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GAMLEG-JR: A PRODUCTION CODE OF MULTI-GROUP CROSS SECTIONS AND ENERGY ABSORPTION COEFFICIENTS FOR GAMMA RAYS

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GAMLEG-JR

A Production Code of Multi-group Cross Sections and Energy Absorption Coefficients for Gamma Rays

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GAMLEG-JR is a modification of GAMLEG to produce multi-group photon cross sections for use in the S_n-type transport codes. In the GAMLEG code, the cross section data for the photoelectric effect, pair production and coherent scattering are read in tabular form by cards. GAMLEG-JR generates these cross section data by simple empirical formulae as a function of atomic number Z. The code also produces the group-averaged gamma-ray energy absorption coefficient (KERMA factor). An integration of obtaining the group averaging transfer cross sections has been modified in the present code, because the original integration method is inadequate for calculations of higher Legendre moments in the low energy region.

The group cross sections produced by the code are compared with the theoretical ones.

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GAMLEG－JR，ガンマ線多群定数および発熱定数作成コード

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（1977年1月26日受理）

GAMLEG－JRはSn輸送計算コード用の多群光子断面積作成コードとして開発されたGAMLEGを改造したものである。GAMLEGでは光電効果，電子対生成およびコヒーレント散乱断面積を入力データとして用意しなければならないが，GAMLEG－JRでは原子番号Zの関数として表わす経験式を用いて，これらの断面積を求めるように変更した。またGAMLEG－JRは群定数化されたガンマ線発熱定数（KERMA）も求められるようプログラムの改造が行なわれている。また原典では，遷移断面積の積分方法が低エネルギー領域で高次のルジャンドルモーメントに対して適切でなくなるので，本コードではその積分法を変更した。

本コードで計算された群定数を理論値等と比較し，その計算精度が評価された。

＊　富士通K．K．

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1. Introduction

The GAMLEG code was designed to generate multigroup photon cross sections for use in the Sn-type transport calculations. For performing numerical integration to produce group-averaged cross sections in the code, the cross section data for photoelectric, pair production and coherent scattering reactions have to be prepared in tabular forms by input cards. However, the preparation of those data are somewhat troublesome for users. In order to eliminate such trouble GAMLEG-JR generates those cross section data by using the simple empirical formulae as a function of atomic number Z. The code also produces the energy deposition coefficient (KERMA factor) given by

$$h_\gamma(I) = 1.6\times10^{-13}(\mu_{en}/\rho) \cdot (M/N_o) \cdot \bar{E}_I \text{ [barn·watt·sec/atom]}, \qquad (1)$$

where M is the atomic mass number, N_o is the Avogadro's number, and $\bar{E}_I$ is the mean energy of the I-th group. The (μ_{en}/ρ) is the mass energy absorption coefficient given by[4)]

$$\mu_{en}/\rho = (\frac{c}{\rho})f_c + (\frac{\tau}{\rho})f_\tau + (\frac{k}{\rho})f_k, \qquad (2)$$

where the first, second and third terms represent respectively the mass energy-transfer coefficient for Compton scattering, photoelectric absorption and pair production. The code calculates the mass energy absorption coefficient by neglecting the bremsstrahlung effect of recoil electrons.

The original code, GAMLEG, calculates analytically the energy integral of an equation for the average transfer cross section. However, this integration method was found not to be adequate for obtaining the higher Legendre moments than the 6th order at low energy region below about 0.1 MeV, because of round-off errors caused by the machine computation. The present code, GAMLEG-JR, calculates this integral by the numerical integration based on the Simposon's rule for equally spaced μ (= 1+1/E'-1/E).

The present code is written in FORTRAN-IV for use on the FACOM-230/75 machine. The program provides up to 50-energy groups and up to nine Legendre moments for each of unlimited number of elements. Flux weighting data are limited to a maximum of 500 values.

The paper presents also the results of evaluation for the calculated cross sections by comparing with theoretical values.

2. Absorption Cross Sections

2.1 Photoelectric Cross Section[1)]

An empirical formula of photoelectric cross section for the K-shell photoeffect above 0.2 MeV, τ_k, is given by

$$\tau_k = Z^5 \sum_{n=1}^{4} \frac{a_n + b_n Z}{1 + c_n Z} E^{-p_n} \qquad \text{(barns/atom)}, \tag{3}$$

where a_n, b_n, c_n and p_n are given in the following table.

n	a_n	b_n	c_n	p_n
1	1.6268×10^{-9}	-2.683×10^{-12}	4.173×10^{-2}	1
2	1.5274×10^{-9}	-5.110×10^{-19}	1.027×10^{-2}	2
3	1.1330×10^{-9}	-2.177×10^{-12}	2.013×10^{-2}	3.5
4	$-9.12 \quad 10^{-11}$	0.0	0.0	4

The ratio of the total photoelectric to K-shell photoelectric cross section is written as

$$\tau_{pe}/\tau_k = 1 + 0.01481\ \ell n^2 Z - 0.000788\ \ell n^2 Z \tag{4}$$

For an element with the atomic number greater than 8, and for photon energy less than $E_o = 0.01 \exp\,[0.031(Z-8)]$ MeV, the cross section for K-shell is calculated by the formula;

$$\tau_k = \frac{3}{2}\phi_o \frac{Z^5}{(137)^4} n^5 (\gamma^2-1)^{3/2} [\frac{4}{3} + \frac{\gamma(\gamma-2)}{\gamma+1} \{1 - \frac{1}{2\gamma(\gamma^2-1)^{1/2}}$$

$$\times\ \ell n \frac{\gamma+(\gamma^2-1)^{1/2}}{\gamma-(\gamma^2-1)^{1/2}} \}] \cdot f \qquad \text{[barn/atom]}, \tag{5}$$

where

$$f = 2\pi(\frac{I}{h\nu})^{1/2} [\frac{\exp(-4x \ \text{arccot}\ x)}{1-\exp(-2\pi x)}],$$

$$\phi_o = 8\pi r_o^2/3 = 6.6537 \times 10^{-25}\ (\text{cm}^2),$$
$$r_o = e^2/(mc^2) = 2.8182 \times 10^{-13}\ (\text{cm}),$$
$$mc^2 = 0.51084\ (\text{MeV}),$$
$$n = mc^2/(h\nu),$$

$\gamma = h\nu/(mc^2) + 1$,

$I = (Z-0.3)^2 Ry$ (photon energy at K-shell edge in units of MeV)

$Ry = 13.52$ (eV) (Rydbery's constant),

$x = [I/(h\nu-I)]^{1/2}$

The cross sections τ_{LI}, τ_{LII} and τ_{LIII} for L-shell are given by

$$\tau_{LI} = \frac{2^{12}\pi\phi_o(137)^3}{(Z-S_2)^2}\left(\frac{\nu_2}{\nu}\right)^4\left(1+3\frac{\nu_2}{\nu}\right)\frac{\exp(-8\xi_2 \text{ arccot } \xi_2)}{1-\exp(-4\pi\xi_2)}, \tag{6}$$

$$\tau_{LII}+\tau_{LIII} = \frac{2^{12}\pi\phi_o(137)^3}{(Z-S_2)^2}\left(\frac{\nu_2}{\nu}\right)^5\left(3+8\frac{\nu_2}{\nu}\right)\frac{\exp(-8\xi_2 \text{ arccot } \xi_2)}{1-\exp(-4\pi\xi_2)}, \tag{7}$$

where

$S_2 = 4.15 \quad (Z>10)$,

$\nu_2 = \frac{1}{4}(Z-S_2)^2 Ry$,

$\xi_2 = [\nu_2/(\nu-\nu_2)]^{1/2}$.

2.2 Pair Production Cross Section[2)]

The pair production cross section, κ, is written as follows:

i) $E < 1.022$ MeV

$$\kappa = 0.0, \tag{8}$$

ii) $1.022 \text{ MeV} < E < 2.0 \text{ MeV}$

$$K = \frac{Z^2 r_o^2}{137}\cdot\frac{2\pi}{3}\cdot\left(\frac{K-2}{K}\right)^3\left[1+\frac{1}{2}\rho+\frac{23}{40}\rho^2+\frac{11}{60}\rho^3+\frac{29}{960}\rho^4+\ldots\right], \tag{9}$$

iii) $E > 2.0$ MeV

$$K = \frac{Z^2\cdot r_o^2}{137}\left\{\frac{28}{9}\ln(2K) - \frac{218}{27} + \left(\frac{2}{K}\right)^2\left[6\ln(2K) - \frac{7}{2}\right.\right.$$

$$\left. + \frac{2}{3}\ln^3(2K) - \ln^2(2K) - \frac{1}{3}\pi^2\ln(2K) + 2\xi(3) + \frac{\pi^2}{6}\right)$$

$$- \left(\frac{2}{K}\right)^4\left[\frac{3}{16}\ln(2K) + \frac{1}{8}\right] - \left(\frac{2}{K}\right)^6\left[\frac{29}{9.256}\ln(2K)\right.$$

$$\left. - \frac{77}{27.512} + \ldots\right\}, \tag{10}$$

where,

$$\rho = (2k-4)/(2+k+2\sqrt{2K}),$$

$$\xi(3) = \sum_{n=1}^{\infty} \frac{1}{n^2} = 1.2020569,$$

$$K = h\nu/mc^2.$$

2.3 Coherent Scattering Cross Section

The coherent scattering cross section is given by

$$\frac{d\sigma_R(\theta)}{d\Omega} = \frac{r_o^2}{2} (1+\cos^2\theta)[F(g,Z)]^2, \tag{11}$$

where F(g,Z) is an atomic form factor and depends on knowledge of the atomic wave function.

Figure 1 shows the coherent scattering cross sections of H, Al, Fe and Pb given in Ref. 3). In the present code, the cross sections are evaluate from a function of atomic number Z and photon energy E obtained by using the least squares method for the data given in Ref. 3).

$$\sigma_R = \exp[-0.09615(\ell nE+11.532)^2+2.357\ell n \frac{Z}{26} +9.436]. \tag{12}$$

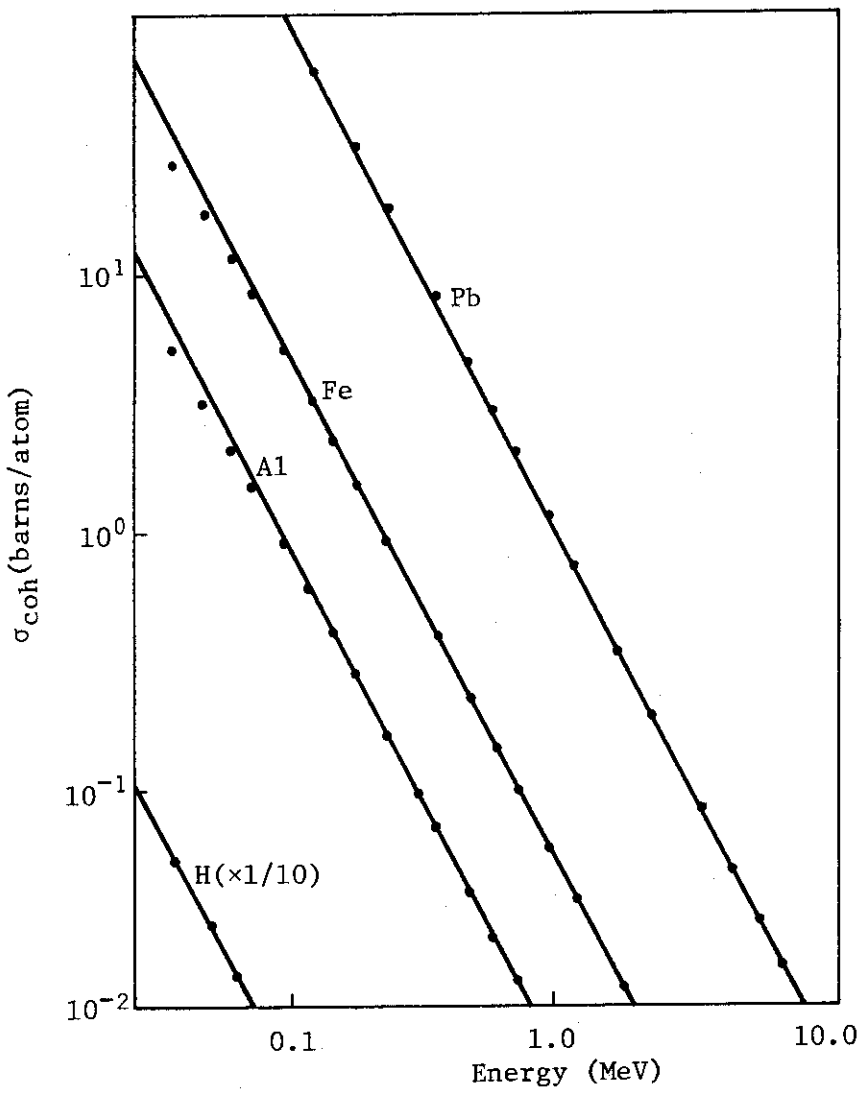

Fig. 1 Coherent gamma-ray scattering cross section[3)]

3. Energy Deposition Coefficient

The mass energy absorption coefficient, μ_{en}/ρ, is the weighted sum of the probabilities per unit path length for Compton scattering (c/ρ), photoelectric absorption (τ/ρ) and pair production (κ/ρ):

$$\frac{\mu_{en}}{\rho} = (\frac{c}{\rho})f_c + (\frac{\tau}{\rho})f_\tau + (\frac{\kappa}{\rho})f_\kappa. \tag{13}$$

The weights f_c, f_τ and f_k are conversion factors which are the fraction of the photon energy converted eventually into kinetic energy of electrons and dissipated to the medium via collision losses as ionization and excitation.

3.1 Compton scattering[4)]

The f_c for the Compton scattering is given by

$$f_c(h\nu) = \frac{1}{h\nu}\int_o^{T_{max}} P_c(h\nu,T)\ T[1-G_{br}(T)]dT, \tag{14}$$

where

$$T_{max} = \frac{2(h\nu)^2}{mc^2+2h\nu},$$

$$P_c(h\nu,T) = (\frac{d\sigma}{dT})/\sigma_T,$$

$$\frac{d\sigma}{dT} = \frac{\pi r_o{}^2 mc^2}{(h\nu_o-T)^2}\{[\frac{mc^2T}{(h\nu_o)^2}]^2 + 2\ [\frac{h\nu_o-T}{h\nu_o}]^2$$

$$+ \frac{h\nu_o-T}{(h\nu_o)^3}[(T-mc^2)^2-(mc^2)^2]\},$$

$$\sigma_T = 2\pi r_o{}^2\{\frac{1+\alpha}{\alpha^3}[\frac{2\alpha(1+\alpha)}{1+2\alpha} - \ell n(1+2\alpha)]$$

$$+ \frac{\ell n(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2}\},$$

$$\alpha = h\nu/(mc^2).$$

The $P_c(h\nu,T)$ is the probability that a free electron is recoiled with kinetic energies between T and T + dT as a result of the Compton scattering

of a photon of energy $h\nu$. The $G_{br}(T)$ is the average fraction that an electron of initial kinetic energy T dissipates its energy in bremsstrahlung. In the code,however, we have assumed that $G_{br}(T) = 0$.

3.2 Photoelectric absorption[4)]

The f_τ for the photoelectric absorption is written as follows:

$$f_\tau = \begin{cases} 1-\left(\frac{\tau_k}{\tau}\right)\left(\frac{F_k\bar{E}_k}{h\nu}\right), & \text{for K-shell,} \\ 1-\frac{F_L\bar{E}_L}{h\nu}, & \text{for L-shell,} \end{cases} \tag{15}$$

where τ^k is the photoelectric cross section for K-shell, F_k and F_L are the mean fluorescence yields for K-shell and L-shell, respectively, and $\bar{E}_k$ and $\bar{E}_L$ are the mean energies of the fluorescence photons. The fluorescence yields and average energies of fluorescence for the K and L shells are shown in Table 1 for several elements.

Table 1 Fluorescence yields and average energies of fluorescence[4)]

Element	Z	F_k	$\bar{E}_k$(keV)	F_L	$\bar{E}_L$(keV)
C	6	0.0	0.279		
N	7	0.0	0.393		
O	8	0.0	0.524		
Na	11	0.013	1.041		0.031
Mg	12	0.020	1.255		0.048
Al	13	0.030	1.487		0.069
P	15	0.051	2.020		0.169
S	16	0.069	2.317		0.206
Ar	18	0.105	2.977		0.286
K	19	0.129	3.337		0.334
Ca	20	0.151	3.719		0.385
Fe	26	0.312	6.472		0.714
Cu	29	0.404	8.142		0.937
Mo	42	0.747	17.787	0.072	2.343
I	53	0.868	29.291	0.134	4.145
Pb	82	0.955	77.002	0.400	11.719
U	92	0.961	100.964	0.449	15.509

3.3 Pair production[4)]

The f_k for the pair production is given by

$$f_k = 1 - \frac{2mc^2}{h\nu} - (h\nu)\int_0^{h\nu-2mc^2} P_p(h\nu_1 T^+ T^-)[T^- G_{br}(T^-) + T^+ G_{br}(T^+) + \tau(T^+)]dT^+ . \tag{16}$$

Table 2 and Fig. 2 give the f_k values[4)] for several elements obtained from Eq. (16) by omitting the integral over $\tau(T^+)$ which accounts for the annihilation of positrons in flight. In the present code the f_k value is obtained with the linear interpolation over photon energies and atomic numbers using Table 2.

Table 2 Energy absorption fraction of pair-production reaction f_k with corrections for bremsstrahlung losses but without correction for annihilation of positrons [4)]

Element / Z / Photon energy (MeV)	H	C	N	O	Na	Mg	Al	P	S	A	K	Ca	Fe	Cu	Pb
	1	6	7	8	11	12	13	15	16	18	19	20	26	29	82
1.5	0.318	0.318	0.318	0.317	0.37	0.37	0.317	0.316	0.316	0.316	0.316	0.316	0.317	0.314	0.312
2.0	0.488	0.487	0.489	0.486	0.485	0.485	0.487	0.484	0.484	0.483	0.483	0.482	0.484	0.480	0.471
3.0	0.658	0.655	0.654	0.654	0.652	0.651	0.653	0.649	0.648	0.647	0.646	0.645	0.646	0.640	0.616
4.0	0.743	0.738	0.737	0.736	0.733	0.732	0.734	0.729	0.728	0.726	0.725	0.724	0.722	0.715	0.675
5.0	0.794	0.787	0.788	0.785	0.780	0.779	0.780	0.775	0.774	0.771	0.770	0.769	0.763	0.757	0.701
6.0	0.828	0.820	0.818	0.816	0.811	0.810	0.809	0.804	0.803	0.799	0.798	0.796	0.788	0.781	0.712
8.0	0.870	0.858	0.855	0.853	0.846	0.843	0.842	0.836	0.834	0.829	0.827	0.824	0.811	0.804	0.712
10.0	0.895	0.879	0.876	0.873	0.863	0.861	0.857	0.851	0.848	0.842	0.839	0.836	0.819	0.808	0.700

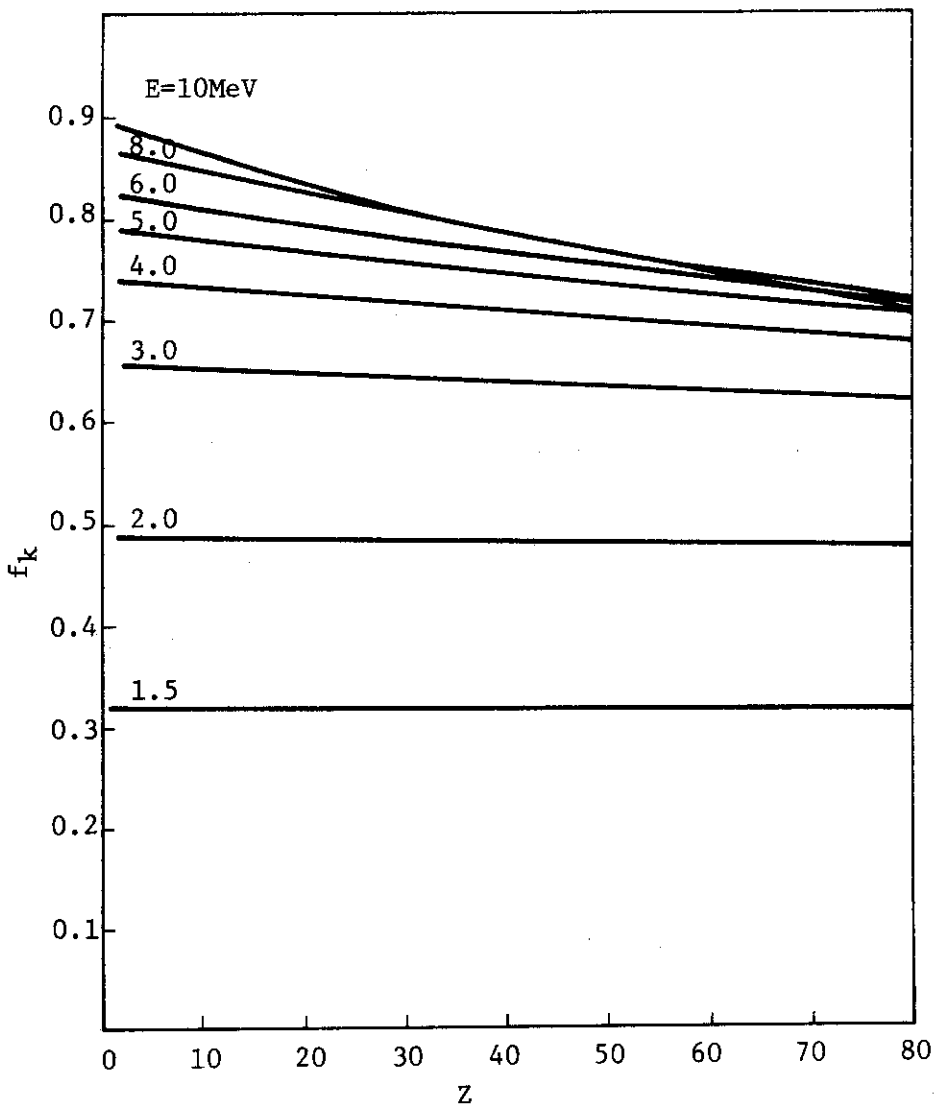

Fig. 2 Energy absorption fraction for pair production reaction f_k with correction for bremsstrahlung losses as a function of incident photon energy and atomic number of medium

4. Modification of Integration Method for Transfer Cross Section

The average transfer cross section from group h to group g is written by

$$\sigma_{sn}^{g\leftarrow h} = \frac{\int_{E' \text{ in } h} f(E') \int_{E \text{ in } g} \sigma_{sn}(E'\rightarrow E) dE\, dE'}{\int_{E' \text{ in } h} f(E') dE'} , \tag{17}$$

where f(E') is a weighting function given by input data and $\sigma_{sn}(E'\rightarrow E)$ of Eq. (17) are given by

$$\sigma_{sn}(E'\rightarrow E) = \frac{3}{8E'^2}[\frac{E'}{E} + \frac{E}{E'} + 2(\frac{1}{E'} - \frac{1}{E}) + (\frac{1}{E'} - \frac{1}{E})^2] \cdot P_n(1 + \frac{1}{E'} - \frac{1}{E}), \tag{18}$$

for $E'/(1+2E') < E < E'$.

The original code, GAMLEG, calculates analytically the E integral of Eq. (18). However, this integration was not adequate for the higher Legendre moments than the 6th order at low energy region below about 0.1 MeV, because of round-off erros caused by the machine computation. Therefore, GAMLEG-JR calculates this integral by using the numerical integration based on the Simpson's rule for equally spaced μ, a Compton scattering angle. The E integral of Eq. (18) is written by

$$\int \sigma_{sn}(E'\rightarrow E) dE = \int \sigma_{sn}(E'\rightarrow E) \frac{dE}{d\mu} d\mu$$

$$= \int \frac{3}{8E'^2}[1+E'(1-\mu) + \frac{1}{1+E'(1-\mu)} + 2(\mu-1) + (\mu-1)^2]$$

$$\times [\frac{E'}{1+E'(1-\mu)}]^2 \cdot P_n(\mu) d\mu , \tag{19}$$

where $\mu = 1 + 1/E' - 1/E$.

4. Modification of Integration Method for Transfer Cross Section

The average transfer cross section from group h to group g is written by

$$\sigma_{sn}^{g\leftarrow h} = \frac{\int_{E' \text{ in } h} f(E') \int_{E \text{ in } g} \sigma_{sn}(E'\rightarrow E) dE\, dE'}{\int_{E' \text{ in } h} f(E') dE'} , \tag{17}$$

where f(E') is a weighting function given by input data and $\sigma_{sn}(E'\rightarrow E)$ of Eq. (17) are given by

$$\sigma_{sn}(E'\rightarrow E) = \frac{3}{8E'^2}[\frac{E'}{E} + \frac{E}{E'} + 2(\frac{1}{E'} - \frac{1}{E}) + (\frac{1}{E'} - \frac{1}{E})^2]\cdot P_n(1 + \frac{1}{E'} - \frac{1}{E}), \tag{18}$$

for $E'/(1+2E') < E < E'$.

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$$\int \sigma_{sn}(E'\rightarrow E) dE = \int \sigma_{sn}(E'\rightarrow E) \frac{dE}{d\mu} d\mu$$

$$= \int \frac{3}{8E'^2}[1+E'(1-\mu) + \frac{1}{1+E'(1-\mu)} + 2(\mu-1) + (\mu-1)^2]$$

$$\times [\frac{E'}{1+E'(1-\mu)}]^2 \cdot P_n(\mu) d\mu , \tag{19}$$

where $\mu = 1 + 1/E' - 1/E$.

5. Evaluations of Calculated Multigroup Cross Sections

In order to evaluate the calculational accuracies of GAMLEG-JR, cross sections generated by the code were compared with experimental and theoretical values given in Ref. 2.

Table 3 shows the ratio of the calculated photoelectric cross sections to those given in Ref. 2 for elements of Z=1, 4, 6, 13, 26, 53, 82 and 92. Deviations from the values given in Ref. 2 are less than 1 to 5 percent for most of energies above 0.2 MeV for all elements except for hydrogen. However, in the energy region below 0.2 MeV, the discrepancies gradually increase because of irregularities in the higher electron shell structure. In the GAMLEG-JR, the photoelectric cross section for hydrogen is corrected empirically by using the ratio given in table 3.

Table 4 shows the ratio of the calculated pair production cross sections to those given in Ref. 2 for elements of Z=1, 6, 13, 26, 53, 82 and 92. Deviations from the values given in Ref. 2 are less than 1 to 2 percent for all energy region and for all elements.

Table 5 presents the ratio of the mass energy absorption coefficients calculated by GAMLEG-JR to those given in Ref. 2 for elements of Z=1, 6, 13, 26, 82 and 92. The calculated values are larger by about 10 to 15 percent than those given in Ref. 2 for energy regions above 0.2 MeV and are smaller by about 10 to 50 percent at lower energies below 0.2 MeV. Major sources of the discrepancies at higher energies may be the neglect of energy dissipation effect due to bremsstrahlung at the Compton scattering and of annililation effect of positrons due to the pair production reactions in the calculation for the energy absorption coefficient. At lower energies, the insufficient accuracy of the empirical formula for the photoelectric cross section is the source of the discrepancy.

Table 3 Ratio of the photoelectric cross sections calculated by GAMLEG-JR to those given by Ref. 2 ($\sigma_{cal}/\sigma_{Ref}$) for a number of elements

E(MeV) \ Z	1	4	6	13	26	53	82	92
1.5(-2)*	0.785	0.509	0.476	0.388	0.979	0.712	0.445	0.546
2.0(-2)	0.986	0.606	0.641	0.610	0.335	0.670	0.598	0.481
4.0(-2)	1.354	0.760	0.929	0.871	0.892	0.884	0.620	0.582
6.0(-2)	1.514	0.820	0.865	0.919	0.989	0.808	0.568	0.532
1.0(-1)	1.663	0.878	0.903	0.954	1.032	0.981	0.908	0.477
1.5(-1)	1.764	0.905	0.927	0.961	1.018	1.017	0.982	0.917
2.0(-1)	1.817	0.923	0.939	0.957	1.004	1.019	1.014	0.993
4.0(-1)	1.948	0.971	0.975	0.983	1.010	1.017	1.018	1.029
6.0(-1)	2.000	0.992	0.998	1.000	1.019	1.000	0.995	1.016
8.0(-1)	2.034	1.009	1.009	1.000	1.017	1.000	0.990	1.000
1.0	2.055	1.020	1.021	1.010	1.015	0.998	0.986	1.000
1.5	2.119	1.038	1.037	1.010	1.019	1.010	1.000	1.011
2.0	2.119	1.037	1.023	0.997	0.998	1.000	0.989	1.018
3.0	2.139	1.036	1.025	0.995	0.993	0.985	1.001	1.007
4.0	2.158	1.045	1.033	0.993	0.992	0.992	1.017	1.024
6.0	2.164	1.045	1.035	0.995	0.986	0.989	1.024	1.033
8.0	2.190	1.049	1.035	0.995	0.987	0.992	1.030	1.032
10.0	1.483	1.039	1.036	0.989	0.983	0.986	1.017	1.021

* to be read as 1.5×10^{-2}

Table 4 Ratio of the pair production cross sections calculated by GAMLEG-JR to those given by Ref. 2 ($\sigma_{cal}/\sigma_{Ref.}$) for a number of elements

Z / E(MeV)	1	6	13	26	53	82	92
1.5	1.002	1.006	1.010	1.009	1.011	1.009	1.009
3.0	0.992	0.995	0.995	1.000	1.000	1.003	1.004
4.0	0.999	1.000	1.000	1.005	1.008	1.010	1.012
6.0	1.007	1.002	1.004	1.010	1.014	1.019	1.019
8.0	1.000	1.003	1.010	1.009	1.017	1.029	1.023
10.0	1.000	1.004	1.008	1.014	1.016	1.016	1.020
15.0	1.007	1.000	1.013	1.017	1.001	0.968	0.957

Table 5 Ratio of the mass energy absorption coefficients calculated by GAMLEG-JR to those given in Ref. 2 ($\mu_{en,cal}/\mu_{en,Ref.}$)

Z / E(MeV)	1	6	13	26	82	92
0.04	1.048	0.928	1.091	0.713	0.549	0.512
0.06	0.938	0.934	1.083	0.991	0.556	0.517
0.1	1.074	1.060	1.075	0.986	0.776	0.613
0.2	1.109	1.105	1.095	1.056	0.971	0.989
0.4	1.072	1.068	1.112	1.065	1.035	1.056
0.6	1.053	1.061	1.079	1.105	1.055	1.081
0.8	1.094	1.093	1.075	1.099	1.073	1.090
1.0	1.088	1.082	1.029	1.092	1.085	1.102
1.5	1.023	1.027	1.086	1.042	1.074	1.098
2.0	1.069	1.073	1.093	1.091	1.100	1.122
3.0	1.070	1.073	1.105	1.098	1.124	1.142
4.0	1.099	1.086	1.073	1.131	1.151	1.168
5.0	1.009	1.082	1.098	1.113	1.131	1.152
6.0	1.034	1.043	1.010	1.090	1.121	1.142
8.0	1.032	1.075	0.928	1.113	1.126	1.154
10.0	1.071	1.079	0.818	1.115	1.116	1.094

6. Input Preparation

The input data necessary for GAMLEG-JR are defined and listed below, in order of the original input. Integers are read according to a 14I5 format, and floating point numbers are read with a 6E12.5 format. All energies are in MeV and read in the descending order beginning at the highest energy.

Card 1 (8I5)

1. IG Number of groups plus one.
2. N Number of integration intervals/group.
3. NMAX Number of Legendre components to be prepared (≤9).
4. KON -1 = input flux weighting.
   0 = no weighting.
   1 = source weighting.
5. ICAL 0 = give the absorption and coherent scattering cross sections by input card.
   1 = calculate above cross sections and gamma-ray heat generation coefficients by the code.
6. IPRTO 0 = no effect.
   1 = print detailed information for absorption and coherent scattering cross sections.
7. IPRT1 0 = no effect.
   1 = print detailed information for heat generation coefficients.
8. NACT 0 = no effect.
   1 = add the gamma-ray heat generation coefficients to the cross section table as an activation cross section.

Cards 2 (input if KON=-1)

Card 2.1 (I5)

IF Number of input fluxes.

Cards 2.2 (6E12.5)

(EFLUX(I), I=1, IF)

Energies at which input fluxes are given.

Cards 2.3 (6E12.5)

(FLUX(I), I=1, IF)

Input flux weighting function.

Cards 3

Card 3.1 (I5)

IS Number of input sources.

Cards 3.2 (6E12.5)

(ES(I), I=1, IS)

Energies at which input sources are given.

Cards 3.3 (6E12.5)

(S(I), I=1, IS)

Input sources.

Cards 4 (6E12.5)

(EG(I), I=1, IG)

Gamma-ray energy group boundaries in MeV.

Cards 5

Card 5.1 (I5)

IZ Number of materials to be processed.

Card 5.2 (6E12.5)

(Z(I), I=1, IZ)

Atomic numbers of elements

Cards 6 (input if ICAL = 0)

Card 6.1 (2I5)

1. IA Number of input absorption cross sections.
2. IC Number of input coherent scattering cross sections.

Card 6.2 (6E12.5)

(SIGA(I), I=1, IA)

Absorption cross sections (barns) for the first element.

Card 6.3 (6E12.5)

(EA(I), I=1, IA)

Energies of which absorption cross sections are given for the first element.

Cards 7 (input if ICAL=0 and IC≠0)

Card 7.1 (6E12.5)

(SIGCOH(I), I=1, IC)

Coherent scattering cross sections (barns) for the first element.

Cards 7.2 (6E12.5)

(ECOH(I), I=1, IC)

Energies at which coherent scattering cross sections are given for the first element.

Input cards 6 and (possibly) 7 are repeated for each element.

7. Sample Input and Output

A sample problem of 20-group structure and nine Legendre moments is present for iron. A no weighting option and ten integration intervals in each group were used. A list of the sample problem is shown in Table C-1 of Appendix C.

The sample output for the average cross sections of iron is presented in Table C-2 of Appendix C. For each group, the column entries are σ_{heat}, σ_a, $\nu\sigma_f$, σ_t, $\sigma_{g\leftarrow g}$, $\sigma_{g\leftarrow g+1}$, ... The heading of each table identifies the element by its atomic number and the Legendre component by P_n, n=0,1,2, ..., NMAX-1.

The format and the sequence of punched output is the same as those of GAMLEG.

Running time required to generate the cross sections for the sample problem was about 6 seconds in CPU on the FACOM 230/75.

References

1) Lathrop K. D.: "GAMLEG", LA-3267 (1965).
2) Hubbell J. H.: "Photon Cross Section, Attenuation Coefficients, and Energy Absorption Coefficients from 10 KeV to 100 GeV", NSRDS-NBS 29 (1969).
3) Storm E., et al.: "Photon Cross Sections from 0.001 to 100 MeV for Element 1 through 100", LA-3753 (1967).
4) Berger, R. T.: "The X- or Gamma-Ray Energy Absorption or Transfer Coefficient: Tabulations and Discussions", Radiation Research, 15, 1 ∿ 29 (1961).

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Appendix A Description of Subroutines Added to GAMLEG

1. CROSS

   called from: Main Routine

   subroutine called: POTO, PAIR, COHER, NROW

   CROSS controls the subroutines which calculate photoelectric, pair-production and coherent scattering cross sections, and heat generation coefficients.

2. POTO

   called from: CROSS

   subroutine called: POTO3

   POTO calculates the photoelectric cross section for K-shell at high energy.

3. POTO3

   called from: POTO

   subroutine called: PO6MV1

   POTO3 calculates the photoelectric cross section for K-shell at low energy.

4. PO6MV1

   called from: POTO3

   subroutine called: FUNC1, FUNC2

5. FUNC1, FUNC2

   called from: PO6MV1

   The function subroutines FUNC1 and FUNC2 calculate the photoelectric cross sections.

6. PAIR

   called from: CROSS

   PAIR calculates the pair-production cross section.

7. COHER

   called from: CROSS

   COHER calculates the coherent scattering cross section.

8. NROW

   called from: CROSS

   subroutine called; INTFK, INTFT, COMPT

NROW calculates the heat generation coefficient for each interaction: photoelectric, f_T, pair production, f_k, and Compton scattering, f_c.

9. INTFT

called from: NROW

INTFT interpolates the fluorescence yield and the averaged energy from the values given in Table 1.

10. INTFK

called from: NROW

INTFK interpolates the f_k value from the values given in Table 2.

Appendix B Program List of GAMLEG-JR

```
SOURCE ELEMENT LIST (8BIT MODE)

ELEMENT NAME  ((GAMLEG  ))     ESTABLISHED  77.01.25

      C                                                                 GAM00010
      C  PROGRAM GAMLEG-JR  ( MODIFIED BY JAERI ON 1976 )               GAM00020
      C     **** FOLLOWING ROUTINE WAS ADDED                            GAM00030
      C     1.  CALCULATION OF PHOTO ELECTRIC, PAIR PROPUCTIVE, AND COHERENT  GAM00040
      C        SCATTERING CROSS SECTION                                 GAM00050
      C     2.  CALCULATION OF HEAT PRODUCTION COEFFICIENT.             GAM00060
      C                                                                 GAM00070
      C                                                                 GAM00080
      C     GIVEN SOURCE AND ABSORPTION ENERGY DEPENDENCE CODE PROVIIDES GAM00090
      C     GROUP AVERAGED CROSS SECTIONS FOR INPUT TO THE DTF OR DDF   GAM00100
      C     CODES. UP TO N (N LESS THAN 10) LEGENDRE TRANSFER SCATTERING CROSSGAM00110
      C     SECTIONS ARE PREPARED.                                      GAM00120
      C                                                                 GAM00130
      C     THREE WEIGHTING OPTIONS ARE AVAILABLE. (A)-UNWEIGHTED, (B)-SOURCE GAM00140
      C     ENERGY WEIGHTING, (C)-WEIGHTING WITH INPUT FLUX             GAM00150
      C                                                                 GAM00160
      C                                                                 GAM00170
            COMMON EG( 51),ASG( 50),SIGS( 50),SIGC( 50),DF( 50),FG( 50), GAM00180
           1FLUX( 500),S( 500),ES( 500),IS,SIGA( 500),EA( 500),IA,SG( 50), GAM00190
           2SIGCOH( 500),ECOH( 500),IC,SIGMAT( 54,50),TRANS( 50, 50, 9), GAM00200
           3FLUXS( 50,101),EFLUX( 500),Z(50),SIGTOT( 50),GXX( 50),ENNU( 500) GAM00210
            COMMON /JDB/IGA,IM,FN,ICAL,IPRT0,IPRT1,J1,GE( 51)           GAM00220
      C                                                                 GAM00230
      C     DEFINITION OF VARIABLES                                     GAM00240
      C     SIGA(I)=ABSORPTION C/S                                      GAM00250
      C     EA(I)=ABSORPTION ENERGIES                                   GAM00260
      C     S(I)=SOURCE                                                 GAM00270
      C     ES(I)=SOURCE ENERGIES                                       GAM00280
      C     SIGCOH(I)=COHERENT SCATTERING CROSS SECTION                 GAM00290
      C     ECOH(I)=ENERGIES FOR ABOVE                                  GAM00300
      C     EG(I)=GROUP ENERGIES                                        GAM00310
      C     ASG(I)=GROUP AVG ABSORPTION CROSS SECTION                   GAM00320
      C     SIGS(I)=GROUP AVG SCATTERING CROSS SECTION                  GAM00330
      C     SIGC(I)=GROUP AVG COHERENT CROSS SECTION                    GAM00340
      C     FG(I)=GROUP AVG FLUX                                        GAM00350
      C     SG(I)=GROUP AVG SOURCE                                      GAM00360
      C     TRANS(I,J)=GROUP AVG TRANSFER CROSS SECTIONS                GAM00370
      C                                                                 GAM00380
      C     SIGMAT(I,J)=SCATTERING TRANSFER MATRIX                      GAM00390
      C                                                                 GAM00400
      C     GXX(I)=GROUP AVG HEAT GENERATION COEFFICIENT                GAM00410
      C     ENNU(I)=FINE GROUP HEAT GENERATION COEFFICIENT              GAM00420
      C                                                                 GAM00430
      C                                                                 GAM00440
      C     FLUXS(I)=WEIGHTING FUNCTION                                 GAM00450
      C                                                                 GAM00460
      C     IA=NO. ABSORPTION ENERGIES                                  GAM00470
      C     IS=NO. SOURCE ENERGIES                                      GAM00480
      C     IC=NO. COHERENT SCATTER ENERGIES                            GAM00490
      C     IG=NO. GROUP ENERGIES                                       GAM00500
      C     N=NO. INTEGRATION PTS. PER GROUP                            GAM00510
      C     IF=NO. OF INPUT FLUXES                                      GAM00520
```

SOURCE ELEMENT LIST (8BIT MODE)

```
C     NMAX=NO. OF LEGENDRE COMPONENTS REQUESTED                          GAM00530
C     Z(I)=ATOMIC NUMBERS                                                GAM00540
C     ICAL  0/1 =INPUT X-SEC / COMPUTE X-SEC AND  COHERENT X-SEC         GAM00550
C     IPRT0 0/1 =NO EFFECT / PRINT DETAIL ABS AND COHERENT X-SEC         GAM00560
C     IPRT1 0/1 =NO EFFECT / PRINT DETAIL HEAT COEFF.                    GAM00570
C                                                                        GAM00580
C                INPUT                                                   GAM00590
C                                                                        GAM00600
      NIN=5                                                              GAM00610
      READ(NIN,501)IG,N,NMAX,KON,ICAL,IPRT0,IPRT1,NACT                   GAM00620
      WRITE( 6,503)IG,N,NMAX,KON,ICAL,IPRT0,IPRT1,NACT                   GAM00630
      IF(KON.GE.0)GOTO2                                                  GAM00640
      READ(NIN,501)IF                                                    GAM00650
      READ(NIN,502)(EFLUX(I),I=1,IF)                                     GAM00660
      READ(NIN,502)(FLUX(I),I=1,IF)                                      GAM00670
      WRITE( 6,504)(I,EFLUX(I),FLUX(I),I=1,IF)                           GAM00680
    2 READ(NIN,501)IS                                                    GAM00690
      READ(NIN,502)(ES(I),I=1,IS)                                        GAM00700
      READ(NIN,502)( S(I),I=1,IS)                                        GAM00710
      READ(NIN,502)(GE(I),I=1,IG)                                        GAM00720
      WRITE( 6,505)(I,ES(I),S(I),I=1,IS)                                 GAM00730
      WRITE( 6,506)(I,GE(I),I=1,IG)                                      GAM00740
  501 FORMAT(14I5)                                                       GAM00750
  502 FORMAT(6E12.5)                                                     GAM00760
  503 FORMAT('1   INPUT DATA'                                    /       GAM00770
     1       '0   IG    NO. OF GROUPS                          ',I5,     GAM00780
     2        '   N     NO. OF INTEGRATION POINTS/GROUP        ',I5/     GAM00790
     3        '   NMAX  NO. OF LEGENDRE COMPONENTS             ',I5,     GAM00800
     4        '   KON   CONTROL -1/0/1 = FLUX/NONE/SOURCE      ',I5/     GAM00810
     5        '   ICAL  0/1 = X-SEC INPUT/CALCULATE            ',I5,     GAM00820
     6        '   IPRT0 0/1 = PRINT DETAIL X-SEC NO/YES        ',I5/     GAM00830
     7        '   IPRT1 0/1 = PRINT DETAIL HEAT COEFF NO/YES   ',I5,     GAM00840
     8        '   NACT  0/1 = OUTPUT HEAT COEFF NO/YES         ',I5)     GAM00850
  504 FORMAT(10H0          ,14H ENERGY (MEV) ,11H INPUT FLUX,/,(3X,I5,2X,GAM00860
     12(E12.5,2X)))                                                      GAM00870
  505 FORMAT(10H0          ,14H ENERGY (MEV) ,7H SOURCE,/,(3X,I5,2X,2(E12GAM00880
     1.5)))                                                              GAM00890
  506 FORMAT(10H0          ,20H GROUP ENERGY BOUNDS,/,(3X,I5,2X,E12.5))  GAM00900
C                                                                        GAM00910
C     CONTROL INTEGERS                                                   GAM00920
      IGA=IG-1                                                           GAM00930
      IM=N+1                                                             GAM00940
      IMA=N+2                                                            GAM00950
      IGB=IG+2+NACT                                                      GAM00960
      IGD=IG-2                                                           GAM00970
      FN=N                                                               GAM00980
      J1=0                                                               GAM00990
C                                                                        GAM01000
C     EXPRESS ENERGIES IN REST MASS UNITS                                GAM01010
      ERM=1./.51099                                                      GAM01020
      ERMIN=0.51099                                                      GAM01030
      DO5I=1,IG                                                          GAM01040
    5 EG(I)=ERM*GE(I)                                                    GAM01050
      DO6I=1,IS                                                          GAM01060
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      6 ES(I)=ERM*ES(I)                                                 GAM01070
        IF(KON.GE.0)GOTO9                                               GAM01080
        DO8I=1,IF                                                       GAM01090
      8 EFLUX(I)=ERM*EFLUX(I)                                           GAM01100
C                                                                       GAM01110
C       INITIALIZE FLUX AND AVERAGE FLUX, SOURCE, AND SCATTERING CROSS  GAM01120
C       SECTION                                                         GAM01130
      9 NNN=1                                                           GAM01140
        DO 18 K=1,IGA                                                   GAM01150
C       H=(EG(K)-EG(K+1))/FN                                            GAM01160
        ASIG=0.                                                         GAM01170
        AFLU=0.                                                         GAM01180
        ASOU=0.                                                         GAM01190
        DO17I=1,IM                                                      GAM01200
C       AA=FLOAT(I-1)*H+EG(K+1)                                         GAM01210
        FFFI1=I-1                                                       GAM01220
C       AA=EG(K+1)*(FN-FFFI1)/FN+EG(K)*FFFI1/FN                         GAM01230
        AA=EG(K)*(FN-FFFI1)/FN+EG(K+1)*FFFI1/FN                         GAM01240
        AB=AA                                                           GAM01250
        IF(KON)10,11,12                                                 GAM01260
     10 CALLAL(AB,FLUX,EFLUX,IF)                                        GAM01270
        GOTO13                                                          GAM01280
     11 AB=1.0                                                          GAM01290
        GOTO13                                                          GAM01300
     12 CALLAL(AB,S,ES,IS)                                              GAM01310
     13 IF(I.EQ.1)GOTO15                                                GAM01320
        IF(I.NE.IM)GOTO16                                               GAM01330
     15 AB=AB*.5                                                        GAM01340
     16 FLUXS(K,I)=AB                                                   GAM01350
        AFLU=AFLU+AB                                                    GAM01360
        ASIG=ASIG+AB*SIGMAS(AA)                                         GAM01370
        CALLAL(AA,S,ES,IS)                                              GAM01380
     17 ASOU=ASOU+AB*AA                                                 GAM01390
        FG(K)=AFLU                                                      GAM01400
        SIGS(K)=ASIG/FG(K)                                              GAM01410
     18 SG(K)=ASOU/FG(K)                                                GAM01420
        WRITE(6,181)(K,FG(K),SIGS(K),SG(K),K=1,IGA)                     GAM01430
    181 FORMAT(6H0GROUP,14H   AVG FLUX   ,14H AVG SIGMA S  ,            GAM01440
       112H  AVG SOURCE,//,(I4,2X,3(E12.5,2X)))                         GAM01450
C                                                                       GAM01460
C       CALCULATE LEGENDRE MOMENTS - FOR EACH ELEMENT                   GAM01470
        DO 37 M=1,NMAX                                                  GAM01480
        DO37K=1,IGA                                                     GAM01490
        DIF=0.                                                          GAM01500
C       HA=(EG(K)-EG(K+1))/FN                                           GAM01510
        DO27L=K,IGA                                                     GAM01520
        AIN=0.                                                          GAM01530
        DO25I=1,IM                                                      GAM01540
C       AX=EG(K)-FLOAT(I-1)*HA                                          GAM01550
        FFFI1=I-1                                                       GAM01560
C       AX=EG(K)*(FN-FFFI1)/FN+EG(K+1)*FFFI1/FN                         GAM01570
        AX=EG(K+1)*(FN-FFFI1)/FN+EG(K)*FFFI1/FN                         GAM01580
        Q=AX/(1.+2.*AX)                                                 GAM01590
        BU=AMIN1(AX,EG(L))                                              GAM01600
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      BL=AMAX1(Q,EG(L+1))                                               GAM01610
      IF(L.EQ.IGA)BL=Q                                                  GAM01620
      QQ=0.0                                                            GAM01630
C                                                                       GAM01640
      IF (BL.LT.BU)  QQ=FLUXS(K,I)*SIGLEG(M,AX,BU,BL)                   GAM01650
   25 AIN=AIN+QQ                                                        GAM01660
      TRANS(K,L,M)=AIN/FG(K)                                            GAM01670
      IF(M.EQ.1) DIF=DIF-TRANS(K,L,M)                                   GAM01680
   27 CONTINUE                                                          GAM01690
      IF(M.NE.1) GO TO 37                                               GAM01700
      DIFF=SIGS(K)+DIF                                                  GAM01710
      WRITE(6,507)K,DIFF                                                GAM01720
  507 FORMAT(43H0DIFFERENCE-GROUP AVG SCATTER CROSS SECTION,            GAM01730
     143H AND SUM OF GROUP AVERAGED TRANSFERS, GROUP,                   GAM01740
     2I2,6H , IS=1PE12.5)                                               GAM01750
      DF(K)=DIF                                                         GAM01760
   37 CONTINUE                                                          GAM01770
C                                                                       GAM01780
C     ELEMENT DEPENDENT PORTION                                         GAM01790
C                                                                       GAM01800
      READ(NIN,501) IZ                                                  GAM01810
      READ(NIN,502) (Z(I),I=1,IZ)                                       GAM01820
      DO 2000 MZ=1,IZ                                                   GAM01830
      ZA=Z(MZ)*0.249375                                                 GAM01840
      WRITE(6,515) Z(MZ)                                                GAM01850
  515 FORMAT('1'///20X,'***  GAMMA-RAY CROSS SECTIONS FOR ATOMIC NUMBER GAM01860
     1=',F4.0,'  ***')                                                  GAM01870
      DO 2000  M=1,NMAX                                                 GAM01880
      DO 20 I=1,IGA                                                     GAM01890
      DO 19 J=1,IGB                                                     GAM01900
   19 SIGMAT(J,I)=0.0                                                   GAM01910
      SIGTOT(I)=0.0                                                     GAM01920
      GXX(I)=0.0                                                        GAM01930
   20 ASG(I)=0.0                                                        GAM01940
  101 IF(M.GT.1)GOTO3000                                                GAM01950
 1000 IF(ICAL .EQ. 0) GO TO 2010                                        GAM01960
      Z3=Z(MZ)                                                          GAM01970
C     CALL CROSS(Z3,IA,IC,EA,SIGA,ECOH,SIGCOH)                          GAM01980
      CALL CROSS(Z3,IA,IC,EA,SIGA,ECOH,SIGCOH,ENNU,DF,ZA)               GAM01990
      GO TO 3002                                                        GAM02000
 2010 CONTINUE                                                          GAM02010
      READ(NIN,501)IA,IC                                                GAM02020
      READ(NIN,502)(SIGA(I),I=1,IA)                                     GAM02030
      READ(NIN,502)(EA(I),I=1,IA)                                       GAM02040
      IF(IC.EQ.0)GOTO31                                                 GAM02050
      READ(NIN,502)(SIGCOH(I),I=1,IC)                                   GAM02060
      READ(NIN,502)(ECOH(I),I=1,IC)                                     GAM02070
      WRITE(6,508)(I,ECOH(I),SIGCOH(I),I=1,IC)                          GAM02080
  508 FORMAT(10H0          ,14H ENERGY (MEV) ,17H COHERENT SCATTER,/,(3X,GAM02090
     1I5,2X,2E14.7))                                                    GAM02100
      DO30I=1,IC                                                        GAM02110
   30 ECOH(I)=ECOH(I)*ERM                                               GAM02120
   31 WRITE(6,509)(I,EA(I),SIGA(I),I=1,IA)                              GAM02130
  509 FORMAT(10H0          ,14H ENERGY (MEV) ,11H ABSORPTION,/,(3X,I5,2X,GAM02140
```

SOURCE ELEMENT LIST (8BIT MODE)

```
          12(E12.5,2X)))                                                GAM02150
          DO32I=1,IA                                                    GAM02160
       32 EA(I)=EA(I)*ERM                                               GAM02170
     3002 CONTINUE                                                      GAM02180
          NNN=1                                                         GAM02190
          DO35J=1,IGA                                                   GAM02200
C         H=(EG(J)-EG(J+1))/FN                                          GAM02210
          AABS=0.                                                       GAM02220
          ACOH=0.                                                       GAM02230
          ANU=0.                                                        GAM02240
          DO34I=1,IM                                                    GAM02250
          IF(ICAL.NE.0) GO TO 33                                        GAM02260
C         AX=FLOAT(I-1)*H+EG(J+1)                                       GAM02270
          FFFI1=I-1                                                     GAM02280
C         AX=EG(J+1)*(FN-FFFI1)/FN+EG(J)*FFFI1/FN                       GAM02290
          AX=EG(J)*(FN-FFFI1)/FN+EG(J+1)*FFFI1/FN                       GAM02300
          AB=AX                                                         GAM02310
          AC=AX                                                         GAM02320
          CALLAL(AB,SIGA,EA,IA)                                         GAM02330
          AABS=AABS+FLUXS(J,I)*AB                                       GAM02340
          IF(IC.EQ.0)GOTO34                                             GAM02350
          CALLAL(AX,SIGCOH,ECOH,IC)                                     GAM02360
          ACOH=ACOH+FLUXS(J,I)*AX                                       GAM02370
          GO TO 34                                                      GAM02380
       33 AABS=AABS+FLUXS(J,I)*SIGA(NNN)                                GAM02390
          ACOH=ACOH+FLUXS(J,I)*SIGCOH(NNN)                              GAM02400
          ANU=ANU+FLUXS(J,I)*ENNU(NNN)                                  GAM02410
          NNN=NNN+1                                                     GAM02420
       34 CONTINUE                                                      GAM02430
          ASG(J)=AABS/FG(J)                                             GAM02440
          IF(ICAL.NE.0) GXX(J)=ANU/FG(J)                                GAM02450
       35 SIGC(J)=ACOH/FG(J)                                            GAM02460
          IF(ICAL.EQ.0) GO TO 103                                       GAM02470
          WRITE(6,2900) (I,ASG(I),SIGC(I),GXX(I),I=1,IGA)               GAM02480
     2900 FORMAT('0          GROUP      ABSORB      COHERENT      HEAT',GAM02490
         *      /'                     X-SEC.       X-SEC.      COEFF.',GAM02500
         *     /(11X,I3,3X,3E13.5))                                     GAM02510
      103 CONTINUE                                                      GAM02520
          DO 102 K=1,IGA                                                GAM02530
          SIGTOT(K)=ASG(K)-DF(K)*ZA+SIGC(K)                             GAM02540
      102 CONTINUE                                                      GAM02550
C                                                                       GAM02560
C         FORM CROSS SECTION TABLE                                      GAM02570
     3000 DO38J=1,IGA                                                   GAM02580
          IF(NACT.EQ.1) SIGMAT(1,J)=GXX(J)                              GAM02590
          SIGMAT(NACT+1,J)=ASG(J)                                       GAM02600
          SIGMAT(NACT+2,J)=0.0                                          GAM02610
       38 SIGMAT(NACT+3,J)=SIGTOT(J)                                    GAM02620
          LLL=M-1                                                       GAM02630
          PC =2*LLL+1                                                   GAM02640
          DO39I=1,IGA                                                   GAM02650
          IAB=I+3+NACT                                                  GAM02660
          DO39J=I,IGA                                                   GAM02670
          JA=J-I+1                                                      GAM02680
```

SOURCE ELEMENT LIST (8BIT MODE)

```
   39 SIGMAT(IAB,J)=PC*TRANS(JA,J,M)*ZA                                GAM02690
      IF(M.GT.1) GO TO 43                                              GAM02700
      DO 42 J=1,IGA                                                    GAM02710
   42 SIGMAT(NACT+4,J)=SIGMAT(NACT+4,J)+SIGC(J)                        GAM02720
   43 CONTINUE                                                         GAM02730
C                                                                      GAM02740
C     PRINT AND PUNCH CROSS SECTION TABLE                              GAM02750
      NAB=M-1                                                          GAM02760
      WRITE(6,510)NAB,Z(MZ)                                            GAM02770
  510 FORMAT(2H0P,I2,20H CROSS SECTION TABLE,                          GAM02780
     115H ATOMIC NUMBER=  E11.3,40X)                                   GAM02790
      MA=1                                                             GAM02800
      MB=8                                                             GAM02810
   40 MC=MIN0(MB,IGA)                                                  GAM02820
      WRITE(6,511)(J,J=MA,MC)                                          GAM02830
      WRITE(6,513)                                                     GAM02840
      DO41I=1,IGB                                                      GAM02850
   41 WRITE(6,512)I,(SIGMAT(I,J),J=MA,MC)                              GAM02860
      MA=MA+8                                                          GAM02870
      MB=MB+8                                                          GAM02880
      IF(MA.LE.IGA)GOTO40                                              GAM02890
  511 FORMAT(7H0        , 8(8H  GROUP=I2,3X))                          GAM02900
  512 FORMAT(I4,3X,  8E13.6)                                           GAM02910
  513 FORMAT(1H0)                                                      GAM02920
      NPUN=7                                                           GAM02930
      DO 514 J=1,IGA                                                   GAM02940
  514 CALL PUNSH(SIGMAT(1,J),IGB,NPUN)                                 GAM02950
C                                                                      GAM02960
C                                                                      GAM02970
 2000 CONTINUE                                                         GAM02980
      STOP                                                             GAM02990
      END                                                              GAM03000
      SUBROUTINE CROSS(Z,NMAX,MMAX,EA,SIGA,ECOH,SIGCOH,ENNU,DF,ZA)     GAM03010
      DIMENSION EA(1),SIGA(1),ECOH(1),SIGCOH(1),SPOT( 500),SPAR( 500), GAM03020
     1          EE( 500),ENNU(1),DF(1)                                 GAM03030
      COMMON /JDB/IGA,IM,FN,ICAL,IPRT0,IPRT1,J1,GE( 51)                GAM03040
C                                                                      GAM03050
C                                                                      GAM03060
C                                                                      GAM03070
      REM=1.0/0.51099                                                  GAM03080
      NMAX=IGA*IM                                                      GAM03090
      MMAX=IGA*IM                                                      GAM03100
      DO 5 I=1,500                                                     GAM03110
      SIGA(I)=0.0                                                      GAM03120
      SPOT(I)=0.0                                                      GAM03130
      SPAR(I)=0.0                                                      GAM03140
      SIGCOH(I)=0.0                                                    GAM03150
      ENNU(I)=0.0                                                      GAM03160
    5 CONTINUE                                                         GAM03170
      IF(J1 .NE. 0) GO TO 20                                           GAM03180
      N=1                                                              GAM03190
      DO 10 K=1,IGA                                                    GAM03200
      DO 10 I=1,IM                                                     GAM03210
      FFFI1=I-1                                                        GAM03220
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      EE(N)=GE(K)*(FN-FFFI1)/FN+GE(K+1)*FFFI1/FN                        GAM03230
      EA(N)=EE(N)*REM                                                   GAM03240
      ECOH(N)=EA(N)                                                     GAM03250
      N=N+1                                                             GAM03260
   10 CONTINUE                                                          GAM03270
   20 CONTINUE                                                          GAM03280
      CALL POTO(Z,NMAX,EE,SPOT)                                         GAM03290
      CALL PAIR(Z,NMAX,EE,SPAR)                                         GAM03300
      DO 30 I=1,NMAX                                                    GAM03310
      SIGA(I)=SPOT(I)+SPAR(I)                                           GAM03320
   30 CONTINUE                                                          GAM03330
   80 FORMAT('1'//'0*** ATOMIC NO.  ',F8.3,' ***'                       GAM03340
     1      /'0',25X,'--- ABSORPTION CROSS SECTION ---',15X,'--- COHERENGAM03350
     2T SCATTERING CROSS SECTION ---'/'0',12X, 'ENERGY        PHOTO C   GAM03360
     3  PAIR C       TOTAL C')                                          GAM03370
      CALL COHER(Z,MMAX,EE,SIGCOH)                                      GAM03380
      IF(IPRTO.EQ.0) GO TO 60                                           GAM03390
      WRITE(6,80) Z                                                     GAM03400
      DO 50 K=1,IGA                                                     GAM03410
      NNN=(K-1)*IM                                                      GAM03420
      WRITE(6,100)  K                                                   GAM03430
      WRITE(6,110)  (EE(NNN+I),SPOT(NNN+I),SPAR(NNN+I),SIGA(NNN+I),     GAM03440
     1               SIGCOH(NNN+I),I=1,IM-1)                            GAM03450
   50 CONTINUE                                                          GAM03460
  100 FORMAT('  GROUP',I3)                                              GAM03470
  110 FORMAT(   10X,E12.5,2X,3E12.4,25X,E12.4)                          GAM03480
   60 CONTINUE                                                          GAM03490
      J1=1                                                              GAM03500
C                                                                       GAM03510
      CALL NROW(Z,NMAX,EE,SPOT,     SPAR,ENNU,DF,ZA)                    GAM03520
      RETURN                                                            GAM03530
      END                                                               GAM03540
      SUBROUTINE POTO(Z,NMAX,EA,SPOT)                                   GAM03550
C     PHOTO ELECTRIC TOTAL CROSS SECTION                                GAM03560
C     NBS-29                                                            GAM03570
C                                                                       GAM03580
C     *****                                                             GAM03590
      DIMENSION SPOT(500),EA(500),A(4,4)                                GAM03600
       A(1,1)=1.6268E-09                                                GAM03610
       A(1,2)=-2.683E-12                                                GAM03620
       A(1,3)=4.173E-02                                                 GAM03630
       A(1,4)=1.                                                        GAM03640
       A(2,1)=1.5274E-09                                                GAM03650
       A(2,2)=-5.110E-13                                                GAM03660
       A(2,3)=1.027E-02                                                 GAM03670
       A(2,4)=2.                                                        GAM03680
       A(3,1)=1.1330E-09                                                GAM03690
       A(3,2)=-2.177E-12                                                GAM03700
       A(3,3)=2.013E-02                                                 GAM03710
       A(3,4)=3.5                                                       GAM03720
       A(4,1)=-9.12E-11                                                 GAM03730
       A(4,2)=0.                                                        GAM03740
       A(4,3)=0.                                                        GAM03750
       A(4,4)=4.                                                        GAM03760
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      AN=6.023E-23                                                      GAM03770
      E0=(Z-0.3)**2*1.352E-5                                            GAM03780
      DO 50 K=1,NMAX                                                    GAM03790
      NNMAX=K                                                           GAM03800
      E=EA(K)                                                           GAM03810
       ZE=0.01*EXP(0.0312*(Z-8.0))                                      GAM03820
      IF(Z.LE.8.) ZE=0.0                                                GAM03830
       IF(E .LE. E0)  GO TO 150                                         GAM03840
       IF(E .LE. ZE)  GO TO 150                                         GAM03850
      TAUK1=0.0                                                         GAM03860
      DO 20 I=1,4                                                       GAM03870
   20 TAUK1=TAUK1+((A(I,1)+A(I,2)*Z)/(1.+A(I,3)*Z))*E**(-A(I,4))        GAM03880
      TAUK=Z**5*TAUK1                                                   GAM03890
      TAUP=TAUK*(1.+0.01481*(ALOG(Z))**2-0.000788*(ALOG(Z))**3)         GAM03900
      IF(Z.GT.1.1) GO TO 30                                             GAM03910
C   CORRECTION FOR HYDROGEN                                             GAM03920
      EX=ALOG10(E)                                                      GAM03930
      FACT=-0.2325*EX*EX + 0.2478*EX + 2.096                            GAM03940
      TAUP=TAUP/FACT                                                    GAM03950
   30 CONTINUE                                                          GAM03960
      SPOT(K)=TAUP                                                      GAM03970
   50 CONTINUE                                                          GAM03980
      GO TO 200                                                         GAM03990
  150 CALL POT03(Z,NNMAX,NMAX,EA,SPOT,E0)                               GAM04000
  200 CONTINUE                                                          GAM04010
      RETURN                                                            GAM04020
      END                                                               GAM04030
      SUBROUTINE POT03(Z,NNMAX,NMAX,EA,SPOT,E0)                         GAM04040
      DIMENSION EA(500),SPOT(500)                                       GAM04050
      DATA PHI/3.1415927/,RY/1.352E-5/,FAI/6.6537E-25/                  GAM04060
      DATA C2M/0.51084/                                                 GAM04070
C                                                                       GAM04080
      A=1.5*FAI*Z**5*1.0E+24/(137.0**4)                                 GAM04090
      DO 10 K=NNMAX,NMAX                                                GAM04100
      NN=K                                                              GAM04110
      E=EA(K)                                                           GAM04120
      HNU=E                                                             GAM04130
      IF(E .LE.E0) GO TO 100                                            GAM04140
      IF(Z.GE.92.0 .AND. E.LE.0.08) GO TO 100                           GAM04150
      B=(C2M/HNU)**5                                                    GAM04160
      G=HNU/ C2M+1.0                                                    GAM04170
      X=SQRT(E0/(HNU-E0))                                               GAM04180
      Y=1.0/X                                                           GAM04190
       F=2.0*PHI*SQRT(E0/HNU)*(EXP(-4.0*X*ATAN(Y)))                     GAM04200
     1   /(1.0-EXP(-2.0*PHI*X))                                         GAM04210
      C=(G**2-1.0)**1.5                                                 GAM04220
      D=G*(G-2.0)/(G+1.0)                                               GAM04230
      R=1.0/(2.0*G*SQRT(G*G-1))                                         GAM04240
      S=(G+SQRT(G*G-1.0))/(G-SQRT(G*G-1.0))                             GAM04250
      S=ALOG(S)                                                         GAM04260
      SPOT(K)=A*B*C*(4.0/3.0+D*(1.0-R*S))*F                             GAM04270
   10 CONTINUE                                                          GAM04280
      GO TO 200                                                         GAM04290
C                                                                       GAM04300
```

SOURCE ELEMENT LIST (8BIT MODE)

```
  100 CALLPO6MV1(Z,NN,NMAX,EA,SPOT)                                  GAM04310
  200 CONTINUE                                                       GAM04320
      RETURN                                                         GAM04330
      END                                                            GAM04340
      SUBROUTINE PO6MV1(Z,NNMAX,NMAX,EA,SPOT)                        GAM04350
      DIMENSION  EA(500),SPOT(500)                                   GAM04360
      CALL  FUNC1(Z,A)                                               GAM04370
      A=A*1.0E+24                                                    GAM04380
C                                                                    GAM04390
      DO 10 K=NNMAX,NMAX                                             GAM04400
      E=EA(K)                                                        GAM04410
      HNU=E                                                          GAM04420
      CALL  FUNC2(Z,HNU,4,1.0,3.0,W1)                                GAM04430
      CALL  FUNC2(Z,HNU,5,3.0,8.0,W2)                                GAM04440
      SPOT(K)= A*(W1+W2)                                             GAM04450
   10 CONTINUE                                                       GAM04460
      RETURN                                                         GAM04470
      END                                                            GAM04480
      SUBROUTINE  FUNC1(Z,A)                                         GAM04490
      PAI=3.1415927                                                  GAM04500
      C=(2.0**12)*PAI*6.6537E-25*(137.0**3)                          GAM04510
      V=(Z-4.15)**2                                                  GAM04520
      A=C/V                                                          GAM04530
      RETURN                                                         GAM04540
      END                                                            GAM04550
      SUBROUTINE FUNC2(Z,HNU,KK,C1,C2,W)                             GAM04560
      DATA  PAI/3.1415927/,C/0.338E-5/                               GAM04570
      HNU2=C*(Z-4.15)**2                                             GAM04580
      B0=HNU2/HNU                                                    GAM04590
      TEMP=1-B0                                                      GAM04600
      IF(TEMP.LE.0.0) GO TO 100                                      GAM04610
      B1=B0**KK                                                      GAM04620
      B2=C1+C2*B0                                                    GAM04630
      X2=(B0/(1-B0))**0.5                                            GAM04640
      F1=-8.0*X2*ATAN2(1.0,X2)                                       GAM04650
      F2=-4.0*PAI*X2                                                 GAM04660
      F=EXP(F1)/(1-EXP(F2))                                          GAM04670
      W=B1*B2*F                                                      GAM04680
  100 CONTINUE                                                       GAM04690
      RETURN                                                         GAM04700
      END                                                            GAM04710
      SUBROUTINEPAIR(Z,NMAX,EA,SPAR)                                 GAM04720
C     *** TOTAL PAIR CREATION CROSS SECTION ***                      GAM04730
C     PAIR CREATION CROSS SECTION                                    GAM04740
C     NBS-29                                                         GAM04750
C                                                                    GAM04760
C                                                                    GAM04770
C     *********                                                      GAM04780
C       * NEGLECT SCREEING CORRECTION --- SHFS                       GAM04790
C         DBM ----- COULOMB CORRECTION                               GAM04800
C         DRA ----- RADIATIVE CORRECTION                             GAM04810
C         DEP ----- EMPIRICAL MULTIPLIER FOR COULOMB CORRECTION      GAM04820
      DIMENSION EA(500),SPAR(500)                                    GAM04830
      RE=7.9398E-26                                                  GAM04840
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      TETA=1.2020569                                                    GAM04850
      C=2.997925E+10                                                    GAM04860
      ERME=0.511006                                                     GAM04870
      EC2=0.511006*2.0                                                  GAM04880
      DO 100 I=1,NMAX                                                   GAM04890
      E=EA(I)                                                           GAM04900
      IF(E-EC2) 90,90,55                                                GAM04910
   55 CONTINUE                                                          GAM04920
      EK=E/0.511006                                                     GAM04930
      IF(E-2.0) 20,30,30                                                GAM04940
   20 ROW=(2.*EK-4.)/(2.+EK+2.*SQRT(2.*EK))                             GAM04950
      SIG=Z**2*RE*2.*3.14159*(EK-2.0)**3*(1.+ROW/2.+23.*ROW**2/40.      GAM04960
     1+11.*ROW**3/60.+29.*ROW**4/960.)/(137.*3.*EK**3)                  GAM04970
      GO TO 35                                                          GAM04980
   30 SIG=(Z**2*RE/137.)*(28.*ALOG(2.*EK)/9.-218./27.+(2./EK)**2*(6.*   GAM04990
     1ALOG(2.*EK)-7./2.+2.*ALOG(2.*EK)**3/3.-ALOG(2.*EK)**2-3.14159**2  GAM05000
     2*ALOG(2.*EK)/3.+2.*TETA+3.14159**2/6.)-(2./EK)**4*(3.*ALOG(2.*EK) GAM05010
     3/16.+1./8.)-(2./EK)**6*(29./9.256*ALOG(2.*EK)-77./27.512))        GAM05020
   35 SA=Z/137.                                                         GAM05030
      FZ=SA**2*(1./(1.+SA**2)+0.20206-0.0369*SA**2+0.0083*SA**4-0.002*SAGAM05040
     1**6)                                                              GAM05050
      DBM=28.*Z**2*RE*FZ/(9.*137.)                                      GAM05060
      DRA=1.012                                                         GAM05070
      IF(E-1.5) 1,1,2                                                   GAM05080
    1 DEP=-0.0677*(E-1.02)/0.48                                         GAM05090
      GO TO 444                                                         GAM05100
    2 IF(E-2.) 3,3,4                                                    GAM05110
    3 DEP=-0.0677-0.0609*(E-1.5)/0.5                                    GAM05120
      GO TO 444                                                         GAM05130
    4 IF(E-3.) 5,5,6                                                    GAM05140
    5 DEP=-0.1286-0.007*(E-2.)/1.0                                      GAM05150
      GO TO 444                                                         GAM05160
    6 DEP=0.0922*E-0.4326                                               GAM05170
  444 SIG=SIG*DRA-DEP*DBM                                               GAM05180
      GO TO 10                                                          GAM05190
   90 SIG=0.0                                                           GAM05200
   10 CONTINUE                                                          GAM05210
      SPAR(I)=SIG*1.0E+24                                               GAM05220
  100 CONTINUE                                                          GAM05230
      RETURN                                                            GAM05240
      END                                                               GAM05250
      SUBROUTINECOHER(Z,MMAX,ECOH,SIGCOH)                               GAM05260
C     COHERENT SCATTERING TOTAL CROSS SECTION                           GAM05270
C     *** USE A APPROXIMATE CURVE. THIS CURVE WAS CALCULATED BY LEAST   GAM05280
C         SQUARES METHOD USING LOS ALAMOS DATA.                         GAM05290
C     *** UNIT = BARN/ATOM                                              GAM05300
C         Z = ATOMIC NUMBER                                             GAM05310
C         E = PHOTON ENERGY (MEV)                                       GAM05320
C     ***                                                               GAM05330
      DIMENSION ECOH(500),SIGCOH(500)                                   GAM05340
      ALP= 2.357*(ALOG(Z/26.0))+9.436                                   GAM05350
C                                                                       GAM05360
      DO 100 I=1,MMAX                                                   GAM05370
      XXXX=ALOG(ECOH(I))                                                GAM05380
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      YYYY=-0.09615*(XXXX+11.532)**2+ALP                                GAM05390
      SIGCOH(I)=EXP(YYYY)                                               GAM05400
  100 CONTINUE                                                          GAM05410
      RETURN                                                            GAM05420
      END                                                               GAM05430
      SUBROUTINEAL(X,Y,XA,J)                                            GAM05440
C     LINEARLY INTERPOLATES FUNCTION Y TO GIVE VALUE AT X               GAM05450
      DIMENSION Y(J),XA(J)                                              GAM05460
      I=1                                                               GAM05470
  100 A=X-XA(I)+.000001                                                 GAM05480
      IF(A)1,6,5                                                        GAM05490
    1 I=I+1                                                             GAM05500
      IF(I.LE.J)GOTO100                                                 GAM05510
      WRITE(6,4) I,J,X,XA(I),A                                          GAM05520
    4 FORMAT(36HOERROR-ENERGY LESS THAN ALL ENERGIES/10X,2I5,3E12.4)    GAM05530
      CALLEXIT                                                          GAM05540
    5 N=I                                                               GAM05550
      IF(N.LE.1)GOTO6                                                   GAM05560
      M=N-1                                                             GAM05570
      X=Y(N)+(X-XA(N))*(Y(M)-Y(N))/(XA(M)-XA(N))                        GAM05580
      RETURN                                                            GAM05590
    6 X=Y(I)                                                            GAM05600
      RETURN                                                            GAM05610
      END                                                               GAM05620
      FUNCTIONSIGMAS(E)                                                 GAM05630
C     KLEIN NISHINA SCATTERING CROSS SECTION                            GAM05640
      A=1.+2.*E                                                         GAM05650
      B=E*E                                                             GAM05660
      C=E-2.-2./E                                                       GAM05670
      SIGMAS=(ALOG(A)*C+4.+2.*B*(1.+E)/(A*A))/B                         GAM05680
      RETURN                                                            GAM05690
      END                                                               GAM05700
      FUNCTION  SIGLEG(N,Y,XU,XL)                                       GAM05710
C-----------------------------------------------------------------------GAM05720
C   N : LEGENDRE ORDER                                                  GAM05730
C   Y : SOURCE ENERGY                                                   GAM05740
C   XU: UPPER SINK ENERGY                                               GAM05750
C   XL: LOWER SINK ENERGY                                               GAM05760
C-----------------------------------------------------------------------GAM05770
C                                                                       GAM05780
C   CONVERT SINK ENERGY TO SCATTERING ANGLE                             GAM05790
      AU=1.0+1.0/Y-1.0/XU                                               GAM05800
      AL=1.0+1.0/Y-1.0/XL                                               GAM05810
C   DETERMINE NUMBER OF INTEGRAL POINTS  K                              GAM05820
      DELTMU=0.02                                                       GAM05830
      IF (N.LE.5)  DELTMU=0.04                                          GAM05840
      K=(AU-AL)/DELTMU                                                  GAM05850
      IF (K.LT.5)  K=5                                                  GAM05860
C   CALL SIMPSON'S INTEGRAL ROUTINE                                     GAM05870
      CALL SIGINT(SIG,N,Y,AU,AL,K)                                      GAM05880
C                                                                       GAM05890
      SIGLEG=SIG                                                        GAM05900
C                                                                       GAM05910
      RETURN                                                            GAM05920
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      END                                                               GAM05930
      SUBROUTINE  SIGINT(SIG,N,Z,AU,AL,K)                               GAM05940
      REAL*8  X,Y,SIGMA ,PN                                             GAM05950
      DIMENSION  PN(1000)                                               GAM05960
C                                                                       GAM05970
      SIGMA(X,Y)=(1.+Y*(1.-X)+1./(1.+Y*(1.-X))+2.*(X-1.)+(X-1.)*(X-1.))/GAM05980
     *   (1.+Y*(1.-X))**2                                               GAM05990
C                                                                       GAM06000
C                                                                       GAM06010
      Y=Z                                                               GAM06020
C   DETERMINE DELTH                                                     GAM06030
      DELTH=(AU-AL)/(2*K)                                               GAM06040
C   CALCULATE PN(X) FOR EACH INTEGRAL POINTS                            GAM06050
      IE=2*K+1                                                          GAM06060
      GO TO (100,110,120,130,140,150,160,170,180),N                     GAM06070
C                                                                       GAM06080
  100 DO 200 I=1,IE                                                     GAM06090
      PN(I)=1.                                                          GAM06100
  200 CONTINUE                                                          GAM06110
      GO TO 250                                                         GAM06120
C                                                                       GAM06130
  110 DO 210 I=1,IE                                                     GAM06140
      X=AL+DELTH*(I-1)                                                  GAM06150
      PN(I)=X                                                           GAM06160
  210 CONTINUE                                                          GAM06170
      GO TO 250                                                         GAM06180
C                                                                       GAM06190
  120 DO 220 I=1,IE                                                     GAM06200
      X=AL+DELTH*(I-1)                                                  GAM06210
      PN(I)=(3.*X*X-1.)/2.                                              GAM06220
  220 CONTINUE                                                          GAM06230
      GO TO 250                                                         GAM06240
C                                                                       GAM06250
  130 DO 230 I=1,IE                                                     GAM06260
      X=AL+DELTH*(I-1)                                                  GAM06270
      PN(I)=(5.*X*X-3.)*X/2.                                            GAM06280
  230 CONTINUE                                                          GAM06290
      GO TO 250                                                         GAM06300
C                                                                       GAM06310
  140 DO 240 I=1,IE                                                     GAM06320
      X=AL+DELTH*(I-1)                                                  GAM06330
      PN(I)=((35.*X*X-30.)*X*X+3.)/8.                                   GAM06340
  240 CONTINUE                                                          GAM06350
      GO TO 250                                                         GAM06360
C                                                                       GAM06370
  150 DO 255 I=1,IE                                                     GAM06380
      X=AL+DELTH*(I-1)                                                  GAM06390
      PN(I)=((63.*X*X-70.)*X*X+15)*X/8.                                 GAM06400
  255 CONTINUE                                                          GAM06410
      GO TO 250                                                         GAM06420
C                                                                       GAM06430
  160 DO 260 I=1,IE                                                     GAM06440
      X=AL+DELTH*(I-1)                                                  GAM06450
      PN(I)=(((231.*X*X-315.)*X*X+105.)*X*X-5.)/16.                     GAM06460
```

SOURCE ELEMENT LIST (8BIT MODE)

```
  260 CONTINUE                                                          GAM06470
      GO TO 250                                                         GAM06480
C                                                                       GAM06490
  170 DO 270 I=1,IE                                                     GAM06500
      X=AL+DELTH*(I-1)                                                  GAM06510
      PN(I)=(((429.*X*X-693.)*X*X+315.)*X*X-35.)*X/16.                  GAM06520
  270 CONTINUE                                                          GAM06530
      GO TO 250                                                         GAM06540
C                                                                       GAM06550
  180 DO 280 I=1,IE                                                     GAM06560
      X=AL+DELTH*(I-1)                                                  GAM06570
      PN(I)=((((6435.*X*X-12012.)*X*X+6930.)*X*X-1260.)*X*X+35.)/128.   GAM06580
  280 CONTINUE                                                          GAM06590
C                                                                       GAM06600
  250 CONTINUE                                                          GAM06610
C                                                                       GAM06620
      SUMEND=0.                                                         GAM06630
      SUMEID=0.                                                         GAM06640
      DO 300 I=1,K                                                      GAM06650
      X=AL+2.*DELTH*(I-1)                                               GAM06660
      SUMEND=SUMEND+SIGMA(X,Y)*PN(2*I-1)                                GAM06670
      SUMEID=SUMEID+SIGMA((X+DELTH),Y)*PN(2*I)                          GAM06680
  300 CONTINUE                                                          GAM06690
C                                                                       GAM06700
      SIG=DELTH/3.*(2.*SUMEND+4.*SUMEID-SIGMA(AL,Y)*PN(1)+SIGMA(AU,Y)*  GAM06710
     1   PN(2*K+1))                                                     GAM06720
      RETURN                                                            GAM06730
      END                                                               GAM06740
      SUBROUTINE NROW(Z,NMAX,EE,TAUP,     PAIR,ENNU,DF,ZA)              GAM06750
C                                                                       GAM06760
C         THIS IS USED TO CALCULATE GAMMA-RAY ENERGY                    GAM06770
C                                   TRANSFER (ABSORPTION) COEFFICIENT   GAM06780
C                                                                       GAM06790
      DIMENSION ZTBL(15),ENNU(500)                                      GAM06800
      DIMENSION TZK(10),TFK(10),TZL(10),TFL(10),TZE(5),TEK(5),TEL(5)    GAM06810
      DIMENSION EE(500),TAUP(500),TAUK(500),PAIR(500),DF(50)            GAM06820
      COMMON /JDB/IGA,IM,FN,ICAL,IPRT0,IPRT1,J1,GE( 51)                 GAM06830
C           TZK -- ATOMIC NO. FOR K-SHELL FLUORESENCE YIELD             GAM06840
      DATA  TZK/ 7.0, 10.0, 15.0, 20.0, 30.0, 40.0, 50.0, 60.0, 80.0,   GAM06850
     *          100.0 /                                                 GAM06860
C           TFK -- FLUORESENCE YIELD OF K-SHELL                         GAM06870
      DATA  TFK/ 0.001, 0.010, 0.051, 0.151, 0.435, 0.711, 0.843,       GAM06880
     *           0.909, 0.953, 0.965 /                                  GAM06890
C           TZL -- ATOMIC NO. FOR L-SHELL FLUORESENCE YIELD             GAM06900
      DATA  TZL/ 31.0, 35.0, 40.0, 50.0, 60.0, 73.0, 74.0, 80.0, 90.0,  GAM06910
     *          100.0 /                                                 GAM06920
C           TFL -- FLUORESENCE YIELD OF L-SHELL                         GAM06930
      DATA  TFL/ 0.010, 0.032, 0.060, 0.118, 0.173, 0.248, 0.293,       GAM06940
     *           0.382, 0.444, 0.467 /                                  GAM06950
C           TZE -- ATOMIC NO. FOR FLUORESENCE ECERGY                    GAM06960
      DATA  TZE/ 3.0, 10.0, 20.0, 50.0, 100.0 /                         GAM06970
C           TEK -- FLUORESENCE ENERGY OF K-SHELL                        GAM06980
      DATA  TEK/ 0.054, 0.849, 3.719, 25.843, 124.054 /                 GAM06990
C           TEL -- FLUORESENCE ENERGY OF L-SHELL                        GAM07000
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      DATA  TEL/ 0.0, 0.018, 0.385, 3.609, 19.141 /                    GAM07010
      DATA      ZTBL/1.0,6.0,7.0,8.0,11.0,12.0,13.0,15.0,16.0,18.0,    GAM07020
     1               19.0,20.0,26.0,29.0,82.0/                         GAM07030
C                                                                      GAM07040
C                                                                      GAM07050
      IF(IPRT1.EQ.1) WRITE(6,1400) Z                                   GAM07060
 1400 FORMAT('1'//'0*** ATOMIC NO.  ',F8.3,'***'                       GAM07070
     1          /'0',25X,'--- MASS ENERGY TRANSFER COEFFICIENT ---'    GAM07080
     1       /'0              ENERGY        F*FT        K*FK        S*FC GAM07090
     2    TRANS COEFF')                                                GAM07100
CCCC   INTERPOLATE EACH TABLES FOR PHOTOELECTRIC ABSORPTION FACTOR     GAM07110
C         K-SHELL                                                      GAM07120
      CALL INTFT(Z,AEK,TZE,TEK, 5)                                     GAM07130
      AEK=AEK*1.0E-3                                                   GAM07140
       CALL INTFT(Z,AFK,TZK,TFK,10)                                    GAM07150
C         L-SHELL                                                      GAM07160
      CALL INTFT(Z,AEL,TZE,TEL, 5)                                     GAM07170
      AEL=AEL*1.0E-3                                                   GAM07180
      CALL INTFT(Z,AFL,TZL,TFL,10)                                     GAM07190
C     THRESHOLD ENERGY OF K-SHELL                                      GAM07200
      ECUT=(Z-0.3)**2*1.352E-5                                         GAM07210
      TEMP=1.0/(1.+0.01481*(ALOG(Z))**2-0.000788*(ALOG(Z))**3)         GAM07220
      K=0                                                              GAM07230
      DO 1000 KK=1,IGA                                                 GAM07240
      IF(IPRT1.EQ.1) WRITE(6,1800) KK                                  GAM07250
      DO 1000 JJ=1,IM                                                  GAM07260
      K=K+1                                                            GAM07270
      E=EE(K)                                                          GAM07280
C***      CALCULATE FTAU (PHOTOELCTRIC ABSORPTION FACTOR)              GAM07290
C                                                                      GAM07300
      IF(E.LE.ECUT) GO TO 20                                           GAM07310
      FTAU = 1.0-TEMP*AEK*AFK/E                                        GAM07320
      GO TO 30                                                         GAM07330
   20 FTAU = 1.0-AEL*AFL/E                                             GAM07340
   30 CONTINUE                                                         GAM07350
C***      CALCULATE FK   (PAIR PRODUCTION FACTOR)                      GAM07360
C                                                                      GAM07370
      IF(E.LE.1.0)  GO TO 180                                          GAM07380
C         SET UP EACH SIDE OF GIVEN ATOMIC NO.                         GAM07390
      IF(Z.LT.ZTBL(1))   GO TO 2000                                    GAM07400
      IF(Z.GT.ZTBL(15))  GO TO 110                                     GAM07410
      DO 120 I=1,15                                                    GAM07420
      IF(Z.EQ.ZTBL(I))   GO TO 130                                     GAM07430
      IF(Z.LT.ZTBL(I))   GO TO 140                                     GAM07440
  120 CONTINUE                                                         GAM07450
  140 ICO=0                                                            GAM07460
      N1=I-1                                                           GAM07470
      N2=I                                                             GAM07480
      GO TO 150                                                        GAM07490
  130 ICO=1                                                            GAM07500
      N1=I                                                             GAM07510
      GO TO 150                                                        GAM07520
  110 ICO=2                                                            GAM07530
      N1=14                                                            GAM07540
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      N2=15                                                             GAM07550
  150 CONTINUE                                                          GAM07560
C         INTERPOLATE ENERGY RANGE                                      GAM07570
      CALL INTFK(N1,Y1,E)                                               GAM07580
      IF(ICO.EQ.1) GO TO 160                                            GAM07590
      CALL INTFK(N2,Y2,E)                                               GAM07600
C                                                                       GAM07610
C         INTERPOLATE ATOMIC NO' RANGE                                  GAM07620
      FK=Y1+(Z-ZTBL(N1))*(Y2-Y1)/(ZTBL(N2)-ZTBL(N1))                    GAM07630
      GO TO 170                                                         GAM07640
  160 FK=Y1                                                             GAM07650
  170 CONTINUE                                                          GAM07660
      IF(FK.GE.0.0) GO TO 190                                           GAM07670
  180 FK=0.0                                                            GAM07680
C***                                                                    GAM07690
  190 FPH=TAUP(K)*FTAU                                                  GAM07700
      FPA=PAIR(K)*FK                                                    GAM07710
      CALL COMPT(E,FC)                                                  GAM07720
      SFC=-DF(KK)*ZA*FC                                                 GAM07730
C    HEAT PRODUCTION COEFF. --- KERMA FACTOR (WATT*SEC*BARN)            GAM07740
      ENNU(K)=FPH+FPA+SFC                                               GAM07750
      IF(IPRT1.EQ.0) GO TO 1000                                         GAM07760
      IF(JJ.EQ.IM) GOTO 1000                                            GAM07770
      WRITE(6,1500)       E,FPH,FPA,SFC,   ENNU(K)                      GAM07780
 1000 ENNU(K)=ENNU(K)*E*1.6E-13                                         GAM07790
C                                                                       GAM07800
C                                                                       GAM07810
      RETURN                                                            GAM07820
 2000 WRITE(6,1700) Z                                                   GAM07830
      STOP                                                              GAM07840
 1500 FORMAT(10X,E12.4,2X,4E12.4)                                       GAM07850
 1800 FORMAT('  GROUP',I3)                                              GAM07860
 1700 FORMAT(10X,'***ERROR  ATOMIC NO. ',F8.4)                          GAM07870
      END                                                               GAM07880
      SUBROUTINE INTFK(N,Y,E)                                           GAM07890
C                                                                       GAM07900
C         THIS IS USED TO INTERPOLATE FK TABLE                          GAM07910
C                                                                       GAM07920
      DIMENSION FK(8,15),EG(8)                                          GAM07930
      DATA  FK/ 0.318,0.488,0.658,0.743,0.794,0.828,0.870,0.895,        GAM07940
     1          0.318,0.487,0.655,0.738,0.787,0.820,0.858,0.879,        GAM07950
     2          0.318,0.489,0.654,0.737,0.786,0.818,0.855,0.876,        GAM07960
     3          0.317,0.486,0.654,0.736,0.785,0.816,0.853,0.873,        GAM07970
     4          0.317,0.485,0.652,0.733,0.780,0.811,0.846,0.863,        GAM07980
     5          0.317,0.485,0.651,0.732,0.779,0.810,0.843,0.861,        GAM07990
     6          0.317,0.487,0.653,0.734,0.780,0.809,0.842,0.857,        GAM08000
     7          0.316,0.484,0.649,0.729,0.775,0.804,0.836,0.851,        GAM08010
     8          0.316,0.484,0.648,0.728,0.774,0.803,0.834,0.848,        GAM08020
     9          0.316,0.483,0.647,0.726,0.771,0.799,0.829,0.842,        GAM08030
     A          0.316,0.483,0.646,0.725,0.770,0.798,0.827,0.839,        GAM08040
     B          0.316,0.482,0.645,0.724,0.769,0.796,0.824,0.836,        GAM08050
     C          0.317,0.484,0.646,0.722,0.763,0.788,0.811,0.819,        GAM08060
     D          0.314,0.480,0.640,0.715,0.757,0.781,0.804,0.808,        GAM08070
     E          0.312,0.471,0.616,0.675,0.701,0.712,0.712,0.700/        GAM08080
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      DATA  EG/1.5,2.0,3.0,4.0,5.0,6.0,8.0,10.0/
C               N --- SUBSCRIPT OF ATOMIC NO. TABLE
C               E --- ENERGY
C               Y --- DEMANDED VALUE
      IF(E.LT.EG(1))   GO TO 100
      IF(E.GT.EG(8))   GO TO 110
      DO 120 I=1,8
      IF(E.EQ.EG(I))   GO TO 130
      IF(E.LT.EG(I))   GO TO 140
  120 CONTINUE
  130 K1=I
      GO TO 160
  140 K1=I-1
      K2=I
      GO TO 150
  100 K1=1
      K2=2
      GO TO 150
  110 K1=7
      K2=8
C
C
  150 CONTINUE
      Y=FK(K1,N)+(E-EG(K1))*(FK(K2,N)-FK(K1,N))/(EG(K2)-EG(K1))
      RETURN
  160 Y=FK(K1,N)
      RETURN
      END
      SUBROUTINE INTFT(Z,E,X,Y,N)
C
C         THIS IS USED TO INTERPOLATE FK OR EK OF FTAU TABLE
C
      DIMENSION X(1),Y(1)
C
      IF(Z.LT.X(1)) GO TO 250
      IF(Z.GT.X(N)) GO TO 130
      DO 100 I=1,N
      IF(Z.EQ.X(I)) GO TO 110
      IF(Z.LT.X(I)) GO TO 120
  100 CONTINUE
  110 K1=I
      GO TO 200
  120 K1=I-1
      K2=I
      GO TO 150
  130 K1=N-1
      K2=N
C
C         INTERPOLATE     LOG(Y) LINER IN LOG(X)
  150 IF(Y(K1).EQ.0.0) GO TO 250
      E=Y(K1)*EXP(ALOG(Z/X(K1))*ALOG(Y(K2)/Y(K1))/ALOG(X(K2)/X(K1)))
      RETURN
  200 E=Y(K1)
      RETURN
```

SOURCE ELEMENT LIST (8BIT MODE)

```
  250 E=0.0                                                          GAM08630
      RETURN                                                         GAM08640
      END                                                            GAM08650
      SUBROUTINE COMPT(E,FC)                                         GAM08660
C                                                                    GAM08670
C         THIS IS USED TO CALCULATE COMPTON SCATTERING COEFF.        GAM08680
C                                                                    GAM08690
      COMMON /JDB/IGA,IM,FN,ICAL,IPRT0,IPRT1,J1,GE( 51)              GAM08700
      REAL MC2                                                       GAM08710
C                                                                    GAM08720
      MC2=0.510976                                                   GAM08730
      NM=E*FN                                                        GAM08740
      IF(NM.LT.10) NM=10                                             GAM08750
      IF(NM.GT.50) NM=50                                             GAM08760
      TMAX=2.*E*E/(MC2+2.*E)                                         GAM08770
      DEL=TMAX/FLOAT(NM)                                             GAM08780
      T1=0.0                                                         GAM08790
      T2=0.0                                                         GAM08800
      TOT=0.0                                                        GAM08810
      DO 1000 I=1,NM                                                 GAM08820
      T1=T2                                                          GAM08830
      T2=T1+DEL                                                      GAM08840
      TOT=TOT+ (PC(E,T1)*T1 + PC(E,T2)*T2)*DEL/2.                    GAM08850
 1000 CONTINUE                                                       GAM08860
      FC=TOT/E                                                       GAM08870
      RETURN                                                         GAM08880
      END                                                            GAM08890
      FUNCTION PC(E,T)                                               GAM08900
C                                                                    GAM08910
      REAL MC2                                                       GAM08920
C                                                                    GAM08930
C                                                                    GAM08940
      PAI=3.1415927                                                  GAM08950
      MC2=0.510976                                                   GAM08960
      R2 =7.9396E-26                                                 GAM08970
      AL=E/0.510976                                                  GAM08980
      TEM=1.0/E**2                                                   GAM08990
C                                                                    GAM09000
      DSIG=PAI*R2*MC2*((MC2*T*TEM)**2 + 2.*TEM*(E-T)**2              GAM09010
     1     +(E-T)*TEM*((T-MC2)**2-MC2**2)/E) / (E-T)**2              GAM09020
      SIGT =2.*PAI*R2*((2.*(1.+AL)/(1.+2.*AL)-ALOG(1.+2.*AL)/AL)     GAM09030
     1       *(1.+AL)/AL**2+ALOG(1.+2.*AL)/(2.*AL)                   GAM09040
     2       -(1.+3.*AL)/(1.+2.*AL)**2)                              GAM09050
C                                                                    GAM09060
      PC=DSIG/SIGT                                                   GAM09070
      RETURN                                                         GAM09080
      END                                                            GAM09090
```

SOURCE ELEMENT LIST (8BIT MODE)
ELEMENT NAME ((POPOP4)) ESTABLISHED 77.01.25

```
      SUBROUTINE  DTFPUN(E,NN,R,ISUM,NCARD,NPUN)                        GAM09100
C *** STOLEN FROM ANISN                                                 GAM09110
C *** DTFPUN USES VARIABLE FORMAT TO PUNCH AND NUMBER CARDS             GAM09120
      DIMENSION E(6),NN(6),R(6),IE(6),IEXP(6),S1(6),S2(6)               GAM09130
      DIMENSION FMT(26),FBT(4),FET(2)                                   GAM09140
      DATA POS,XNEG/'+   ','-   '/                                      GAM09150
      DATA FMT(1),FMT(26),FET(1),FET(2)/'(   ','I8) ','T73,','I8) '/    GAM09160
      DATA FBT(1),FBT(2) ,FBT(3),FBT(4)/'I2,2','A1,I','5,A1',',I2,'/    GAM09170
      DO 2 J=1,6                                                        GAM09180
      K=(J-1)*4 + 1                                                     GAM09190
      DO 3 I=1,4                                                        GAM09200
      L=K+I                                                             GAM09210
    3 FMT(L)=FBT(I)                                                     GAM09220
    2 CONTINUE                                                          GAM09230
      IF(ISUM.EQ.6)GO TO 4                                              GAM09240
      K=ISUM*4 + 2                                                      GAM09250
      FMT(K)=FET(1)                                                     GAM09260
      FMT(K+1)=FET(2)                                                   GAM09270
    4 DO 1 I=1,ISUM                                                     GAM09280
      S1(I)=POS                                                         GAM09290
      IF(E(I).LT.0.0)S1(I)=XNEG                                         GAM09300
      CALL FLTFX(E(I),IE(I),IEXP(I))                                    GAM09310
      S2(I)=XNEG                                                        GAM09320
      IF(IEXP(I).GE.0)S2(I)=POS                                         GAM09330
      IEXP(I)=IABS(IEXP(I))                                             GAM09340
    1 CONTINUE                                                          GAM09350
C***  WRITE (7,FMT) (NN(I),R(I),S1(I),IE(I),S2(I),IEXP(I),I=1,ISUM)     GAM09360
      WRITE(NPUN,FMT) (NN(I),R(I),S1(I),IE(I),S2(I),IEXP(I),I=1,ISUM)   GAM09370
     1,NCARD                                                            GAM09380
      RETURN                                                            GAM09390
      END                                                               GAM09400
      SUBROUTINE FLTFX(E1,NE1,N1)                                       GAM09410
C *** STOLEN FROM ANISN                                                 GAM09420
C   *** FLTFX CONVERTS FLOATING NUMBER TO INTEGER                       GAM09430
      N=-4                                                              GAM09440
      E=ABS(E1)                                                         GAM09450
      IF(E.NE.0.0)GO TO 1                                               GAM09460
      N=0                                                               GAM09470
      NE=0                                                              GAM09480
      GO TO 6                                                           GAM09490
    3 E=E*10.0                                                          GAM09500
      N=N-1                                                             GAM09510
    1 IF(E.GE.1.0)GO TO 4                                               GAM09520
      GO TO 3                                                           GAM09530
    5 E=E/10.0                                                          GAM09540
      N=N+1                                                             GAM09550
    4 IF(E.GE.10.0)GO TO 5                                              GAM09560
      E=E*10000.0                                                       GAM09570
    2 NE=E                                                              GAM09580
      E=E-FLOAT(NE)                                                     GAM09590
      IF(E.LT.0.5)GO TO 6                                               GAM09600
      IF(NE.NE.99999)GO TO 7                                            GAM09610
```

SOURCE ELEMENT LIST (8BIT MODE)

```
      N=N+1                                                             GAM09620
      NE=10000                                                          GAM09630
      GO TO 6                                                           GAM09640
    7 NE=NE+1                                                           GAM09650
    6 NE1=NE                                                            GAM09660
      N1=N                                                              GAM09670
      RETURN                                                            GAM09680
      END                                                               GAM09690
      SUBROUTINE PUNSH(X,N,NPUN)                                        GAM09700
C *** STOLEN FROM ANISN                                                 GAM09710
C   *** CLEVER SET OF SUBROUTINES WHICH PUNCH CARDS IN ANISN FORMAT     GAM09720
C   *** PUNSH SETS UP EACH CARD PUNCHED BY DTFPUN UTILIZING REPEATS     GAM09730
      DIMENSION ETR(6),NN(6),R(6),X(1)                                  GAM09740
      DATA BB,RR/'    ','R   '/                                         GAM09750
      NCARD=1                                                           GAM09760
      I6=0                                                              GAM09770
      K=0                                                               GAM09780
      ITRIP=0                                                           GAM09790
      II=N+1                                                            GAM09800
      DO 1 I=2,II                                                       GAM09810
      IF(ITRIP.LE.0)GO TO 2                                             GAM09820
      ITRIP=0                                                           GAM09830
      GO TO 3                                                           GAM09840
    2 IF(I.GE.II)GO TO 4                                                GAM09850
      IF(X(I).NE.X(I-1))GO TO 4                                         GAM09860
      K=K+1                                                             GAM09870
      IF(K.LT.98)GO TO 1                                                GAM09880
      ITRIP=1                                                           GAM09890
    4 I6=I6+1                                                           GAM09900
      NN(I6)=0                                                          GAM09910
      R(I6)=BB                                                          GAM09920
      IF(K.LE.0)GO TO 5                                                 GAM09930
      NN(I6)=K+1                                                        GAM09940
      R(I6)=RR                                                          GAM09950
      K=0                                                               GAM09960
    5 ETR(I6)=X(I-1)                                                    GAM09970
      IF(I6.GE.6)GO TO 6                                                GAM09980
    3 IF(I.LT.II)GO TO 1                                                GAM09990
    6 CALL DTFPUN(ETR,NN,R,I6,NCARD,NPUN)                               GAM10000
      NCARD=NCARD +1                                                    GAM10010
      I6=0                                                              GAM10020
    1 CONTINUE                                                          GAM10030
      RETURN                                                            GAM10040
      END                                                               GAM10050
```

Appendix C List of Sample Input and Output

Table C-1 Sample input data

```
....*....1....*....2....*....3....*....4....*....5....*....6....
*HLIEDRUN  RFNAME=J9103,GAMLEGJR
*DISK  PUNCH
*DATA
   21    10     9     0     1     0     0     1
   21
 14,0        12,0        10,0        8,0        6,5        5,0
  4,0         3,0         2,5        2,0        1,66       1,33
  1,0         0,8         0,6        0,4        0,3        0,2
  0,1         0,05        0,02
  1,0         1,0         1,0        1,0        1,0        1,0
  1,0         1,0         1,0        1,0        1,0        1,0
  1,0         1,0         1,0        1,0        1,0        1,0
  1,0         1,0         1,0
 14,0        12,0        10,0        8,0        6,5        5,0
  4,0         3,0         2,5        2,0        1,66       1,33
  1,0         0,8         0,6        0,4        0,3        0,2
  0,1         0,05        0,02
    3
  8,0        26,0        82,0
```

Table C-2 Sample output

```
INPUT DATA

IG     NO. OF GROUPS                              21   N      NO. OF INTEGRATION POINTS/GROUP          10
NMAX   NO. OF LEGENDRE COMPONENTS                  9   KON    CONTROL -1/0/1 = FLUX/NONE/SOURCE         0
ICAL   0/1 = X-SEC INPUT/CALCULATE                 1   IPRTO  0/1 = PRINT DETAIL X-SEC NO/YES           0
IPRT1  0/1 = PRINT DETAIL HEAT COEFF NO/YES        0   NACT   0/1 = OUTPUT HEAT COEFF NO/YES            1

          ENERGY (MEV)  SOURCE
     1    0.14000E+02 0.10000E+01
     2    0.12000E+02 0.10000E+01
     3    0.10000E+02 0.10000E+01
     4    0.80000E+01 0.10000E+01
     5    0.65000E+01 0.10000E+01
     6    0.50000E+01 0.10000E+01
     7    0.40000E+01 0.10000E+01
     8    0.30000E+01 0.10000E+01
     9    0.25000E+01 0.10000E+01
    10    0.20000E+01 0.10000E+01
    11    0.16600E+01 0.10000E+01
    12    0.13300E+01 0.10000E+01
    13    0.10000E+01 0.10000E+01
    14    0.80000E+00 0.10000E+01
    15    0.60000E+00 0.10000E+01
    16    0.40000E+00 0.10000E+01
    17    0.30000E+00 0.10000E+01
    18    0.20000E+00 0.10000E+01
    19    0.10000E+00 0.10000E+01
    20    0.50000E-01 0.10000E+01
    21    0.20000E-01 0.10000E+01

          GROUP ENERGY BOUNDS
     1    0.14000E+02
     2    0.12000E+02
     3    0.10000E+02
     4    0.80000E+01
     5    0.65000E+01
     6    0.50000E+01
     7    0.40000E+01
     8    0.30000E+01
     9    0.25000E+01
    10    0.20000E+01
    11    0.16600E+01
    12    0.13300E+01
    13    0.10000E+01
    14    0.80000E+00
    15    0.60000E+00
    16    0.40000E+00
    17    0.30000E+00
    18    0.20000E+00
    19    0.10000E+00
    20    0.50000E-01
    21    0.20000E-01

GROUP   AVG FLUX     AVG SIGMA S    AVG SOURCE

  1   0.10000E+02   0.16858E+00   0.10000E+01
  2   0.10000E+02   0.19092E+00   0.10000E+01
  3   0.10000E+02   0.22116E+00   0.10000E+01
  4   0.10000E+02   0.25788E+00   0.10000E+01
  5   0.10000E+02   0.30315E+00   0.10000E+01
  6   0.10000E+02   0.35698E+00   0.10000E+01
  7   0.10000E+02   0.42038E+00   0.10000E+01
  8   0.10000E+02   0.48712E+00   0.10000E+01
  9   0.10000E+02   0.54912E+00   0.10000E+01
 10   0.10000E+02   0.61752E+00   0.10000E+01
 11   0.10000E+02   0.69001E+00   0.10000E+01
```

12	0.10000E+02	0.78636E+00	0.10000E+01
13	0.10000E+02	0.89204E+00	0.10000E+01
14	0.10000E+02	0.10033E+01	0.10000E+01
15	0.10000E+02	0.11631E+01	0.10000E+01
16	0.10000E+02	0.13392E+01	0.10000E+01
17	0.10000E+02	0.15159E+01	0.10000E+01
18	0.10000E+02	0.17863E+01	0.10000E+01
19	0.10000E+02	0.21047E+01	0.10000E+01
20	0.10000E+02	0.23592E+01	0.10000E+01

```
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 1 , IS=-1.86265E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 2 , IS=-2.23517E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 3 , IS=-2.23517E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 4 , IS=-2.98023E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 5 , IS=-4.47035E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 6 , IS=-5.21541E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 7 , IS=-5.21541E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 8 , IS=-5.96046E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP 9 , IS=-1.04308E-07
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP10 , IS=-1.34110E-07
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP11 , IS=-1.93715E-07
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP12 , IS=-2.23517E-07
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP13 , IS=-2.83122E-07
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP14 , IS=-1.78814E-07
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP15 , IS=-1.19209E-07
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP16 , IS=-2.98023E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP17 , IS= 2.98023E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP18 , IS= 2.98023E-08
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP19 , IS= 2.98023E-07
DIFFERENCE-GROUP AVG SCATTER CROSS SECTION AND SUM OF GROUP AVERAGED TRANSFERS, GROUP20 , IS= 2.68221E-06
```

*** GAMMA-RAY CROSS SECTIONS FOR ATOMIC NUMBER = 8. ***

GROUP	ABSORB X-SEC.	COHERENT X-SEC.	HEAT COEFF.
1	0.16376E+00	0.39593E-05	0.81256E-12
2	0.14631E+00	0.62334E-05	0.70097E-12
3	0.12589E+00	0.10696E-04	0.59384E-12
4	0.10481E+00	0.18785E-04	0.50097E-12
5	0.83326E-01	0.34447E-04	0.42197E-12
6	0.62398E-01	0.63555E-04	0.35401E-12
7	0.43031E-01	0.11992E-03	0.29851E-12
8	0.26930E-01	0.21195E-03	0.25293E-12
9	0.15253E-01	0.34435E-03	0.22083E-12
10	0.81289E-02	0.55705E-03	0.19180E-12
11	0.29804E-02	0.89316E-03	0.16642E-12
12	0.38440E-03	0.15880E-02	0.13863E-12
13	0.15219E-03	0.27898E-02	0.11198E-12
14	0.27002E-03	0.48585E-02	0.89388E-13
15	0.64983E-03	0.10106E-01	0.64698E-13
16	0.16871E-02	0.20526E-01	0.44286E-13
17	0.48056E-02	0.40731E-01	0.30302E-13
18	0.28365E-01	0.11460E+00	0.16517E-13
19	0.25669E+00	0.39042E+00	0.84969E-14
20	0.30229E+01	0.14277E+01	0.15513E-13

P 0 CROSS SECTION TABLE ATOMIC NUMBER= 0.800E+01

	GROUP= 1	GROUP= 2	GROUP= 3	GROUP= 4	GROUP= 5	GROUP= 6	GROUP= 7	GROUP= 8
1	0.812564E-12	0.700975E-12	0.593837E-12	0.500969E-12	0.421973E-12	0.354013E-12	0.298514E-12	0.252932E-12
2	0.163757E+00	0.146305E+00	0.125887E+00	0.104812E+00	0.833257E-01	0.623984E-01	0.430312E-01	0.269297E-01
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.500071E+00	0.527198E+00	0.567111E+00	0.619309E+00	0.688142E+00	0.774646E+00	0.881800E+00	0.998944E+00
5	0.115049E-01	0.159455E-01	0.235674E-01	0.273215E-01	0.428199E-01	0.469849E-01	0.762777E-01	0.634457E-01
6	0.0	0.244885E-01	0.344168E-01	0.387147E-01	0.595572E-01	0.633240E-01	0.102407E+00	0.844818E-01
7	0.0	0.0	0.255675E-01	0.271676E-01	0.410161E-01	0.421567E-01	0.672959E-01	0.537520E-01
8	0.0	0.0	0.0	0.208642E-01	0.300418E-01	0.304373E-01	0.473154E-01	0.372868E-01
9	0.0	0.0	0.0	0.0	0.237821E-01	0.231410E-01	0.355661E-01	0.273647E-01
10	0.0	0.0	0.0	0.0	0.0	0.187772E-01	0.278473E-01	0.211754E-01
11	0.0	0.0	0.0	0.0	0.0	0.0	0.230154E-01	0.169135E-01
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.141467E-01
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	GROUP= 9	GROUP=10	GROUP=11	GROUP=12	GROUP=13	GROUP=14	GROUP=15	GROUP=16
1	0.220826E-12	0.191800E-12	0.166418E-12	0.138629E-12	0.111980E-12	0.893880E-13	0.646985E-13	0.442863E-13
2	0.152535E-01	0.812892E-02	0.298035E-02	0.384399E-03	0.152193E-03	0.270018E-03	0.649832E-03	0.168710E-02
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.111109E+01	0.124063E+01	0.138044E+01	0.157075E+01	0.178256E+01	0.200665E+01	0.233110E+01	0.269395E+01
5	0.934249E-01	0.969983E-01	0.138978E+00	0.222649E+00	0.229930E+00	0.366138E+00	0.665318E+00	0.699163E+00

6	0,133647E+00	0,135160E+00	0,195353E+00	0,288098E+00	0,282754E+00	0,454295E+00	0,701571E+00	0,643602E+00
7	0,869210E-01	0,921352E-01	0,131806E+00	0,194765E+00	0,172523E+00	0,272886E+00	0,427922E+00	0,338051E+00
8	0,582424E-01	0,630222E-01	0,941255E-01	0,139684E+00	0,124925E+00	0,183296E+00	0,299576E+00	0,253461E+00
9	0,420237E-01	0,442843E-01	0,674312E-01	0,105337E+00	0,950898E-01	0,141613E+00	0,226845E+00	0,201600E+00
10	0,317365E-01	0,330241E-01	0,492896E-01	0,792151E-01	0,751370E-01	0,113113E+00	0,186677E+00	0,163172E+00
11	0,250089E-01	0,255057E-01	0,376967E-01	0,601171E-01	0,586404E-01	0,924040E-01	0,155025E+00	0,137500E+00
12	0,202155E-01	0,203740E-01	0,295903E-01	0,470093E-01	0,456748E-01	0,738355E-01	0,129555E+00	0,115197E+00
13	0,170265E-01	0,166120E-01	0,238607E-01	0,374007E-01	0,362245E-01	0,583675E-01	0,104881E+00	0,963858E-01
14	0,0	0,140606E-01	0,195685E-01	0,303852E-01	0,290520E-01	0,466202E-01	0,834078E-01	0,777533E-01
15	0,0	0,0	0,166165E-01	0,250301E-01	0,237003E-01	0,375185E-01	0,666972E-01	0,614692E-01
16	0,0	0,0	0,0	0,213047E-01	0,195676E-01	0,306497E-01	0,536361E-01	0,488575E-01
17	0,0	0,0	0,0	0,0	0,166735E-01	0,253176E-01	0,437542E-01	0,390753E-01
18	0,0	0,0	0,0	0,0	0,0	0,215739E-01	0,360865E-01	0,317350E-01
19	0,0	0,0	0,0	0,0	0,0	0,0	0,307109E-01	0,260787E-01
20	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,221359E-01
21	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

	GROUP=17	GROUP=18	GROUP=19	GROUP=20	GROUP=
1	0,303022E-13	0,165175E-13	0,849689E-14	0,155133E-13	
2	0,480561E-02	0,283647E-01	0,256687E+00	0,302293E+01	
3	0,0	0,0	0,0	0,0	
4	0,306970E+01	0,370668E+01	0,484591E+01	0,915718E+01	
5	0,121617E+01	0,278778E+01	0,408360E+01	0,613425E+01	
6	0,117210E+01	0,184873E+01	0,890537E+00	0,505629E+00	
7	0,666475E+00	0,820999E+00	0,0	0,0	
8	0,495682E+00	0,355055E+00	0,0	0,0	
9	0,404922E+00	0,104938E+00	0,0	0,0	
10	0,290905E+00	0,118816E-01	0,0	0,0	
11	0,204546E+00	0,0	0,0	0,0	
12	0,154674E+00	0,0	0,0	0,0	
13	0,117333E+00	0,0	0,0	0,0	
14	0,898421E-01	0,0	0,0	0,0	
15	0,663096E-01	0,0	0,0	0,0	
16	0,482511E-01	0,0	0,0	0,0	
17	0,359361E-01	0,0	0,0	0,0	
18	0,272667E-01	0,0	0,0	0,0	
19	0,212790E-01	0,0	0,0	0,0	
20	0,169428E-01	0,0	0,0	0,0	
21	0,140648E-01	0,0	0,0	0,0	
22	0,0	0,0	0,0	0,0	
23	0,0	0,0	0,0	0,0	
24	0,0	0,0	0,0	0,0	

—— Deleted the output list for P_1, P_2, ..., P_7 cross section tables ——

P 8 CROSS SECTION TABLE ATOMIC NUMBER= 0.800E+01

	GROUP= 1	GROUP= 2	GROUP= 3	GROUP= 4	GROUP= 5	GROUP= 6	GROUP= 7	GROUP= 8
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.181907E+00	0.244958E+00	0.344227E+00	0.389429E+00	0.548589E+00	0.585992E+00	0.767985E+00	0.706656E+00
6	0.0	0.317955E+00	0.391668E+00	0.383571E+00	0.463898E+00	0.358496E+00	0.306572E+00	0.129666E+00
7	0.0	0.0	0.201300E+00	0.142048E+00	0.101214E+00	-0.265922E-01	-0.218831E+00	-0.287883E+00
8	0.0	0.0	0.0	0.539307E-01	-0.196505E-01	-0.108366E+00	-0.272836E+00	-0.251353E+00
9	0.0	0.0	0.0	0.0	-0.558443E-01	-0.118248E+00	-0.233658E+00	-0.179825E+00
10	0.0	0.0	0.0	0.0	0.0	-0.110009E+00	-0.188277E+00	-0.126156E+00
11	0.0	0.0	0.0	0.0	0.0	0.0	-0.154426E+00	-0.896439E-01
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.675694E-01
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	GROUP= 9	GROUP=10	GROUP=11	GROUP=12	GROUP=13	GROUP=14	GROUP=15	GROUP=16
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.832100E+00	0.843932E+00	0.857260E+00	0.583861E+00	0.568934E+00	-0.280440E-01	-0.142082E+00	-0.160588E+00
6	0.106123E+00	-0.150448E+00	-0.511407E+00	-0.120635E+01	-0.109139E+01	-0.949805E+00	0.427132E+00	0.161883E+00
7	-0.487379E+00	-0.589232E+00	-0.793901E+00	-0.658495E+00	0.206228E+00	0.855573E+00	0.259156E+00	-0.486300E+00
8	-0.376765E+00	-0.355549E+00	-0.368797E+00	0.640894E-01	0.547321E+00	0.582525E+00	-0.549529E+00	0.397444E+00
9	-0.223144E+00	-0.143434E+00	-0.498962E-01	0.333339E+00	0.454873E+00	0.121009E+00	-0.464670E+00	0.450000E+00
10	-0.124327E+00	-0.369229E-01	0.930635E-01	0.360907E+00	0.292868E+00	-0.146469E+00	-0.209037E+00	0.150766E+00
11	-0.691156E-01	0.121258E-01	0.128260E+00	0.295751E+00	0.140016E+00	-0.255444E+00	-0.586212E-02	-0.530698E-01
12	-0.373519E-01	0.313854E-01	0.126578E+00	0.219848E+00	0.383923E-01	-0.270168E+00	0.111640E+00	-0.157626E+00
13	-0.207191E-01	0.380080E-01	0.112926E+00	0.159303E+00	-0.118923E-01	-0.236228E+00	0.166001E+00	-0.188453E+00
14	0.0	0.388085E-01	0.975131E-01	0.116799E+00	-0.346777E-01	-0.189754E+00	0.172502E+00	-0.173134E+00
15	0.0	0.0	0.848217E-01	0.869694E-01	-0.423209E-01	-0.148254E+00	0.154151E+00	-0.138086E+00
16	0.0	0.0	0.0	0.681286E-01	-0.432998E-01	-0.116167E+00	0.130306E+00	-0.103463E+00
17	0.0	0.0	0.0	0.0	-0.415252E-01	-0.918611E-01	0.108242E+00	-0.760460E-01
18	0.0	0.0	0.0	0.0	0.0	-0.754713E-01	0.896777E-01	-0.565802E-01
19	0.0	0.0	0.0	0.0	0.0	0.0	0.761890E-01	-0.427404E-01
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.338898E-01

21	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

	GROUP=17	GROUP=18	GROUP=19	GROUP=20	GROUP=
1	0,0	0,0	0,0	0,0	
2	0,0	0,0	0,0	0,0	
3	0,0	0,0	0,0	0,0	
4	0,0	0,0	0,0	0,0	
5	-0,837052E-01	0,470903E-01	-0,170503E-01	0,611579E-04	
6	0,305637E+00	0,844195E-01	-0,469525E-01	0,171103E-01	
7	-0,155056E+00	-0,142633E+00	0,0	0,0	
8	0,257148E+00	0,143510E+00	0,0	0,0	
9	-0,296205E+00	-0,148211E+00	0,0	0,0	
10	-0,177188E+00	0,612444E-01	0,0	0,0	
11	-0,134940E-01	0,0	0,0	0,0	
12	0,730120E-01	0,0	0,0	0,0	
13	0,103711E+00	0,0	0,0	0,0	
14	0,100657E+00	0,0	0,0	0,0	
15	0,785379E-01	0,0	0,0	0,0	
16	0,530240E-01	0,0	0,0	0,0	
17	0,334172E-01	0,0	0,0	0,0	
18	0,201524E-01	0,0	0,0	0,0	
19	0,120394E-01	0,0	0,0	0,0	
20	0,702016E-02	0,0	0,0	0,0	
21	0,423505E-02	0,0	0,0	0,0	
22	0,0	0,0	0,0	0,0	
23	0,0	0,0	0,0	0,0	
24	0,0	0,0	0,0	0,0	