-01	20	7.7000E-05	3.5000E-02	1.2000E-02	INFINITE MASS	1.0000E-00	5.0000E-01
2.1200E-01	20	3.0000E-05	3.3000E-02	3.7500E-02	INFINITE MASS	1.0000E-00	5.0000E-01
2.1600E-01	20	3.2300E-05	3.1000E-02	1.5500E-01	INFINITE MASS	1.0000E-00	5.0000E-01
2.5000E-01	20	4.6000E-05	3.7000E-02	4.5000E-02	INFINITE MASS	1.0000E-00	5.0000E-01
4.4400E-01	20	5.2000E-05	2.5000E-02	4.0000E-03	INFINITE MASS	1.0000E-00	5.0000E-01
5.4500E-01	20	2.2000E-05	3.3000E-02	3.7500E-02	INFINITE MASS	1.0000E-00	5.0000E-01
5.9000E-01	20	1.6000E-05	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
6.1700E-01	20	2.7000E-05	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
6.3800E-01	20	2.8000E-04	4.5000E-02	1.5000E-02	NARROW	1.0000E-00	5.0000E-01
7.0900E-01	20	10.0000E-05	3.4000E-02	2.2000E-02	NARROW	1.0000E-00	5.0000E-01
8.7900E-01	20	10.0000E-04	4.1000E-02	5.2000E-02	NARROW	1.0000E-00	5.0000E-01
9.2700E-01	20	1.2000E-04	3.3000E-02	4.4000E-03	NARROW	1.0000E-00	5.0000E-01
9.7000E-01	20	5.0000E-05	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
1.0180E-01	21	6.4000E-05	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
1.0600E-01	21	3.3000E-05	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
1.1650E-01	21	7.0000E-04	3.3000E-02	2.6000E-03	NARROW	1.0000E-00	5.0000E-01
1.2400E-01	21	1.4000E-03	4.2000E-02	1.8000E-02	NARROW	1.0000E-00	5.0000E-01
1.2800E-01	21	3.9000E-06	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
1.3350E-01	21	9.9000E-05	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
1.3800E-01	21	1.5000E-04	3.3000E-02	9.8000E-02	NARROW	1.0000E-00	5.0000E-01
1.4100E-01	21	2.0000E-04	2.3000E-02	1.6600E-01	NARROW	1.0000E-00	5.0000E-01
1.4650E-01	21	1.5000E-04	3.3000E-02	4.0000E-02	NARROW	1.0000E-00	5.0000E-01
1.5440E-01	21	2.3000E-04	3.3000E-02	1.8000E-02	NARROW	1.0000E-00	5.0000E-01
1.6100E-01	21	3.4000E-04	3.3000E-02	9.2000E-03	NARROW	1.0000E-00	5.0000E-01
1.6700E-01	21	2.7000E-04	3.3000E-02	2.3000E-02	NARROW	1.0000E-00	5.0000E-01
1.8100E-01	21	3.4000E-04	3.3000E-02	4.6000E-02	NARROW	1.0000E-00	5.0000E-01
1.8600E-01	21	2.0000E-04	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
1.9300E-01	21	2.9000E-03	5.6000E-02	6.4000E-02	NARROW	1.0000E-00	5.0000E-01
2.0650E-01	21	3.6400E-04	3.3000E-02	2.0000E-02	NARROW	1.0000E-00	5.0000E-01
2.1100E-01	21	1.1050E-03	3.3000E-02	3.0000E-02	NARROW	1.0000E-00	5.0000E-01
2.2940E-01	21	6.6900E-04	3.3000E-02	1.6000E-02	NARROW	1.0000E-00	5.0000E-01
2.3700E-01	21	1.6100E-03	3.3000E-02	1.8000E-02	NARROW	1.0000E-00	5.0000E-01
2.4300E-01	21	4.9300E-04	3.3000E-02	3.8000E-02	NARROW	1.0000E-00	5.0000E-01
2.5300E-01	21	3.8200E-04	3.3000E-02	1.9800E-02	NARROW	1.0000E-00	5.0000E-01
2.5600E-01	21	6.0700E-04	3.3000E-02	3.1300E-02	NARROW	1.0000E-00	5.0000E-01
2.5900E-01	21	4.0700E-04	3.3000E-02	8.2000E-03	NARROW	1.0000E-00	5.0000E-01
2.6530E-01	21	5.1500E-04	3.3000E-02	8.2000E-02	NARROW	1.0000E-00	5.0000E-01
2.7150E-01	21	1.1000E-04	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
2.7820E-01	21	7.3700E-04	3.3000E-02	2.5000E-02	NARROW	1.0000E-00	5.0000E-01

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RESONANCE PARAMETERS FOR MATERIAL NUMBER 101 URANIUM-235

2.8400E-01	21	3.7300E-04	3.3000E-02	1.1000E-02	NARROW	1.0000E-00	5.0000E-01
2.9700E-01	21	3.8200E-04	3.3000E-02	7.3000E-03	NARROW	1.0000E-00	5.0000E-01
3.0900E-01	21	4.6500E-04	3.3000E-02	1.1000E-02	NARROW	1.0000E-00	5.0000E-01
3.2100E-01	21	1.7050E-03	3.3000E-02	2.5000E-02	NARROW	1.0000E-00	5.0000E-01
3.3570E-01	21	2.0900E-03	3.3000E-02	2.1000E-02	NARROW	1.0000E-00	5.0000E-01
3.4400E-01	21	3.4700E-03	3.3000E-02	2.3000E-02	NARROW	1.0000E-00	5.0000E-01
3.5300E-01	21	5.9400E-03	3.3000E-02	3.4000E-02	NARROW	1.0000E-00	5.0000E-01
3.7400E-01	21	1.6100E-04	3.3000E-02	3.7500E-02	NARROW	1.0000E-00	5.0000E-01
3.7500E-01	21	2.5200E-03	3.3000E-02	3.4000E-02	NARROW	1.0000E-00	5.0000E-01
4.1900E-01	21	2.2650E-03	3.3000E-02	2.1000E-02	NARROW	1.0000E-00	5.0000E-01
4.3450E-01	21	9.9000E-04	3.3000E-02	1.2000E-02	NARROW	1.0000E-00	5.0000E-01
4.4700E-01	21	1.8050E-03	3.3000E-02	2.4000E-02	NARROW	1.0000E-00	5.0000E-01
4.7000E-01	21	1.2350E-03	3.3000E-02	7.2000E-02	NARROW	1.0000E-00	5.0000E-01
4.8600E-01	21	5.2300E-03	3.3000E-02	5.5000E-03	NARROW	1.0000E-00	5.0000E-01
5.1600E-01	21	4.6000E-03	3.3000E-02	1.7000E-03	NARROW	1.0000E-00	5.0000E-01
5.5400E-01	21	2.9000E-03	3.3000E-02	8.4000E-02	NARROW	1.0000E-00	5.0000E-01
5.6400E-01	21	8.6400E-03	3.3000E-02	2.7600E-02	NARROW	1.0000E-00	5.0000E-01
5.9300E-01	21	3.8300E-03	3.3000E-02	2.8700E-02	NARROW	1.0000E-00	5.0000E-01
6.1000E-01	21	1.1720E-03	3.3000E-02	1.2400E-01	NARROW	1.0000E-00	5.0000E-01

AGN-GAM DATA TAPE NUMBER 1003 1 JUL 1964

SUMMARY TABLES

MAT NO.	MATERIAL DESCRIPTION	ATOMIC WEIGHT	VALID GRPS.	ABSOR.	FISS.	SCAT.	INEL.	N--2N	TRANS	RESON	DATE ADDED TO TAPE	SOURCE OF DATA
42	CHROMIUM	52.0100	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
43	MANGANESE	54.9400	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
44	IRON	55.8450	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
45	COBALT	58.9332	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
46	NICKEL	58.7100	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
47	COPPER	63.5460	68	YES	NO	YES	YES	NO	YES	NO	FEB 62	6A-GAM DATA TAPE 101
48	UNSPECIFIED	-0.	68	NO	NO	NO	NO	NO	NO	NO		
49	UNSPECIFIED	-0.	68	NO	NO	NO	NO	NO	NO	NO		
50	YTTRIUM	88.9059	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
51	ZIRCONIUM	91.2240	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
52	NIOBIUM (INF DIL)	92.9063	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
53	MOLYBDENUM (INF DIL)	95.94	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
54	TUNGSTEN (INF DIL)	183.84	75	YES	NO	YES	YES	NO	YES	NO	14 NOV 1963	AGN
55	CESIUM	132.9054	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
56	MERCURY	200.59	75	YES	NO	YES	YES	NO	YES	NO	12 JULY 1962	AGN
57	LEAD	207.2	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 1964	AGN
58	BISMUTH (IND. ARS)	208.98	68	NO	NO	YES	YES	YES	NO	NO	FEB 62	6A - GAM TAPE 101
59	STAINLESS STEEL-304	54.6181	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
60	STAINLESS STEEL-316	55.2832	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
61	STAINLESS STEEL - 321	54.6575	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
62	STAINLESS STEEL-347	54.6836	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
63	STAINLESS STEEL-410	54.4999	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
64	STAINLESS STEEL - 44CR	53.1646	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
65	HASTELLOY - X	58.5508	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
66	INCONEL	57.1951	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
67	INCONEL - X	57.0385	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
68	FEERAL	52.7741	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN
69	ALUMINUM - 6061	27.2403	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
70	UNSPECIFIED	-0.	68	NO	NO	NO	NO	NO	NO	NO		
71	HAYNES - 25	63.5879	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
72	ALUMINUM OXIDE	20.3917	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN
73	MAGNESIUM OXIDE	20.1600	68	YES	NO	YES	YES	NO	NO	NO	1 JUNE 1962	AGN-GA
74	THERMOFLEX (1800)	20.1331	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
75	REFRASIL	19.9646	75	YES	NO	YES	YES	NO	YES	NO	1 JULY 64	AGN-GA
76	UNSPECIFIED	-0.	68	NO	NO	NO	NO	NO	NO	NO		
77	UNSPECIFIED	-0.	68	NO	NO	NO	NO	NO	NO	NO		
78	UNSPECIFIED	-0.	68	NO	NO	NO	NO	NO	NO	NO		
79	UNSPECIFIED	-0.	68	NO	NO	NO	NO	NO	NO	NO		
80	UNSPECIFIED	-0.	68	NO	NO	NO	NO	NO	NO	NO		
81	BORON	10.8200	75	YES	NO	YES	YES	NO	YES	NO	20 MAR 62	AGN
82	CALCIUM (INF DIL)	112.4100	75	YES	NO	YES	YES	NO	YES	NO	20 MAR 62	AGN

FIGURE E-5. (CONTINUED)

APPENDIX F

AGN-GAM PROGRAM LISTING

A simplified block diagram of the AGN-GAM code is shown in Figure F-1. Used with the program listing, this diagram will help explain the overall operation of the code. The large number of comment cards inserted into the FORTRAN source program will also help to explain the operations being performed.

Since the listing of the program contains 51 pages and since this type of material is of interest to only a few who will read this document, the actual listing is omitted. However, it can be obtained from the Argonne Code Center.

Further explanations of the program, its operation, or other items concerning AGN-GAM may be obtained from the authors.

F-2

AGN TM-407

FIGURE F-1. SIMPLIFIED BLOCK DIAGRAM, AGN-GAM CODE

Subgroup integrated quantities, such as the flux and current terms are designated by

$$X_i = \int_i dE X(E) \quad (4)$$

The mean-value theorem is used to specify the pertinent subgroup constants

$$Y_i = \frac{\int_i dE Y(E) X(E)}{\int_i dE X(E)} \quad (5)$$

Group transfer cross sections are specified in the usual (Section II-A-2 and Appendix B) manner with the (n,2n) transfer probability normalized to unity. In addition, only isotropic inelastic and (n,2n) reactions will be considered while elastic scattering may include components up to and including the linear anisotropic component.

2. The P_1 Equations

a. The Subgroup Relations

The P_1 equations obtained (with Equations A-24 and A-25 of Appendix A) under the above assumptions are as follows:

$$\begin{aligned} \tilde{J}(E) + \Sigma_t(E)\varphi(E) &= \int_E^{E/\alpha} dE' \Sigma_{el}^0(E'-E)\varphi(E') + \int_E^\infty dE' \Sigma_{ie}^0(E'-E)\varphi(E') \\ &+ 2 \int_E^\infty dE' \Sigma_{n,2n}^0(E'-E)\varphi(E') + S_v(E) + S_s(E) \end{aligned} \quad (6)$$

$$\mathcal{L}(E)\varphi(E) + 3\Sigma_t(E)\tilde{J}(E) = \int_E^{E/\alpha} dE' \Sigma_{el}^1(E'-E)\tilde{J}(E') \quad (7)$$

where:

S_v is the volume source term

S_s is the surface source term

These equations are now integrated over the i^{th} subgroup. (Later on, the volume source term will be assumed proportional to a known, for example fission, spectrum.) If Equations (4) and (5) are used and if it is assumed that the intragroup flux and current spectra are similar, the following expressions are obtained when the intragroup transfer terms are moved to the left side of the equations.

$$\begin{aligned} \tilde{J}_i + \left[\Sigma_{t_i} - \left(\Sigma_{el,i \rightarrow i}^0 + \Sigma_{ie,i \rightarrow i}^0 + 2\Sigma_{n,2n,i \rightarrow i}^0 \right) \right] \varphi_i = S_{v_i} + S_{s_i} \\ + \sum_{j < i} \left(\Sigma_{el,j \rightarrow i}^0 + \Sigma_{ie,j \rightarrow i}^0 + 2\Sigma_{n,2n,j \rightarrow i}^0 \right) \varphi_j \end{aligned} \quad (8)$$

$$\Sigma_{t_i} \varphi_i + \left(3\Sigma_{t_i} - \Sigma_{el,i \rightarrow i}^1 \right) \tilde{J}_i = \sum_{j < i} \Sigma_{el,j \rightarrow i}^1 \tilde{J}_j \quad (9)$$

The following definitions are now made:

$$\left. \begin{aligned} \Sigma_{0_i} &= \Sigma_{t_i} - \left(\Sigma_{el,i \rightarrow i}^0 + \Sigma_{ie,i \rightarrow i}^0 + 2\Sigma_{n,2n,i \rightarrow i}^0 \right) \\ \Sigma_{1_i} &= 3\Sigma_{t_i} - \Sigma_{el,i \rightarrow i}^1 \\ S_i^0 &= \sum_{j < i} \left(\Sigma_{el,j \rightarrow i}^0 + \Sigma_{ie,j \rightarrow i}^0 + 2\Sigma_{n,2n,j \rightarrow i}^0 \right) \varphi_j \\ S_i^1 &= \sum_{j < i} \Sigma_{el,j \rightarrow i}^1 \tilde{J}_j \\ S_i &= S_{v_i} + S_{s_i} \end{aligned} \right\} \quad (10)$$

Thus, the P_1 equations are:

$$\tilde{J}_i + \Sigma_{0i} \varphi_i = S_i^0 + S_i \quad (11)$$

$$\mathcal{L}_i \varphi_i + \Sigma_{1i} \tilde{J}_i = S_i^1 \quad (12)$$

Solving Equation (12) for $\tilde{J}_i$ and substituting into Equation (11) yields the P_1 difference equations:

$$\varphi_i = \frac{\Sigma_{1i} (S_i^0 + S_i) - S_i^1}{\Sigma_{0i} \Sigma_{1i} - \mathcal{L}_i} \quad (13)$$

$$\tilde{J}_i = \frac{S_i^1 - \mathcal{L}_i \varphi_i}{\Sigma_{1i}} \quad (14)$$

b. The Group Leakage Term, $\mathcal{L}_i$

The subgroup leakage parameter has been defined by Equation 5 as a flux weighted average of its energy dependent counterpart, i.e.:

$$\mathcal{L}_i = \frac{\int \text{div grad } \varphi_i(\vec{r}) dV}{\varphi_i} \quad (15)$$

Using the group form of Fick's law (Equation 43) along the same lines of Appendix A. IV-A., one obtains the two relationships:

$$\mathcal{L}_i = - 3 \Sigma_{tr_i} \frac{L_{out_i}}{\varphi_i} \quad (16)$$

and

$$\mathcal{L}_i = \frac{\int \nabla^2 \varphi_i(\vec{r}) dV}{\varphi_i} - 3 \Sigma_{tr_i} \frac{L_{in_i}}{\varphi_i} \quad (17)$$

where:

L_{out_i} is the group integrated leakage out of the region

L_{in_i} is the equivalent leakage into the region. (Both L_{out} and L_{in} are positive quantities.)

Usually, only the multigroup (Section II.D.1) leakage parameter, $\mathcal{L}_\ell$, is known. The multigroup and subgroup equations are self-consistent and thus Equations (15) - (17) are satisfied by $\mathcal{L}_\ell$ (replacing subscript i by ℓ). From Equation (15), the relationship of the sub and multigroup leakage parameters is established:

$$\mathcal{L}_\ell = \frac{\sum_i \mathcal{L}_i \varphi_i}{\varphi_\ell} \quad (18)$$

To estimate the energy (or lethargy) dependence of the subgroup leakage parameter, $\mathcal{L}_i$, the multigroup terms, $\mathcal{L}_\ell$, are plotted as a bar graph and a smooth curve is drawn through this graph. This reveals the gross structure of this dependence and subgroup values can be read off the curve.

If the multigroup leakage parameter is also not available, the one group theory (Section IV, Appendix A) can be used to estimate $\mathcal{L}$; the accuracy of the estimate is greater if the group diffusion coefficients are known.

3. The B_1 Equations

The pertinent B_1 equations are given by Equations (A-43) and (A-44) of Appendix A.

$$\begin{aligned} BJ(E) + \Sigma_t(E)\varphi(E) = & \int_E^{E/\alpha} dE' \Sigma_{el}^0(E' \rightarrow E)\varphi(E') + \int_E^\infty dE' \Sigma_{ie}^0(E' \rightarrow E)\varphi(E') \\ & + 2 \int_E^\infty dE' \Sigma_{n,2n}^0(E' \rightarrow E)\varphi(E') + S(E) \end{aligned} \quad (19)$$

$$- B\varphi(E) + 3\Sigma_t(E)\alpha(E)J(E) = \int_E^{E/\alpha} dE' \Sigma_{el}^1(E' \rightarrow E)J(E') \quad (20)$$

The argument B , which is inherent in all flux and current terms, has been omitted.

If integration is performed over the i^{th} subgroup, in the same fashion as the corresponding P_1 relations are reduced, and if the average of a product is assumed equal to the product of the averages, the following expressions are derived with definitions of Equation (10).

$$BJ_i + \Sigma_{0_i} \varphi_i = S_i^0 + S_i \quad (21)$$

$$-B \varphi_i + \Sigma_{2_i} J_i = S_i^1 \quad (22)$$

where:

$$\Sigma_{2_i} = 3\Sigma_{t_i} \alpha_i - \Sigma_{el_{i \rightarrow i}}^1 \quad (23)$$

Solving Equation (22) for J_i and substituting into Equation (21) yields the B_1 difference equations:

$$\varphi_i = \frac{\Sigma_{2_i} (S_i^0 + S_i) - B S_i^1}{\Sigma_{0_i} \Sigma_{2_i} + B^2} \quad (24)$$

$$J_i = \frac{S_i^1 + B \varphi_i}{\Sigma_{2_i}} \quad (25)$$

4. The Combined P_1 - B_1 Relations

The P_1 and B_1 equations can be combined into one set of relations.

$$\varphi_i = \frac{\Sigma_{2_i} (S_i^0 + S_i) - a_i S_i^1}{\Sigma_{0_i} \Sigma_{2_i} - b_i} \quad (26)$$

$$J_i = \frac{S_i^1 - c_i \varphi_i}{\Sigma_{2_i}} \quad (27)$$

where:

	P_1 Approx.	B_1 Approx.
a_i	1.0	B
b_i	Σ_i	$-B^2$
c_i	Σ_i	$-B$

α_i in Equation (23) is redefined as

$$\left. \begin{aligned} \alpha_i &= 1.0 \text{ for the } P_1 \text{ approximation} \\ \alpha_i &= \frac{B}{\Sigma_{t_i}} \frac{\tan^{-1} \left(\frac{B}{\Sigma_{t_i}} \right)}{3 \left(1 - \frac{B}{\Sigma_{t_i}} \tan^{-1} \left(\frac{B}{\Sigma_{t_i}} \right) \right)} \text{ for the } B_1 \text{ approximation} \end{aligned} \right\} (28)$$

Σ_{0_i} as well as the source terms, are defined by Equation (10).

Finally, the volume source term, may be written as

$$S_{v_i} = k h_i \quad (29)$$

where:

k is the constant which normalizes the volume source to the surface source

h_i is the integral of a known spectrum over the i^{th} subgroup

For either a P_1 problem without a surface source or a B_1 calculation, the normalization is arbitrary and k is taken as unity.

5. Current Calculation Using a Known Flux

If the neutron flux and the sources are known, the current term (in the P_1 sense) can be calculated directly from the conservation relation (Equation 11).

$$J_i = S_i^0 + S_i - \Sigma_{0_i} \varphi_i \quad (30)$$

The calculation can be performed with both a volume and a surface source if the input flux is consistent with the source magnitudes. Specifically, this is accomplished by use of the constant in Equation (29). Since Equation (30)

is an exact relation, the accuracy of the current term is equivalent to the accuracy of the original flux calculation.

6. The Moment Equations

The relevant moment equations (Equations A-55 through A-57 of Appendix A) are:

$$\begin{aligned} \Sigma_t(E)M_{00}(E) = & \int_E^{E/\alpha} dE' \Sigma_{el.}^0(E' \rightarrow E) M_{00}(E') + \int_E^{\infty} dE' \Sigma_{ie.}^0(E' \rightarrow E) M_{00}(E') \\ & + 2 \int_E^{\infty} dE' \Sigma_{n,2n}^0(E' \rightarrow E) M_{00}(E') + S(E) \end{aligned} \quad (31)$$

$$\Sigma_t(E)M_{11}(E) = \frac{1}{3} \int_E^{E/\alpha} dE' \Sigma_{el.}^1(E' \rightarrow E) M_{11}(E') + M_{00}(E) \quad (32)$$

$$\begin{aligned} \Sigma_t(E)M_{20}(E) = & \int_E^{E/\alpha} dE' \Sigma_{el.}^0(E' \rightarrow E) M_{20}(E') + \int_E^{\infty} dE' \Sigma_{ie.}^0(E' \rightarrow E) M_{20}(E') \\ & + 2 \int_E^{\infty} dE' \Sigma_{n,2n}^0(E' \rightarrow E) M_{20}(E') + \frac{1}{3} M_{11}(E) \end{aligned} \quad (33)$$

These relations are integrated over the i^{th} subgroup, in the same fashion as the reduction of the P_1 relations was performed. The following definitions apply

$$\left. \begin{aligned} s_{00_i} &= \sum_{j < i} \left[\Sigma_{el.j \rightarrow i}^0 + \Sigma_{ie.j \rightarrow i}^0 + 2 \Sigma_{n,2n.j \rightarrow i}^0 \right] M_{00_j} \\ s_{11_i} &= \sum_{j < i} \Sigma_{el.j \rightarrow i}^1 M_{11_j} \\ s_{20_i} &= \sum_{j < i} \left[\Sigma_{el.j \rightarrow i}^0 + \Sigma_{ie.j \rightarrow i}^0 + 2 \Sigma_{n,2n.j \rightarrow i}^0 \right] M_{20_j} \end{aligned} \right\} \quad (34)$$

The moments difference equations that are obtained can be solved successively for each subgroup.

$$M_{00_i} = \frac{S_{00_i} + S_i}{\Sigma_{0_i}} \quad (35)$$

$$M_{11_i} = \frac{S_{11_i} + 3M_{00_i}}{\Sigma_{1_i}} \quad (36)$$

$$M_{20_i} = \frac{S_{20_i} + \frac{1}{3}M_{11_i}}{\Sigma_{0_i}} \quad (37)$$

where the age is:

$$\tau_i = \frac{M_{20_i}}{M_{00_i}} \quad (38)$$

This age represents an average value for the i^{th} subgroup.

D. MULTIGROUP CONSTANTS

1. The Group Structure

The multigroup structure is similar to the subgroup structure used in the development of the spectrum generation difference equations except that the differential energy elements are replaced by subgroups and the subgroups by groups. The assumption is made that there is an integer number of subgroups in a given group (Figure 2).

FIGURE 2. GROUP STRUCTURE

The spectral weighing parameters are:

$$\left. \begin{aligned} \varphi_{\ell} &= \sum_{i \text{ in } \ell} \varphi_i \\ J_{\ell} &= \sum_{i \text{ in } \ell} J_i \end{aligned} \right\} \quad (39)$$

The group source term is equal to

$$S_{\ell} = \sum_{i \text{ in } \ell} S_i \quad (40)$$

2. Group Averaged Parameters

The group-averaged parameters are defined by the relation

$$Y_{\ell} = \frac{1}{\varphi_{\ell}} \sum_{i \text{ in } \ell} Y_i \varphi_i \quad (41)$$

where Y is equal to the following cross sections

$$Y = \Sigma_t, \Sigma_s, \Sigma_a, \Sigma_f, \nu\Sigma_f, \text{ and } \Sigma_c$$

and the corresponding microscopic quantities. The group averaged ν is:

$$\nu_{\ell} = \frac{1}{\Sigma_{f\ell} \varphi_{\ell}} \sum_{i \text{ in } \ell} (\nu\Sigma_f)_i \varphi_i \quad (42)$$

3. The Transport Cross Section and Diffusion Coefficient

a. Definition

The multigroup transport cross section and diffusion coefficient are defined by the multigroup Fick's law

$$\vec{J}_\ell(\vec{r}) = \frac{1}{3\Sigma_{tr_\ell}} \text{grad } \varphi_\ell(\vec{r}) \quad (43)$$

and

$$D_\ell \equiv \frac{1}{3\Sigma_{tr_\ell}} \quad (44)$$

Similar results are valid for the equivalent subgroup parameters.

The explicit form of the group transport cross section for the P_1 or B_1 approximations is obtained with the P_1 or B_1 group equation. This form is related to the cross sections of the medium. The corresponding microscopic cross section is obtained in a fashion similar to the energy dependent case (Appendix A). In fact, the group transport cross section is just a current term average of the corresponding energy dependent cross section over the group.

b. The P_1 Relation

The multigroup form of Fick's law is obtained by integrating the divergence of Equation (43) over the volume.

$$\Sigma_{tr_\ell} = - \frac{\int \ell \varphi_\ell}{3\tilde{J}_\ell} \quad (45)$$

Substituting for $\int \ell \varphi_\ell$ in the multigroup equivalence of Equation (9) yields

$$\Sigma_{tr_\ell} = \langle \Sigma_t \rangle_\ell = \frac{\sum_{m \leq \ell} \Sigma_{m \rightarrow \ell}^1 \tilde{J}_m}{3\tilde{J}_\ell} \quad (46)$$

where:

$\langle \Sigma_t \rangle_\ell$ is the total cross section, averaged with respect to the current term

Because the equation is linear in the cross sections, it can also be used for the microscopic transport cross section. The subgroup relations are equivalent to Equations (45) and (46). The connection between the sub and multigroup cross section is a current term average.

$$\Sigma_{tr\ell} = \frac{\sum_{i \text{ in } \ell} \Sigma_{tr i} \tilde{J}_i}{\tilde{J}_\ell} \quad (47)$$

Similarly, by integrating Equation (A-29) of Appendix A over the group, it develops that the group transport cross section is a current term average of its energy dependent equivalence.

c. The B_1 Relation

The multigroup Fick's law in the B_1 approximation is derived from Equation (43) in a fashion similar to the way the results leading up to Equation (A-48) of Appendix A were obtained.

$$\Sigma_{tr\ell} = \frac{B\phi_\ell}{3J_\ell} \quad (48)$$

Substituting for $B\phi_\ell$ in the multigroup equivalence of Equation (22) yields

$$\Sigma_{tr\ell} = \langle \Sigma_t^\alpha \rangle_\ell - \frac{\sum_{m \leq \ell} \Sigma_{m \rightarrow \ell}^1 J_m}{3J_\ell} \quad (49)$$

where:

$\langle \Sigma_t^\alpha \rangle_\ell$ is current averaged over the subgroups.

This same equation may also be used for the microscopic cross section by taking α as an extensive property of the medium.

The subgroup relations are identical (except for changed subscripts) to Equation (48) and (49). The connection given by Equation (47) then follows.

d. The Monoenergetic Relation

The transport cross section relation in the monoenergetic approximation is:

$$\Sigma_{tr\ell} = \Sigma_{t\ell} - \frac{1}{\phi_\ell} \sum_{i \text{ in } \ell} \Sigma_{el i} L1_i \phi_i \quad (50)$$

where:

$L1$ is the average L system cosine for elastic scattering.

4. Scattering Matrices

The isotropic elastic and the inelastic scattering matrices are given by

$$\Sigma_{x, \ell \rightarrow m}^0 = \frac{1}{\varphi_\ell} \sum_{i \text{ in } \ell} \varphi_i \sum_{j \text{ in } m} \Sigma_{x, i \rightarrow j}^0 \quad (51)$$

where:

$$x = \text{el. or ie.}$$

The n,2n transfer matrix is given by

$$\Sigma_{n, 2n, \ell \rightarrow m}^0 = \frac{2}{\varphi_\ell} \sum_{i \text{ in } \ell} \varphi_i \sum_{j \text{ in } m} \Sigma_{n, 2n, i \rightarrow j}^0 \quad (52)$$

and the linear anisotropic elastic scattering matrix by

$$\Sigma_{\text{el.}, \ell \rightarrow m}^1 = \frac{1}{3J_\ell} \sum_{i \text{ in } \ell} J_i \sum_{j \text{ in } m} \Sigma_{\text{el.}, i \rightarrow j}^1 \quad (53)$$

The total isotropic scattering matrix is the sum

$$\Sigma_{\ell \rightarrow m}^{0^*} = \Sigma_{\text{el.}, \ell \rightarrow m}^0 + \Sigma_{\text{ie.}, \ell \rightarrow m}^0 + \Sigma_{n, 2n, \ell \rightarrow m}^0 \quad (54)$$

The total isotropic transfer coefficients are:

$$\mu_{\ell \rightarrow m}^0 = \frac{\Sigma_{\ell \rightarrow m}^0}{\Sigma_s^\ell} \quad (55)$$

With the inclusion of the n,2n reaction:

$$\sum_{m \geq \ell} \mu_{\ell \rightarrow m}^0 \geq 1 \quad (56)$$

Two other cross sections which can be used in a few-group analysis are now defined; namely, Σ_{out} , the out of group scattering cross section, and Σ_r , the cross section for neutron removal.

$$\Sigma_{\text{out } \ell} = \sum_{m > \ell} \Sigma_{\ell \rightarrow m}^0 \quad (57)$$

$$\Sigma_r \ell = \Sigma_{\text{out } \ell} + \Sigma_{a \ell} \quad (58)$$

5. S_n Transport Theory Relations

The transport approximation (Appendix C) is used to derive group constants for S_n transport theory programs. The isotropic and linear anisotropic scattering are considered separately.

a. Isotropic Theory

A group "transport correcting" cross section is defined in the multigroup approximation by:

$$\Sigma_{\ell}^1 = \frac{1}{3J_{\ell}} \sum_{m \leq \ell} \Sigma_{\ell \rightarrow m}^1 J_m \quad (59)$$

Such a cross section in the monogroup approximation is:

$$\Sigma_{\ell}^1 = \frac{1}{\phi_{\ell}} \sum_{i \text{ in } \ell} \Sigma_{\ell \rightarrow i} L1_i \phi_i \quad (60)$$

The group cross section is:

$$\Sigma_{\ell} = \Sigma_{t \ell} - \Sigma_{\ell}^1 \quad (61)$$

The ingroup scattering term is:

$$\Sigma_{\ell \rightarrow \ell}^0 = \Sigma_{\ell \rightarrow \ell}^0 \text{ (From Eq. (54))} - \Sigma_{\ell}^1 \quad (62)$$

All other components of the transfer matrix are obtained with Equation (54).

b. Linear Anisotropic Theory

The "transport correcting" cross section for this case is only used in the monogroup approximation:

$$\Sigma_{\ell}^2 = \frac{1}{\varphi_{\ell}} \sum_{i \text{ in } \ell} \Sigma_{e\ell, i} L_{i\ell}^2 \varphi_i \quad (63)$$

The group cross section is:

$$\Sigma_{\ell} = \Sigma_{t\ell} - \Sigma_{\ell}^2 \quad (64)$$

The ingroup scattering terms are:

$$\Sigma_{\ell \rightarrow \ell}^0 = \Sigma_{\ell \rightarrow \ell}^0 \quad (\text{From Eq. (54)}) - \Sigma_{\ell}^2 \quad (65)$$

$$\Sigma_{\ell \rightarrow \ell}^1 = \Sigma_{\ell \rightarrow \ell}^1 \quad (\text{From Eq. (53)}) - \Sigma_{\ell}^2 \quad (66)$$

The other elements of the isotropic matrix are obtained with Equation (54) and the other elements of the linear anisotropic matrix with Equation (53).

The Los Alamos discrete S_n program, DTK, uses the absorption location of the anisotropic matrix in the material buckling calculation as follows:

$$B^2 = \frac{\sum_{\ell} \sum_i (\nu \Sigma_{f\ell} - \Sigma_{a\ell})_i V_i \varphi_{i\ell}}{\frac{1}{3} \sum_{\ell} \sum_i \frac{V_i \varphi_{i\ell}}{(\Sigma_{\ell} - \Sigma_{a\ell} \text{ (aniso)})_i}} \quad (67)$$

where:

the subscript i refers to volume increments and the subscript ℓ to the multigroup scheme. Thus, to obtain

$$\Sigma_{tr\ell} = \Sigma_{\ell} - \Sigma_{a\ell} \text{ (aniso)} \quad (68)$$

the anisotropic absorption cross section must be defined:

$$\Sigma_{a\ell} \text{ (aniso)} = \Sigma_{\ell}^2 - \Sigma_{\ell}^1 \quad (\text{From Equation (59)}) \quad (69)$$

This cross section is not included in the printout but only in the punched card output.

III. USE OF THE CODE

The AGN-GAM code was written to make the input as simple as possible. The first part of this section describes the input formats required for code operation. In the second part a sample problem is solved and the results are discussed, to classify the overall procedure..

A. INPUT REQUIREMENTS

For any machine code that offers both a wide choice in calculational methods and a great number of input options, the card input requirements can become quite complicated and confusing. To eliminate most of this confusion the sketch shown in Figure 3 was drawn. Each block of cards in this figure represents the input for a certain type of information. The blocks are input in the order given except when a complete block is omitted due to the type of calculation performed.

Table 3 lists the five possible types of problems and indicates which of the input blocks are required. Table 4 gives the "cook book" input formats for the data blocks themselves.

FIGURE 3. AGN-GAM INPUTS

TABLE 4 - AGN-GAM PROBLEM TYPES AND REQUIRED INPUTS

Type of Calculation	Problem Type	Basic Parameters (1000)	Group Boundaries (2000)	Leakage Terms (3000)	Volume Sources (4000)	Surface Sources (5000)	Input Flux (6000)	Input Current (7000)	Material Properties (8000)	End Card (9000)
P - 1; Complete Calculation	1.0	X	X	X	X	X	No	No	X	X
P - 1; Flux Input but Current Calculated	2.0	X	X	No	X	X	X	No	X	X
Flux and Current both Input	3.0	X	X	No	No	No	X	X	X	X
B - 1; Complete Calculation	4.0	X	X	X*	X	No	No	No	X	X
Same flux and current as previous problem	5.0	X	X	No	No	No	No	No	X	X

Notes: * Input one value of leakage for all 75 groups. This value is equal to $-B^2$

TABLE 5 - INPUT FOR AGN-GAM CODE

NOTE: All cards, except the title card, have a (6E12.5) format.

BASIC PARAMETERS (1000 Series Cards)

Card # 1000	Col. 1-72	Problem description
Card # 1001	Col. 1-12	Problem number
	Col. 13-24	Type of flux solution desired (1.0 to 5.0). See Table 1 for description of the types available.
	Col. 25-36	Type of cross section averaging to be used to obtain broad group constants. 1.0 = Diffusion theory 2.0 = Isotropic transport theory - Type 1 (energy dependent) 3.0 = Isotropic transport theory - Type 2 (monoenergetic) 4.0 = Anisotropic transport theory
	Col. 37-48	Number of broad groups desired (≤ 32). This does not include a thermal group but only the "fast" groups included in the AGN-GAM energy range.
	Col. 49-60	Number of groups downscatter desired in broad group constants.
	Col. 61-72	Geometry to be used in resonance calculations. If no resonance materials are present in problem, leave blank ; 1.0 = slab 2.0 = cylinder 3.0 = sphere
Card # 1002	Col. 1-12	Set equal to 1.0 if it is desired to punch the calculated values of flux and current.

TABLE 5 - Continued

Col. 13-24	Option to punch calculated broad group macroscopic and microscopic (if applicable) cross sections; 0.0 = do not punch cross sections 1.0 = punch for input to DSN, TDC, or 2DXY codes 2.0 = punch for input to DTK or DDK codes 3.0 = punch for input to ZOOM code 4.0 = punch for input to ANGIE code 5.0 = punch for input to AIM-6 code 6.0 = punch for input to PDQ-2 code
Col. 25-36	If cross sections are desired for the DSN, TDC, 2DXY, DTK, or DDK codes, input the number of activation cross sections desired in the cross section block. Zeros will be punched in the cards by AGN-GAM for these activation values.
Col. 37-48	For the same codes as above, indicate the number of groups up-scattering desired in the cross section block. Since there is no up-scattering considered in the AGN-GAM energy range, the values will also be punched as zeros.

BROAD GROUP BOUNDARIES (2000 Series Cards)

Cards # 2000, 2001, etc.

The energy at the bottom of each of the broad groups is expressed in electronvolts and as many values as broad groups (Col. 37-48 of Card #1001) must be supplied. Start with the highest energy group on card #2000 and proceed, in order, for the required number of groups.

TABLE 5 - ContinuedLEAKAGE TERMS (3000 Series Cards)

This data required only for certain type of problems; see Table 1.

Card # 3000	Col. 1-12	Method used to input values;
		1.0 = Single value to be used in all 75 fine groups
		2.0 = Same value to be used in all the fine groups within a given broad group.
		3.0 = Values supplied for all 75 fine groups.
	Col. 13-24	If the above option is set equal to 1.0, input the single value of $\mathcal{L}$ to be used in this location and omit all the following cards in this set.

Cards # 3001, 3002, etc.

Starting with the highest energy group, supply the needed values of $\mathcal{L}$. There will be the same number of values as there are the broad groups if option 2 (above) is chosen or 75 if option 3 is picked.

VOLUME SOURCE TERM (4000 Series Cards)

This data required only for certain types of problems, see Table 1.

Card # 4000	Col. 1-12	Type of method used to obtain volume source:
		0.0 = Set volume source equal to zero in all 75 fine groups
		1.0 = read a single value of the volume source and use it in all fine groups.
		2.0 = read a value of the volume source for each broad group and use it within each fine group within the broad group.

TABLE 5 - Continued

- 3.0 = read a value for each of the 75 fine groups
- 4.0 = read the volume source from the AGN-GAM data tape. The tape number of this source appears in Columns 13-24.
- 5.0 = place a unit source in one fine group only. The number of this group appears in Columns 13-24.
- 6.0 = use the same source as the previous problem.

Col. 13-24	Either the source number of the source requested from the data tape (option 4.0 above) or the fine group into which a unit source is to be specified (option 5.0 above). Otherwise, leave blank.
Col. 25-36	Normalization constant for the volume source. If this number is left blank or set to zero, it will automatically be made equal to one.

Cards # 4001, 4002, etc.

If input values are required beyond those given on Card # 4000, they are input on these cards starting with the highest energy group.

SURFACE SOURCE TERM (5000 Series Cards)

This data required only for certain types of problems, see Table 1.

Card # 5000	Col. 1-12	Type of method used to obtain the surface source:
		0.0 = set equal to zero in all 75 fine groups
		1.0 = read a single value and use in all 75 fine groups

TABLE 5 - Continued

2.0 = read a value for each broad group
and use in each fine group within
the broad group.

3.0 = read a value for each fine group

Col. 13-24 Single value of surface source if above
option is equal to 1.0. Skip remaining
cards in this section if this option is
used.

Cards # 5001, 5002, etc.

Specify required surface sources, if necessary, on these cards
starting with highest energy term.

INPUT FLUX (6000 Series Cards)

This data required only for certain types of problems, see Table 1.

Card # 6000 Col. 1-12 Same method of input as is used for sur-
face source. See 5000 series inputs

Col. 13-24 Ditto

Cards # 6001, 6002, etc. Ditto

INPUT CURRENT TERMS (7000 Series Cards)

This data required only for certain types of problems, see Table 1.

Card # 7000 Col. 1-12 Same method of input as is used for sur-
face source, see 5000 series inputs

Col. 13-24 Ditto

Cards # 7001, 7002, etc. Ditto

MATERIAL PROPERTIES (8000 Series Cards)

Supply one set of 8000 series cards for each material in the
problem. If desired, the card number may be prefixed by a material identi-
fication number or symbol. Each material requires from 1 to 15 cards to describe
it depending upon the use of self-shielding factors and the special resonance
treatment. It is not necessary to place the materials in any particular order.

TABLE 5 - Continued

Card # 8000	Col. 1-12	AGN-GAM Tape ID number of the material
	Col. 13-24	Number density of the material (atoms/cc $\times 10^{-24}$)
	Col. 25-36	Physical density of the material (gm/cc)
	<u>NOTE:</u>	Either the number density <u>or</u> the physical density must be input. If both are given, the number density will be used in the problem and the corresponding physical density calculated. It is permissible to leave blank the one quantity that is not supplied.
	Col. 37-48	Option for self-shielding factors.
		0.0 If no self-shielding exists (i.e., the values are all one) omit cards #8001 - 8013.
		1.0 If factors are supplied by broad groups. The one value per broad group will then be used in each fine group within that broad group. In this case, use as many of the 8001 - 8013 cards as are necessary.
		2.0 If the factors are supplied for all 75 fine groups.
	Col. 49-60	Set equal to 1.0 if microscopic cross sections are wanted.

Cards # 8001 - 8013

These cards contain the self-shielding factors requested by the option in Col. 37-48 of Card # 8000. Start with the highest energy group in the first location. If there is no-self-shielding, these cards must all be omitted.

TABLE 5 - Continued

Card # 8014

Required only for those materials which compute resonance absorption and fission from individual resonance parameters.

Col. 1-12	Number density (atoms/cc x 10^{-24}) of the resonance material within the "lump"
Col. 13-24	Dimension (cm) of the "lump". Thickness of a slab, radius of a cylinder or sphere. Equivalent dimension may be used for hollow cylinders, pin bundles, etc.
Col. 25-36	Physical temperature of the material ($^{\circ}\text{K}$)
Col. 37-48	σ_m , the scattering cross section of all other materials within the "lump". In barns per atom of the resonance material.
Col. 49-60	σ_p , the total scattering cross section of all materials within the "lump". In barns per atom of the resonance material.

END CARD (9000 Series Card)

NOTE: The end card must be supplied in each problem

Card # 9000 Col. 1-12 " + 99999.0 "

B. SAMPLE PROBLEM

To illustrate the use of the AGN-GAM code, a sample problem is defined and solved. The problem is designed to show how the code functions, not to convey "magic" numbers, constants, or methods.

For the sample problem it is desired to calculate fast group cross sections for a system composed of Hastelloy X clad fuel pins arranged in a triangular lattice and in a water moderator. Each fuel pin contains fully enriched $\text{UO}_2\text{-BeO}$ fuel with a U-235 loading of 1.616 grams/inch. The dimensions of the lattice and pins are given in Figure 4. Results are to be used in a 16 group DSN code calculation using anisotropic transport theory. Resonance calculations are performed for U-235 only. The composition of the unit cell is calculated on a purely geometric basis and to permit greater accuracy, the U-235 density is derived from known fuel loadings, rather than volume fractions. It is assumed that all the materials in the cell "see" the same flux (i.e., there is no self-shielding to permit the flux, at any energy, to be higher in one material than in another). Table 6 shows the results obtained.

A P-1 calculation is performed. The completed basic parameter cards are listed in Figure 5. The following comments apply to these inputs.

- 1) The problem number is assigned for reference purposes only.
- 2) Fifteen groups are specified; the code calculates only fast group constants; the constants for the sixteenth (thermal) group must be obtained from other sources. However, scattering into the sixteenth group (defined with energy limits from the bottom of the fifteenth group to zero) is calculated.
- 3) Five broad groups of downscattering are desired. All scattering to groups below this point are added to the last group considered.
- 4) Since more than one type of resonance geometry cannot be used and since cylindrical fuel pins are involved, a cylindrical geometry is selected for the resonance calculations. The choice of geometry defines which of three possible tables of $L(t, \xi, \beta)$ must be used in the machine.

FIGURE 4. FUEL PIN LATTICE FOR AGN-GAM SAMPLE PROBLEM

11.2-65-779

EXAMPLE PROBLEM FOR AGN-TM-407

+7.0001	E+00+1.0	E+00+4.0	E+00+1.5	E+01+5.0	E+00+2.0	E+00	1000
+0.0	E+00+1.0	E+00+1.0	E+00+0.0	E+00			1001
+3.0	E+06+1.4	E+06+9.0	E+05+4.0	E+05+1.0	E+05+1.7	E+04	2000
+3.0	E+03+4.54	E+02+6.144	E+01+2.26	E+01+8.315	E+00+3.059	E+00	2001
+1.1256	E+00+4.141	E-01+1.523	E-01				2002
+2.0	E+00						3000
-6.91	E-03-7.82	E-03-9.21	E-03-1.005	E-02-1.058	E-02-1.105	E-02	3001
-1.125	E-02-1.129	E-02-1.129	E-02-1.130	E-02-1.130	E-02-1.130	E-02	3002
-1.132	E-02-1.140	E-02-1.178	E-02				3003
+4.0	E+00+1.0	E+00+1.0	E+00				4000
+0.0	E+00						5000
+6.0	E+00	+7.73	E-01+0.0	E+00+0.0	E+00	H20	8000
+6.5	E+01	+8.55	E-01+0.0	E+00+0.0	E+00	HX	8000
+8.0	E+00	+1.82	E-01+0.0	E+00+0.0	E+00	BE0	8000
+1.01	E+02	+4.55	E-01+0.0	E+00+1.0	E+00	U35	8000
+9.8	E-03+2.09	E-01+2.93	E+02+4.58	E+01+5.58	E+01	U35	8014
+1.7	E+01	+3.40	E-02+0.0	E+00+0.0	E+00	U38	8000
+3.2	E+01	+6.70	E-02+0.0	E+00+0.0	E+00	OX	8000
+4.3	E+01+0.0	E+00+0.0	E+00+1.0	E+00+1.0	E+00	MN	8000
+1.10	E+00+1.05	E+00+1.03	E+00+1.01	E+00+1.00	E+00+1.00	E+00MN	8001
+1.00	E+00+1.00	E+00+1.00	E+00+1.00	E+00+1.00	E+00+0.98	E+00MN	8002
+0.95	E+00+0.91	E+00+0.85	E+00			MN	8003
+9.9999	E+04						9000

FIGURE 5. LIST OF INPUT CARDS FOR SAMPLE PROBLEM

TABLE 6 - COMPOSITION OF SAMPLE PROBLEM

<u>Material</u>	<u>Volume Fraction</u>	<u>Pure Material Density (g/cc)</u>	<u>Cell Density (g/cc)</u>
Water	0.7732	1.00	0.773
Hastelloy-X	0.1039	8.23	0.855
Void	0.0040	----	----
Fuel Pellet			
BeO	0.0648	2.81	0.182
UO ₂	0.0541		
a) U-235		8.41	0.455
b) U-238		0.63	0.034
c) Oxygen		1.23	<u>0.067</u>
	1.0000		2.366

- 5) No punched fluxes and currents are requested.
- 6) Punched cross sections for the DSN code are requested. Macroscopic results for the mixture are provided in addition to the microscopic values for any material indicated later in the input.
- 7) In the punched cross section block, room for one activation cross section is left (it is punched as a zero). No up-scattering on the transfer matrices is provided for.

The energy breaks between the broad groups correspond with the common LASL values. These specified energies do not have to correspond with the one quarter lethargy values used with the library data tape; the code will find the nearest division on the library tape and use it.

Leakage terms are calculated by estimating the buckling for a bare cylindrical core 56 cm high and 25 cm in radius. A U-235 fission source on the AGN-GAM data tape is selected for the volume source. The surface source is set to zero.

Material constants are input as previously specified. Identification numbers for the data tape are obtained from Table D-IV in Appendix D. Microscopic cross sections for U-235 are calculated with the resonance treatment, and therefore, an extra card containing the appropriate parameters is supplied. Table 7 shows how the needed values are obtained. It is assumed that the pins are at a physical temperature of 20°C.

TABLE 7 - CALCULATION OF PARAMETERS FOR RESONANCE CALCULATION

<u>Material</u>	<u>Density in Fuel Pin (g/cc)</u>	<u>Number Density In Fuel Pin (at/cc)</u>	<u>σ_{scatt} (barns)</u>	<u>$N \sigma_{\text{scatt}}$ (cm⁻¹)</u>
Be	0.551	0.0369×10^{24}	6	0.221
U-235	3.827	0.0098×10^{24}	10	0.098
U-238	0.286	0.0008×10^{24}	10	0.008
Oxygen	1.543	0.0581×10^{24}	3.8	0.220

$$\sigma_m = \frac{0.221 + 0.008 + 0.220}{0.0098} = 45.8 \text{ barns}$$

$$\sigma_p = \frac{0.221 + 0.098 + 0.008 + 0.220}{0.0098} = 55.8 \text{ barns}$$

As an added complication, it is assumed that a manganese wire exists in the system for experimental purposes, and that cross sections for this wire are desired. The assumption is made that self-shielding factors are known for the manganese by broad groups. The manganese is added with zero density, which will cause it not to be considered in the calculation of the macroscopic cross sections but will permit calculation of microscopic values. The self-shielding factors are automatically included in these microscopic values.

Figure 6 shows the output from this problem. Note the energy specifications and how they have been adjusted to fall on the one quarter lethargy values. In addition it is apparent that the materials have been placed according to ID numbers (in ascending order). Self-shielding factors are printed only when they were input. Results of the resonance calculations are shown with totals; following the input quantities, the calculated flux, current, and ages appear. Listed next are the averaged macroscopic cross sections for the specified mixture (in cm⁻¹), followed by the requested microscopic values (in barns).

Figure 7 shows a listing of part of the punched card outputs for input to the DSN code; the meaning of the ID field symbols are indicated on this figure. Values for the thermal group have been punched as zeros and must be replaced with the correct values.

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AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

BROAD GROUP SPECIFICATIONS

GROUP NO.	TOP ENERGY	DESIRED BOTTOM ENERGY	ACTUAL BOTTOM ENERGY	DELTA U	SUB-GROUPS
1	1.000E 07	3.000E 06	2.865E 06	1.25	1 TO 5
2	2.865E 06	1.400E 06	1.353E 06	0.75	6 TO 8
3	1.353E 06	9.000E 05	8.208E 05	0.50	9 TO 10
4	8.208E 05	4.000E 05	3.877E 05	0.75	11 TO 13
5	3.877E 05	1.000E 05	1.111E 05	1.25	14 TO 18
6	1.111E 05	1.700E 04	1.503E 04	2.00	19 TO 26
7	1.503E 04	3.000E 03	3.355E 03	1.50	27 TO 32
8	3.355E 03	4.500E 02	4.540E 02	2.00	33 TO 40
9	4.540E 02	6.144E 01	6.144E 01	2.00	41 TO 48
10	6.144E 01	2.260E 01	2.260E 01	1.00	49 TO 52
11	2.260E 01	8.315E 00	8.315E 00	1.00	53 TO 56
12	8.315E 00	3.059E 00	3.059E 00	1.00	57 TO 60
13	3.059E 00	1.126E 00	1.125E 00	1.00	61 TO 64
14	1.125E 00	4.11E-01	4.140E-01	1.00	65 TO 68
15	4.140E-01	1.53E-01	1.523E-01	1.00	69 TO 72

MATERIAL SPECIFICATIONS -- CROSS SECTIONS TAKEN FROM AGN-GAM DATA TAPE NUMBER 1003

ID NUMBER 6	WATER, LIGHT	DENSITY = 7.7300E-01 GRAMS/CC	NUMBER DENSITY = 7.7351E 22 ATOMS/CC
ID NUMBER 8	BERYLLIUM OXIDE	DENSITY = 1.8200E-01 GRAMS/CC	NUMBER DENSITY = 8.7675E 21 ATOMS/CC
ID NUMBER 17	URANIUM-238 (INF. DIL)	DENSITY = 3.4000E-02 GRAMS/CC	NUMBER DENSITY = 8.6024E 19 ATOMS/CC
ID NUMBER 32	OXYGEN	DENSITY = 6.7000E-02 GRAMS/CC	NUMBER DENSITY = 2.5229E 21 ATOMS/CC
ID NUMBER 43	MANGANESE	DENSITY = 0. GRAMS/CC	NUMBER DENSITY = 0. ATOMS/CC
SELF-SHIELDING FACTORS			
1	1.10000E 00	16 1.00000E 00	31 1.00000E 00
2	1.10000E 00	17 1.00000E 00	32 1.00000E 00
3	1.10000E 00	18 1.00000E 00	33 1.00000E 00
4	1.10000E 00	19 1.00000E 00	34 1.00000E 00
5	1.10000E 00	20 1.00000E 00	35 1.00000E 00
6	1.05000E 00	21 1.00000E 00	36 1.00000E 00
7	1.05000E 00	22 1.00000E 00	37 1.00000E 00
8	1.05000E 00	23 1.00000E 00	38 1.00000E 00
9	1.03000E 00	24 1.00000E 00	39 1.00000E 00
10	1.03000E 00	25 1.00000E 00	40 1.00000E 00
11	1.01000E 00	26 1.00000E 00	41 1.00000E 00
12	1.01000E 00	27 1.00000E 00	42 1.00000E 00
13	1.01000E 00	28 1.00000E 00	43 1.00000E 00
14	1.00000E 00	29 1.00000E 00	44 1.00000E 00
15	1.00000E 00	30 1.00000E 00	45 1.00000E 00
ID NUMBER 65	HASTELLOY - X	DENSITY = 8.5500E-01 GRAMS/CC	NUMBER DENSITY = 8.7979E 21 ATOMS/CC
ID NUMBER 101	URANIUM-235	DENSITY = 4.5500E-01 GRAMS/CC	NUMBER DENSITY = 1.1659E 21 ATOMS/CC

FIGURE 6. OUTPUT FROM SAMPLE PROBLEM

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

RESONANCE DATA		DIMENSION (CM) = 2.0900E-01		TEMPERATURE (K) = 2.9300E 02	
LUMP DENSITY = 9.8000E-03		SIGMA-P = 5.5800E 01		CYLIN.	
SIGMA-M = 4.5800E 01					
ENERGY(EV)	GROUP	SURFACE INTEGRALS		VOLUME INTEGRALS	
		ABSORPTION	FISSION	ABSORPTION	FISSION
2.0350E 00	62	1.2668E 00	3.2344E-01	2.1905E 00	5.5929E-01
2.8200E 00	61	1.0160E-01	5.4044E-02	6.5468E-01	3.4824E-01
3.1600E 00	60	1.9668E 00	1.6390E 00	4.1319E 00	3.4432E 00
3.6000E 00	60	2.8056E 00	1.5397E 00	3.1750E 00	1.7424E 00
4.8400E 00	59	1.9261E 00	2.6566E-01	1.5834E 00	2.1841E-01
5.4500E 00	58	4.3607E-01	2.3195E-01	9.8728E-01	5.2515E-01
5.8000E 00	58	1.9630E-01	1.0441E-01	7.3553E-01	3.49124E-01
6.1700E 00	58	3.7762E-01	2.0086E-01	9.8437E-01	5.2360E-01
6.3800E 00	58	4.8453E 00	1.2113E 00	3.4854E 00	8.7136E-01
7.0900E 00	57	1.4784E 00	5.8080E-01	1.7157E 00	6.17403E-01
8.7900E 00	56	7.0095E 00	3.9193E 00	4.9408E 00	2.47626E 00
9.2700E 00	56	1.1089E 00	1.3046E-01	1.1497E 00	1.43526E-01
9.7000E 00	56	2.9310E-01	1.5590E-01	7.2006E-01	3.8301E-01
1.0180E 01	56	3.7150E-01	1.9761E-01	7.8649E-01	4.1835E-01
1.0600E 01	56	1.2094E-01	6.4332E-02	4.5338E-01	2.4116E-01
1.1650E 01	55	3.2345E 00	2.3623E-01	1.8892E 00	1.43797E-01
1.2400E 01	55	4.6131E 00	1.3839E 00	2.9069E 00	8.47207E-01
1.2800E 01	55	1.3365E-03	7.1088E-04	4.7116E-02	2.5062E-02
1.3350E 01	55	3.4756E-01	1.8487E-01	6.8281E-01	3.6320E-01
1.3800E 01	54	4.8556E-01	3.6324E-01	9.7506E-01	7.2944E-01
1.4100E 01	54	5.9710E-01	4.9808E-01	1.2754E 00	1.0639E 00
1.4650E 01	54	4.8057E-01	2.6333E-01	7.7956E-01	4.2716E-01
1.5440E 01	54	7.3968E-01	2.6106E-01	8.5004E-01	3.0001E-01
1.6100E 01	54	1.0750E 00	2.3437E-01	9.3768E-01	2.0442E-01
1.6700E 01	54	7.3873E-01	3.0341E-01	8.4718E-01	3.4795E-01
1.8100E 01	53	7.6767E-01	4.4700E-01	9.3341E-01	5.4350E-01
1.8600E 01	53	3.9788E-01	2.1164E-01	6.3878E-01	3.3977E-01
1.9300E 01	53	4.2349E 00	2.2586E 00	2.9422E 00	1.5692E 00
2.0650E 01	53	6.7174E-01	2.5349E-01	7.2448E-01	2.7339E-01
2.1100E 01	53	1.8336E 00	8.7316E-01	1.2653E 00	6.0253E-01
2.2940E 01	52	1.0313E 00	3.3674E-01	8.3332E-01	2.7211E-01
2.3700E 01	52	1.9385E 00	6.8417E-01	1.1882E 00	4.1938E-01
2.4300E 01	52	6.3308E-01	3.3883E-01	7.2533E-01	3.6821E-01
2.5300E 01	52	4.5951E-01	1.7232E-01	5.5932E-01	2.0975E-01
2.5600E 01	52	7.3693E-01	3.5872E-01	7.2982E-01	3.5526E-01
2.5900E 01	52	4.8367E-01	9.6265E-02	5.3535E-01	1.0655E-01
2.6530E 01	52	5.2619E-01	3.7520E-01	7.3677E-01	5.2535E-01
2.7150E 01	52	6.1285E-02	3.2599E-02	2.2933E-01	1.12199E-01
2.7820E 01	52	7.7098E-01	3.3232E-01	7.0107E-01	3.0218E-01
2.8400E 01	52	3.4992E-01	8.7480E-02	4.5379E-01	1.1345E-01
2.9700E 01	51	3.2727E-01	5.9282E-02	4.2584E-01	7.7138E-02
3.0900E 01	51	5.6800E-01	1.4200E-01	5.4507E-01	1.13627E-01
3.2100E 01	51	1.2485E 00	5.3813E-01	8.5021E-01	3.6647E-01
3.3570E 01	51	1.3434E 00	5.2243E-01	8.5444E-01	3.3228E-01
3.4400E 01	51	1.7746E 00	7.2884E-01	1.0281E 00	4.2227E-01
3.5300E 01	51	2.2896E 00	1.1619E 00	1.3240E 00	6.7188E-01
3.8400E 01	50	4.2636E-02	2.2679E-02	1.7076E-01	9.0829E-02

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

3.9500E 01	50	1.1899E 00	6.0381E-01	7.9935E-01	4.0564E-01
4.1900E 01	50	9.8344E-01	3.8245E-01	6.6263E-01	2.5769E-01
4.3450E 01	50	4.2425E-01	1.1313E-01	4.2134E-01	1.1236E-01
4.4700E 01	50	7.2509E-01	3.0530E-01	5.6177E-01	2.3653E-01
4.7000E 01	50	4.1260E-01	2.8292E-01	5.0733E-01	3.4788E-01
4.8600E 01	49	1.2671E 00	1.8101E-01	6.6749E-01	9.5355E-02
5.1600E 01	49	1.0757E 00	5.2699E-02	5.7635E-01	2.8236E-02
5.5400E 01	49	7.3850E-01	5.3021E-01	6.4145E-01	4.6653E-01
5.6400E 01	49	1.4085E 00	6.4149E-01	7.7761E-01	3.5416E-01
5.8300E 01	49	8.3916E-01	3.9034E-01	5.5666E-01	2.5893E-01
6.1000E 01	49	2.0810E-01	1.6436E-01	3.6480E-01	2.8812E-01
RESOLVED SUM		6.8381E 01	2.8030E 01	6.3817E 01	2.8794E 01
UNRESOLVED SUM		8.1246E 00	4.3216E 00	2.3489E 01	1.1249E 01
TOTALS		7.6506E 01	3.2351E 01	8.7306E 01	4.1288E 01
TOTAL INTEGRAL		1.6381E 02	7.3639E 01		

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

FLUX AND CURRENT CALCULATED USING THE P-1 METHOD

LEAKAGE TERM					
1	-6.91000E-03	16	-1.05800E-02	31	-1.12500E-02
2	-6.91000E-03	17	-1.05800E-02	32	-1.12500E-02
3	-6.91000E-03	18	-1.05800E-02	33	-1.12900E-02
4	-6.91000E-03	19	-1.10500E-02	34	-1.12900E-02
5	-6.91000E-03	20	-1.10500E-02	35	-1.12900E-02
6	-7.82000E-03	21	-1.10500E-02	36	-1.12900E-02
7	-7.82000E-03	22	-1.10500E-02	37	-1.12900E-02
8	-7.82000E-03	23	-1.10500E-02	38	-1.12900E-02
9	-9.21000E-03	24	-1.10500E-02	39	-1.12900E-02
10	-9.21000E-03	25	-1.10500E-02	40	-1.12900E-02
11	-1.00500E-02	26	-1.10500E-02	41	-1.12900E-02
12	-1.00500E-02	27	-1.12500E-02	42	-1.12900E-02
13	-1.00500E-02	28	-1.12500E-02	43	-1.12900E-02
14	-1.05800E-02	29	-1.12500E-02	44	-1.12900E-02
15	-1.05800E-02	30	-1.12500E-02	45	-1.12900E-02
				46	-1.12900E-02
				47	-1.12900E-02
				48	-1.12900E-02
				49	-1.13000E-02
				50	-1.13000E-02
				51	-1.13000E-02
				52	-1.13000E-02
				53	-1.13000E-02
				54	-1.13000E-02
				55	-1.13000E-02
				56	-1.13000E-02
				57	-1.13000E-02
				58	-1.13000E-02
				59	-1.13000E-02
				60	-1.13000E-02
				61	-1.13200E-02
				62	-1.13200E-02
				63	-1.13200E-02
				64	-1.13200E-02
				65	-1.14000E-02
				66	-1.14000E-02
				67	-1.14000E-02
				68	-1.14000E-02
				69	-1.14000E-02
				70	-1.17800E-02
				71	-1.17800E-02
				72	-1.17800E-02
				73	-1.17800E-02
				74	-1.17800E-02
				75	-1.17800E-02

VOLUME SOURCE (NORMALIZED TO 1.0000E 00) THE U-235 SPECTRUM - PROMPT + DELAYED					
1	5.92215E-03	16	1.46944E-02	31	-0.
2	1.69400E-02	17	1.11518E-02	32	-0.
3	3.91915E-02	18	7.65003E-03	33	-0.
4	6.82856E-02	19	5.50842E-03	34	-0.
5	9.56418E-02	20	3.90346E-03	35	-0.
6	1.13306E-01	21	2.73522E-03	36	-0.
7	1.18131E-01	22	1.90776E-03	37	-0.
8	1.11680E-01	23	1.30115E-03	38	-0.
9	4.80453E-02	24	8.95425E-04	39	-0.
10	8.13981E-02	25	5.97612E-04	40	-0.
11	6.47789E-02	26	4.06736E-04	41	-0.
12	4.99605E-02	27	2.80817E-04	42	-0.
13	3.76086E-02	28	-0.	43	-0.
14	2.77939E-02	29	-0.	44	-0.
15	2.02928E-02	30	-0.	45	-0.
				46	-0.
				47	-0.
				48	-0.
				49	-0.
				50	-0.
				51	-0.
				52	-0.
				53	-0.
				54	-0.
				55	-0.
				56	-0.
				57	-0.
				58	-0.
				59	-0.
				60	-0.
				61	-0.
				62	-0.
				63	-0.
				64	-0.
				65	-0.
				66	-0.
				67	-0.
				68	-0.
				69	-0.
				70	-0.
				71	-0.
				72	-0.
				73	-0.
				74	-0.
				75	-0.

SURFACE SOURCE					
1	0.	16	0.	31	0.
2	0.	17	0.	32	0.
3	0.	18	0.	33	0.
4	0.	19	0.	34	0.
5	0.	20	0.	35	0.
6	0.	21	0.	36	0.
7	0.	22	0.	37	0.
8	0.	23	0.	38	0.
9	0.	24	0.	39	0.
10	0.	25	0.	40	0.
11	0.	26	0.	41	0.
12	0.	27	0.	42	0.
13	0.	28	0.	43	0.
14	0.	29	0.	44	0.
15	0.	30	0.	45	0.
				46	0.
				47	0.
				48	0.
				49	0.
				50	0.
				51	0.
				52	0.
				53	0.
				54	0.
				55	0.
				56	0.
				57	0.
				58	0.
				59	0.
				60	0.
				61	0.
				62	0.
				63	0.
				64	0.
				65	0.
				66	0.
				67	0.
				68	0.
				69	0.
				70	0.
				71	0.
				72	0.
				73	0.
				74	0.
				75	0.

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

FLUX					
1	5.39179E-02	16	4.23120E-01	31	1.89294E-01
2	1.59691E-01	17	3.78284E-01	32	1.88432E-01
3	3.50746E-01	18	3.39006E-01	33	1.86457E-01
4	5.41791E-01	19	3.07703E-01	34	1.82612E-01
5	7.85678E-01	20	2.76392E-01	35	1.81015E-01
6	1.05454E 00	21	2.36433E-01	36	1.79422E-01
7	1.05334E 00	22	2.45093E-01	37	1.77744E-01
8	1.07109E 00	23	2.30109E-01	38	1.77043E-01
9	8.92779E-01	24	2.19150E-01	39	1.74816E-01
10	8.53665E-01	25	2.11657E-01	40	1.72688E-01
11	8.71700E-01	26	2.01790E-01	41	1.71760E-01
12	7.07040E-01	27	2.03276E-01	42	1.68603E-01
13	5.19149E-01	28	1.94551E-01	43	1.67017E-01
14	5.82874E-01	29	1.93369E-01	44	1.65014E-01
15	4.79170E-01	30	1.92188E-01	45	1.61023E-01
				46	1.57867E-01
				47	1.57614E-01
				48	1.54497E-01
				49	1.49682E-01
				50	1.46912E-01
				51	1.42483E-01
				52	1.39948E-01
				53	1.33809E-01
				54	1.35717E-01
				55	1.31870E-01
				56	1.27860E-01
				57	1.30561E-01
				58	1.24043E-01
				59	1.28258E-01
				60	1.22397E-01
				61	1.24711E-01
				62	1.24095E-01
				63	1.21718E-01
				64	1.14801E-01
				65	1.10234E-01
				66	1.09512E-01
				67	1.04456E-01
				68	9.64801E-02
				69	8.33469E-02
				70	7.30018E-02
				71	6.62880E-02
				72	6.08461E-02
				73	5.52338E-02
				74	4.93339E-02
				75	4.42810E-02

CURRENT TERM					
1	1.24500E-03	16	4.39982E-03	31	1.18933E-03
2	3.57351E-03	17	3.81919E-03	32	1.17033E-03
3	6.89441E-03	18	3.39099E-03	33	1.18072E-03
4	8.21324E-03	19	3.00622E-03	34	1.14133E-03
5	1.04802E-02	20	2.58019E-03	35	1.14631E-03
6	1.70398E-02	21	2.32068E-03	36	1.13890E-03
7	1.59415E-02	22	2.17998E-03	37	1.11830E-03
8	1.52112E-02	23	1.94553E-03	38	1.11207E-03
9	1.19555E-02	24	1.74384E-03	39	1.09719E-03
10	9.86448E-03	25	1.62320E-03	40	1.07079E-03
11	1.13213E-02	26	1.40750E-03	41	1.05620E-03
12	9.14921E-03	27	1.54500E-03	42	9.96866E-04
13	5.40982E-03	28	1.41809E-03	43	1.01058E-03
14	6.44483E-03	29	1.35213E-03	44	9.94734E-04
15	5.10597E-03	30	1.28447E-03	45	9.46199E-04
				46	9.12912E-04
				47	9.32962E-04
				48	9.11304E-04
				49	8.78761E-04
				50	8.33317E-04
				51	8.14733E-04
				52	8.09385E-04
				53	7.53870E-04
				54	7.78926E-04
				55	7.58889E-04
				56	7.32541E-04
				57	7.59595E-04
				58	7.10351E-04
				59	7.52858E-04
				60	7.07300E-04
				61	7.33615E-04
				62	7.31428E-04
				63	7.14675E-04
				64	6.61669E-04
				65	6.31931E-04
				66	6.30546E-04
				67	5.93082E-04
				68	5.33426E-04
				69	4.43719E-04
				70	3.71042E-04
				71	3.23825E-04
				72	2.84192E-04
				73	2.45364E-04
				74	2.01737E-04
				75	1.65738E-04

AGN-GAM PROBLEM NUMBER 7.0001 EXAMPLE PROBLEM FOR AGN-TM-407

FERMI AGE - SQ. CM.									
1	3.35221E 01	16	2.17578E 01	31	2.43344E 01	46	2.61142E 01	61	2.77038E 01
2	3.36741E 01	17	2.20074E 01	32	2.44578E 01	47	2.62389E 01	62	2.78202E 01
3	3.21382E 01	18	2.23265E 01	33	2.45955E 01	48	2.63470E 01	63	2.79265E 01
4	2.29077E 01	19	2.25437E 01	34	2.47129E 01	49	2.64444E 01	64	2.80065E 01
5	2.02674E 01	20	2.27114E 01	35	2.48459E 01	50	2.65358E 01	65	2.80909E 01
6	2.24306E 01	21	2.29010E 01	36	2.49753E 01	51	2.66348E 01	66	2.81947E 01
7	2.13782E 01	22	2.31142E 01	37	2.50974E 01	52	2.67423E 01	67	2.82751E 01
8	2.12676E 01	23	2.32663E 01	38	2.52242E 01	53	2.68219E 01	68	2.83332E 01
9	1.95637E 01	24	2.33991E 01	39	2.53471E 01	54	2.69427E 01	69	2.83532E 01
10	1.92465E 01	25	2.35442E 01	40	2.54631E 01	55	2.70434E 01	70	2.83740E 01
11	2.04137E 01	26	2.36291E 01	41	2.55822E 01	56	2.71384E 01	71	2.84032E 01
12	2.08578E 01	27	2.38470E 01	42	2.56780E 01	57	2.72651E 01	72	2.84314E 01
13	2.02130E 01	28	2.39898E 01	43	2.58030E 01	58	2.73496E 01	73	2.84536E 01
14	2.10780E 01	29	2.41173E 01	44	2.59187E 01	59	2.74866E 01	74	2.84640E 01
15	2.14222E 01	30	2.42361E 01	45	2.60155E 01	60	2.75733E 01	75	2.84724E 01

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