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SMAUG, A COMPUTER CODE TO CALCULATE THE NEUTRON AND GAMMA PROMPT DOSE ENVIRONMENT IN THE VICINITY OF AN ATMOSPHERIC NUCLEAR DETONATION

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November 1972

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AFWL-TR-72-2

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Weapons Laboratory (SAA) Kirtland Air Force Base, New Mexico 87117	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

SMAUG, A COMPUTER CODE TO CALCULATE THE NEUTRON AND GAMMA PROMPT DOSE ENVIRONMENT IN THE VICINITY OF AN ATMOSPHERIC NUCLEAR DETONATION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

December 1970-February 1972

5. AUTHOR(S) (First name, middle initial, last name)

Harry M. Murphy

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1972	~~105~~ 109	37

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 8809	AFWL-TR-72-2
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	AFWL (SAA) Kirtland AFB, NM 87117

13. ABSTRACT

(Distribution Limitation Statement A)

SMAUG is a digital computer code, written in ANSI FORTRAN, that calculates the neutron and prompt gamma dose environment in the vicinity of a low to medium yield atmospheric nuclear detonation. SMAUG does mass-integral scaling of ANISN discrete ordinates and SORS Monte Carlo results to obtain values of the neutron, prompt gamma, and secondary gamma spectra and doses at user-selected receiver points. In addition, SMAUG is capable of computing altitudes and ranges at which selected dose values occur, as well as calculating isodose contour values. This report describes the calculations performed by SMAUG in detail. Technical Report No. AFWL-TR-72-3 is the SMAUG User's Guide.

DD FORM 1 NOV 65 1473 PRINTED IN U.S.A.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Absorbed dose						
Computer code						
Gamma dose						
Gamma transport						
Initial radiation						
Neutron dose						
Neutron transport						
Nuclear radiation						
Secondary gamma rays						
SMAUG						

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FOREWORD

This report was prepared under Program Element 62601F, Project 8809, Task 03.

Inclusive dates of the work reported herein are December 1970 through February 1972. The report was submitted 1 September 1972 by the Air Force Weapons Laboratory Project Officer, Mr. Harry M. Murphy (SAA).

The author thanks Major John J. Prentice and Major William A. Yingling for their invaluable help and suggestions during the writing of this report, and especially for their comments during their review of the final draft.

This technical report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement A)

SMAUG is a digital computer code, written in ANSI FORTRAN, that calculates the neutron and prompt gamma dose environment in the vicinity of a low to medium yield atmospheric nuclear detonation. SMAUG does mass-integral scaling of ANISN discrete ordinates and SORS Monte Carlo results to obtain values of the neutron, prompt gamma, and secondary gamma spectra and doses at user-selected receiver points. In addition, SMAUG is capable of computing altitudes and ranges at which selected dose values occur, as well as calculating isodose contour values. This report describes the calculations performed by SMAUG in detail. Technical Report No. AFWL-TR-72-3 is the SMAUG User's Guide.

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SECTION I

INTRODUCTION

This report describes SMAUG*, a high-speed digital computer program which calculates the initial neutron and gamma radiation dose environment in the vicinity of a low to medium yield atmospheric nuclear detonation.

Studies of the prompt nuclear radiation hazards associated with modern warfare, such as the study of aircrew doses resulting from nearby nuclear detonations, usually involve many dose calculations under many different conditions of burst yield, burst altitude, and receiver position. The use of detailed radiation transport codes which use the Monte Carlo or discrete ordinate computational technique to solve such problems would be very expensive, both in problem preparation time and in computer time. SMAUG was written specifically to provide such dose estimates quickly, in an easily understood format, with a minimum effort on the part of the user. It does this by performing mass integral scaling of the results of Monte Carlo and discrete ordinates calculations made for infinite, homogeneous air.

Given a nuclear detonation specified in terms of burst yield, burst altitude, neutron source spectrum, and gamma source spectrum and given a receiver point specified in terms of altitude and ground range from the burst, SMAUG computes

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*The program name, SMAUG, is taken from the following passage in *The Hobbit*, a popular work of fantasy fiction by J. R. R. Tolkien:

> "There was a most specially greedy, strong and wicked worm called Smaug. One day he flew up into the air and came south.
>
> * * *
>
> "We saw the dragon settle on our mountain in a spout of flame. Then he came down the slopes and when he reached the woods they all went up in fire.
>
> * * *
>
> "The dwarves rushed out of their great gate - but there was the dragon waiting for them...."

the prompt radiation environment at the receiver point, including the neutron and gamma fluence, energy fluence, mean energy, and energy spectrum as well as the absorbed dose in both tissue and silicon.

Control card options enable SMAUG to read neutron or gamma source spectra or to use internally stored unclassified "nominal" fission or thermonuclear source spectra. Other control cards enable the computation of isofluence or isodose receiver positions under constraints of fixed receiver altitude or fixed receiver ground range, or to compute the isofluence or isodose contour point in 10-degree angular increments around the burst point. Still other control cards enable the user to specify the use of English or metric units in the output, while other control cards permit the user to edit the results by including or excluding portions of the printed output.

SMAUG is written entirely in American National Standards Institute FORTRAN (ANSI FORTRAN, Refs. 1, 2) and is a machine-independent computer program capable of execution on any digital computer which accepts and compiles ANSI FORTRAN. When compiled and run on the AFWL CDC-6600 computer*, SMAUG requires 18,560 computer words (44,200 octal) for instructions and storage. Compilation of object code from FORTRAN source code requires approximately 19 seconds of central processor time. The running time of the SMAUG code depends on the length and complexity of the input data deck, but on the AFWL CDC-6600 computer, time is typically about 1.5 seconds of central processor time per receiver point.

This report provides a detailed description of the data base and the computational techniques used in SMAUG and is not intended for use as a user's guide. Persons interested in using the SMAUG code may obtain the User's Guide (Ref. 3) from the Defense Documentation Center (DDC) or from the US Department of Commerce National Technical Information Service (NTIS).

SMAUG has been released as a code package to the Radiation Shielding Information Center (RSIC), Oak Ridge National Laboratory, Oak Ridge, Tennessee, and may be obtained from that Center.

---

*CDC FORTRAN Version 2.3 as compiled by the RUN compiler under the Scope 3.0 operating system.

SECTION II

COMPUTATIONAL TECHNIQUE

This section outlines the basic calculations performed in the SMAUG code. Included is a discussion of the use of mass integral scaling, the application of mass integral scaling to neutron, prompt gamma and secondary gamma calculations, extrapolation, peak gamma dose rate calculation, and the basis of the dose calculations in air, tissue, and silicon.

1. MASS INTEGRAL SCALING FUNCTIONS

The Morte Carlo and discrete ordinates air transport results on which the SMAUG code is based were obtained for particles released in infinite constant-density sea level air. To provide solutions for practical problems, it is necessary to account for the variation in air density with altitude. To do this, SMAUG uses the technique of mass integral scaling as a first-order correction for the effect of variable air density on neutron and gamma transport. Mass integral scaling is based on the following considerations:

For a monoenergetic source of particles released in constant-density infinite air, the number of particles which reach range, r, without loss of energy is given by

$$N = N_0 \, e^{-\Sigma r} \qquad (1)$$

where

N_0 is the number of particles released

Σ is the macroscopic total cross section in units of cm^{-1}

r is the range in centimeters

The macroscopic total cross section is given by

$$\Sigma = \sigma\rho A/W \qquad (2)$$

where

σ is the total effective cross section for air in units of cm^2

ρ is the air density in $grams/cm^3$

A is Avogadro's number (6.023×10^{23} per mole)

W is the mean atomic weight of air (14.48 grams/gram-mole)

Equation (1) can be expanded to

$$N = N_o\, e^{-\sigma\rho(A/W)r} \tag{3}$$

or

$$N = N_o\, e^{-4.16 \cdot 10^{22}\, \sigma\rho r} \tag{4}$$

Since the effective cross section, σ, is constant for this monoenergetic problem, the exponential is governed by the product ρr, whose dimensions are typically grams per square centimeter, corresponding to the areal density between the source and the receiver.

The uncollided particle fluence at range, r, is computed by correcting the above expression for the spherical divergence of the particles.

$$\phi = \frac{N_o\, e^{-4.16 \cdot 10^{22}\, \sigma\rho r}}{4\pi r^2} \tag{5}$$

In cases where the air density, ρ, is not constant between the source and the receiver, the product ρr, is replaced by the following expression which integrates the density along the line which connects the source and the receiver:

$$\text{"}\rho r\text{"} \equiv \int_0^r \rho(x)\, dx \tag{6}$$

where $\rho(x)$ is the air density function evaluated at distance x from the source.

Since the areal density is obtained by summing or integrating the mass of air in a cylinder whose base area is 1 square centimeter and which extends from the source to the receiver, this technique of fluence calculation based on areal density is called mass integral scaling.

Only rarely is the uncollided particle fluence of much practical interest; usually what is needed is the total fluence above some minimum energy, or the particle fluence in some energy band. For such cases--even for particles in a single-source energy band--one must consider the fact that the particles will probably make several collisions, losing energy each time, between the source and the receiver point and that the interaction cross sections are energy dependent. Thus, a simple exponential function cannot be expected to provide acceptable solutions in such cases.

The application of mass integral scaling to such cases is a matter of some debate; however, one can make the argument that scattering and energy degradation are primarily dependent on the total mass between the source and the receiver and not so dependent on the distribution of the mass. If such an argument is valid, then one can replace the exponential term with an empiric transmission function to give

$$N = N_0 \, T(\rho r) \tag{7}$$

where $T(\rho r)$ is the empiric transmission function which gives the number of particles in the energy range of interest which reach depth ρr grams/cm^2 in air.

In reference 4 Webster describes what appears to be the first use of a complete set of such empiric transmission functions to represent the number of neutrons in a given receiver band, per source neutron, as a function of depth in air.

In slightly modified form, Webster's empiric transmission function is

$$Tw_{i,j}(X) = \exp\left(A_{i,j} + B_{i,j}X^{1/2} + C_{i,j}X + D_{i,j}X^{-1} + E_{i,j}X^{-2} + F_{i,j}X^{-3}\right) \tag{8a}$$

where $Tw_{i,j}(X)$ is the number of neutrons in receiver energy band i, per neutron in source band j, at a range X meters from the source, and the coefficients $A_{i,j}$, $B_{i,j}$, $C_{i,j}$, $D_{i,j}$, $E_{i,j}$, and $F_{i,j}$ were obtained by least-squares fitting the results of SORS Monte Carlo neutron calculations (Ref. 5).

Although Webster's transmission function is given in terms of meters from the source, it is easily adapted to areal density units since his SORS Monte

Carlo calculation is based on transmission in infinite air at a constant density of $1.23 \cdot 10^{-3}$ g/cc.

Webster used 12 monoenergetic neutron sources and collected the neutrons in 28 energy bands; thus the number of six-constant transmission functions is potentially the product of 12 and 28, or 336, for a total of 2016 constants. However, since neutrons at a given source energy cannot contirbute to higher energy bands, Webster's set consists of only 230 equations for a total of 1320 constants. These constants are tabulated in reference 4.

The first version of the SMAUG computer code, written in January 1970, used Webster's transmission function and his tabulated constants. This code still exists at AFWL as the SMAUGN computer code.

Because Webster's transmission function contains three reciprocal terms, the function becomes indefinite when evaluated at zero. Further, in his report Webster points out that his function has several roots in the vicinity of zero and that, as a consequence of these roots, the function oscillates as the range approaches zero. For this reason, he warns that his equations should be considered ill-behaved for ranges less than 2.5 meters.

The current version of SMAUG is based on the use of a new empiric transmission function of the following form:

$$T_{i,j}(X) = \exp\left(A_{i,j} + B_{i,j}X + C_{i,j}X^2 + D_{i,j}X^{3/2} + E_{i,j}X^{1/2} + F_{i,j}X^{1/3}\right) \tag{8b}$$

where $T_{i,j}(X)$ is the number of neutrons in receiver energy band i at a distance corresponding to X grams/cm², per neutron released at the source point in source energy band j, and the coefficients $A_{i,j}$, $B_{i,j}$, $C_{i,j}$, $D_{i,j}$, $E_{i,j}$, and $F_{i,j}$ are obtained by least-squares fitting techniques.

The selection of the terms used in this transmission function was entirely empiric. The first three terms lend themselves well to cases in which the transmission is exponential, or nearly exponential. The fourth term, involving $X^{3/2}$ was selected on the practical basis that such a term seems essential in the function. The square root and the cube root terms account for the build-up that occurs over the first few mean free paths. The structure of the function is such that--in some cases where the transmission is nearly exponential--terms can be dropped from the right-hand side of the function without significantly affecting the quality of the fit.

This class of function can be adapted to the calculation of gamma fluence and to the calculation of neutron-induced secondary gamma radiation by fitting gamma transport and secondary gamma data generated by detailed radiation transport codes such as SORS or ANISN (Refs. 5, 6, 7).

For gamma calculations, the transmission function is interpreted in terms of photons per source photon; for secondary gamma calculations the function is interpreted in terms of photons per source neutron. In each case, the same scaling rules apply.

2. NEUTRON CALCULATION

SMAUG neutron calculations are based on the use of transmission functions fit by least-squares techniques to data reported in ORNL-4464 by Straker and Gritzner (Ref. 8).

In their report, Straker and Gritzner present the results of using the discrete ordinates code, ANISN, to compute the neutron and secondary gamma spectra resulting from the release of neutrons in homogeneous, constant-density infinite air (Ref. 7). The air was assumed to be 79 percent nitrogen and 21 percent oxygen at a density of 1.11 milligrams per square centimeter.

The nine neutron source energy bands used by Straker and Gritzner and by SMAUG are given in table I.

Table I

NEUTRON SOURCE ENERGY BANDS

Band No.	Energy range (MeV)
1	0.0033 - 0.111
2	0.111 - 1.108
3	1.108 - 2.35
4	2.35 - 4.06
5	4.06 - 6.36
6	6.36 - 8.18
7	8.18 - 10.0
8	10.0 - 12.2
9	12.2 - 15.0

The 22 neutron receiver energy bands used by Straker and Gritzner and by SMAUG are given in table II.

Table II

NEUTRON RECEIVER ENERGY BANDS

Band No.	Energy range (MeV)			Average energy
1	0.0	-	4.14(-7)[a]	2.07(-7)
2	4.14(-7)	-	1.12(-6)	7.67(-7)
3	1.12(-6)	-	3.06(-6)	2.09(-6)
4	3.06(-6)	-	1.07(-5)	6.88(-6)
5	1.07(-5)	-	2.90(-5)	1.99(-5)
6	2.90(-5)	-	1.01(-4)	6.50(-5)
7	1.01(-4)	-	5.83(-4)	3.42(-4)
8	5.83(-4)	-	3.35(-3)[b]	1.97(-3)
9	3.35(-3)[b]	-	1.11(-1)	5.72(-2)
10	1.11(-1)	-	5.50(-1)	3.31(-1)
11	0.55	-	1.11	0.830
12	1.11	-	1.83	1.470
13	1.83	-	2.35	2.090
14	2.35	-	2.46	2.405
15	2.46	-	3.01	2.735
16	3.01	-	4.07	3.540
17	4.07	-	4.97	4.520
18	4.97	-	6.36	5.665
19	6.36	-	8.19	7.275
20	8.19	-	10.0	9.095
21	10.0	-	12.2	11.10
22	12.2	-	15.0	13.6

[a] Read as 4.14×10^{-7}.

[b] An error exists in the tabulation for this energy value in ORNL-4464. The value given here is correct.

A series of 149 transmission functions, $T_{i,j}(X)$, have been fit to this data set.

Figure 1 compares data points from reference 8 with the transmission function fit to those points for the case of neutrons in the 12.2 to 15 MeV source band arriving in the 10.0 to 12.2 MeV receiver band.

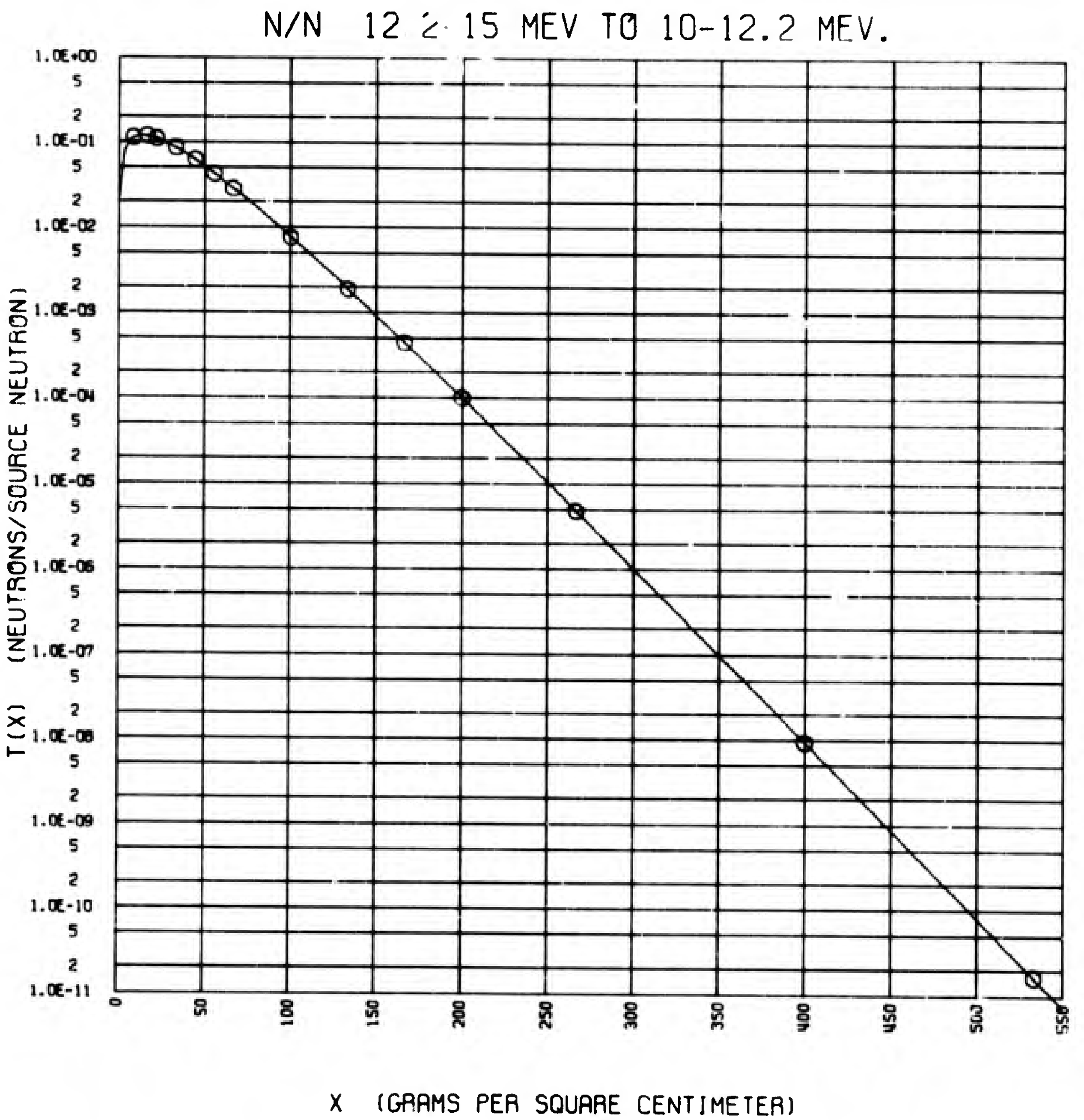

Figure 1. Fit of Transmission Function for 12.2 to 15.0 MeV Neutrons Arriving in the 10.0 to 12.2 MeV Receiver Band (Points are taken from ANISN results of Straker and Gritzner (Ref. 8))

Figure 2 compares data points from reference 8 with the transmission function fit to these points for the case of neutrons in the 12.2 to 15.0 MeV source band arriving in the 1.11 to 1.83 MeV receiver band.

The neutron transmission function coefficients are tabulated in appendix I of this report.

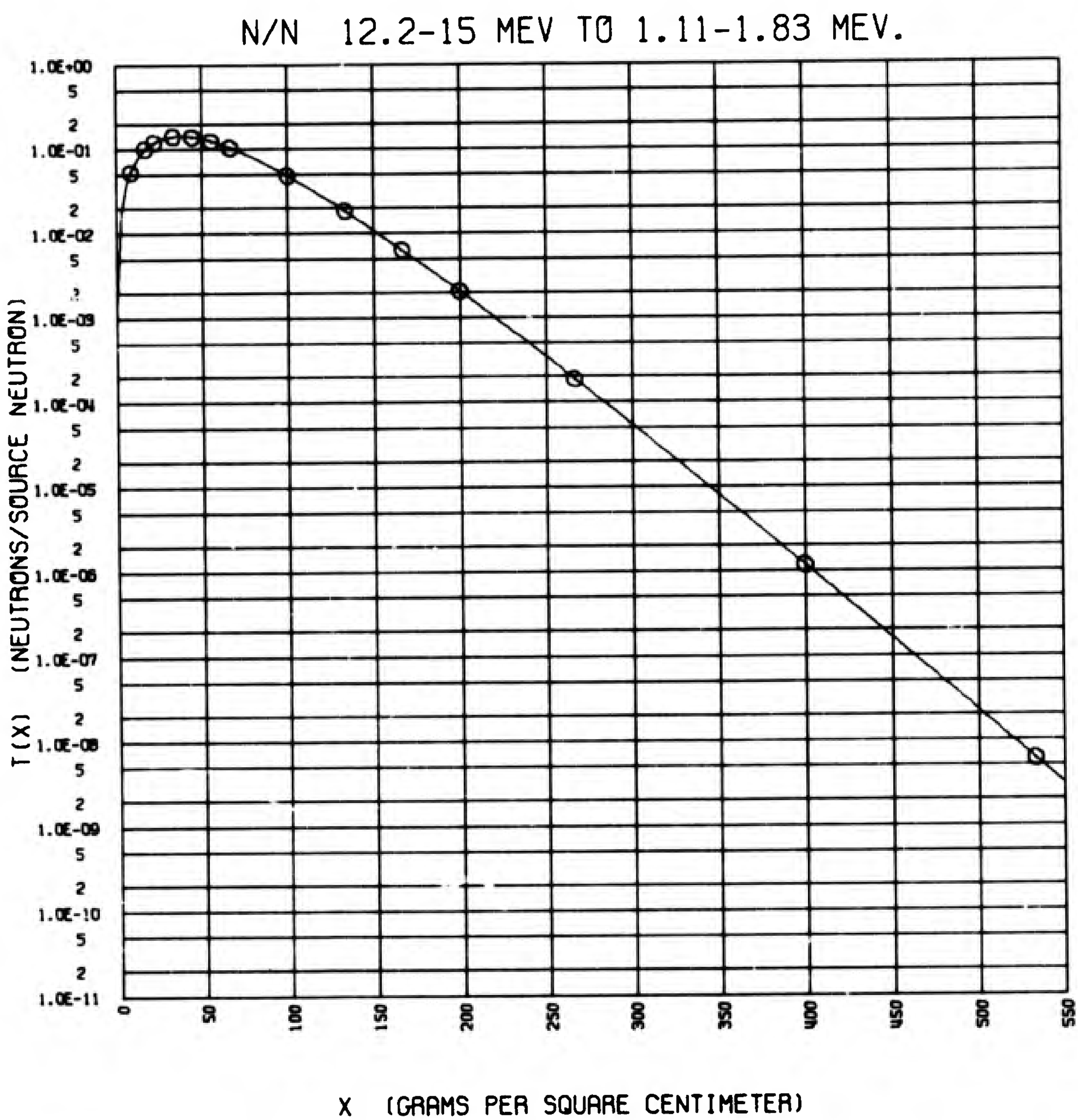

Figure 2. Fit of Transmission Function for 12.2 to 15.0 MeV Neutrons Arriving in the 1.11 to 1.83 MeV Receiver Band (Points are taken from ANISN results of Straker and Gritzner (Ref. 8))

The neutron spectrum at a point is computed by summing the contributions of each of the nine source bands to each of the 22 receiver bands. If the receiver is at a range of r meters, corresponding to a depth of X grams per square centimeter, the neutron fluence in receiver band i is given by

$$\Phi_i = \frac{10^{-4}}{4\pi r^2} \sum_{j=1}^{j=9} N_j \, T_{i,j}(X) \qquad (9)$$

where N_j is the number of neutrons in source band, j, and the factor of 10^{-4} accounts for the fact that r is given in meters, while the dimensions of fluence are neutrons per square centimeter.

3. PROMPT GAMMA CALCULATION

SMAUG prompt gamma calculations are based on the use of transmission functions fit by least-squares techniques to gamma transport data prepared for the SMAUG code by Robert A. Bigoni of the Air Force Weapons Laboratory. Bigoni used the SORS Monte Carlo computer code, described in reference 6, to calculate the gamma spectra resulting from the release of photons in homogeneous, constant-density infinite air as a function of depth in air expressed in units of grams per square centimeter.

The 10 gamma source energy bands used by Bigoni and by SMAUG are given in table III.

Table III

GAMMA SOURCE ENERGY BANDS

Band No.	Energy range (MeV)
1	0.1 - 0.2
2	0.2 - 0.4
3	0.4 - 0.7
4	0.7 - 1.0
5	1.0 - 1.5
6	1.5 - 2.0
7	2.0 - 3.0
8	3.0 - 5.0
9	5.0 - 7.0
10	7.0 - 10.0

The 18 gamma receiver energy bands used by Bigoni were selected to conform to Straker's gamma receiver band structure used in ORNL-4464 (Ref. 8). These bands, which are used by SMAUG, are given in table IV.

Table IV

GAMMA RECEIVER ENERGY BANDS

Band No.	Energy range (MeV)	Average energy
1	0.02 - 0.05	0.035
2	0.05 - 0.10	0.075
3	0.10 - 0.20	0.150
4	0.20 - 0.30	0.250
5	0.30 - 0.40	0.350
6	0.40 - 0.60	0.500
7	0.50 - 0.80	0.700
8	0.80 - 1.00	0.900
9	1.00 - 1.33	1.165
10	1.33 - 1.66	1.495
11	1.66 - 2.00	1.830
12	2.00 - 2.50	2.250
13	2.50 - 3.00	2.750
14	3.00 - 4.00	3.500
15	4.00 - 5.00	4.500
16	5.00 - 6.50	5.750
17	6.50 - 8.00	7.250
18	8.00 - 10.00	9.000

A series of 108 transmission functions, $T_{i,j}(X)$, have been fit to Bigoni's Monte Carlo results. Because in Monte Carlo calculations relatively few photons are available at depths of 200 to 300 grams per square centimeter, the transmission factors for such depths contain larger relative statistical errors than the transmission factors for shallower depths. To account for the statistical error associated with the data reciprocal variance weighting was used in performing the least-squares fits (Refs. 9, 10, 11).* Variances were based on the estimates supplied by the SORS code of the standard deviation associated with each point.

Figure 3 compares Bigoni's SORS data points with the transmission function fit to these points for photons in the 7 to 10 MeV source band arriving in the 5 to 6.5 MeV receiver band.

Figure 4 compares data points with the transmission function fit to these points for photons in the 7 to 10 MeV source band arriving in the 1 to 1.33 MeV receiver band.

In both figures the relative scatter of the data points around the fit function increases for depths greater than 200 grams per square centimeter. This scatter is the result of the statistical nature of the Monte Carlo calculation and is not seen in the results of the ANISN discrete ordinates code shown in figures 1 and 2.

The coefficients for this data set are tabulated in appendix II.

The prompt gamma spectrum at a point is computed by summing the contributions of photons in each of the 10 source bands to each of the 18 receiver banks in a way exactly analogous to the neutron receiver spectrum calculation. In particular, if the receiver is at a range of r meters, corresponding to a depth of x grams per square centimeter, the photon fluence in receiver band i is given by

$$\Phi = \frac{10^{-4}}{4\pi r^2} \sum_{j=1}^{j=10} N_j \, T_{i,j}(X) \qquad (10)$$

*Scarborough's precision index, h, used in Article 143 of reference 9, is related to standard deviation by

$$h = (\sqrt{2}\,\sigma)^{-1}$$

Thus, weighting by the square of the precision index, recommended in Article 148, is equivalent to weighting by the reciprocal of the standard deviation squared, which is identical to weighting by the reciprocal of the variance.

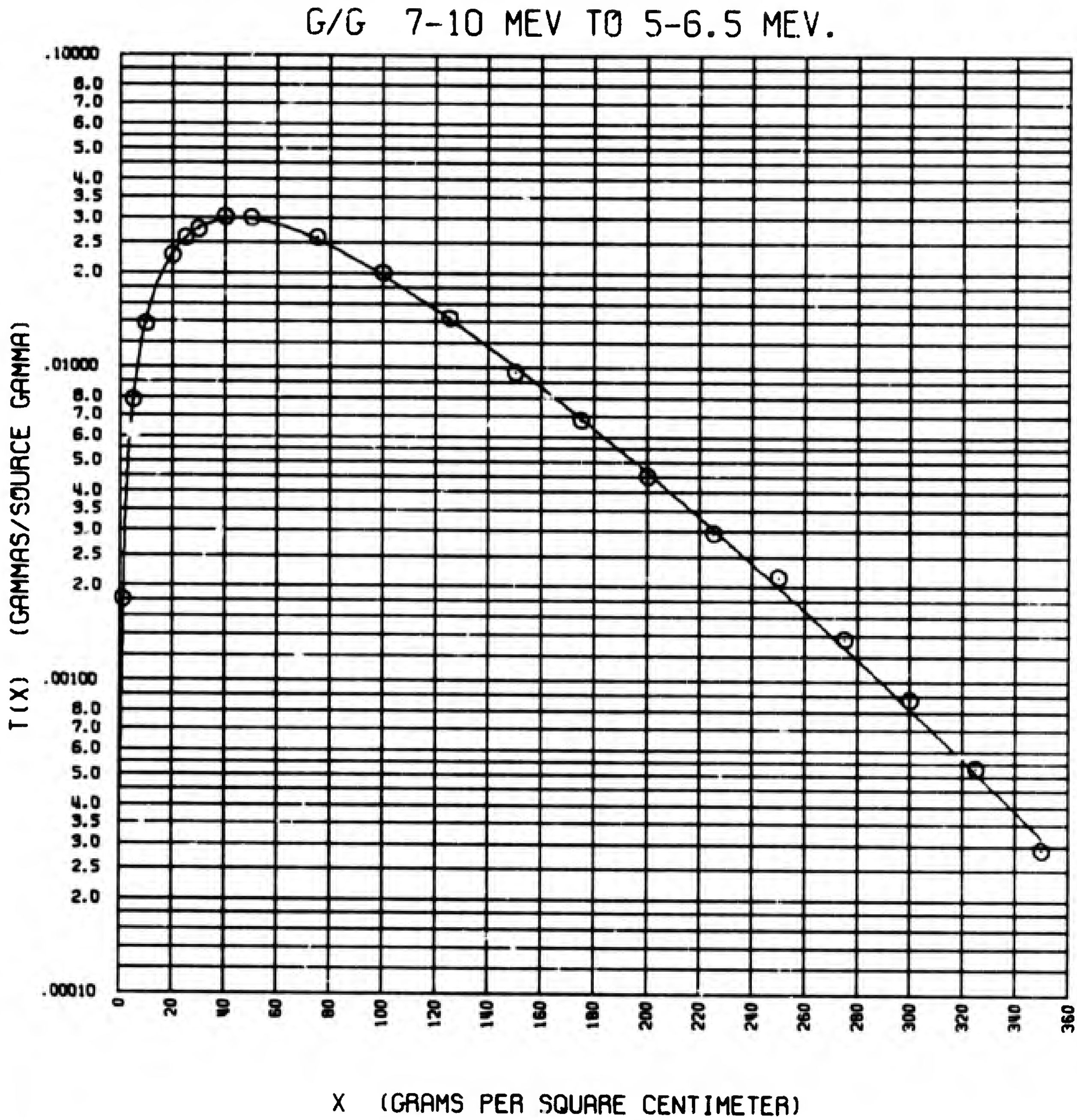

Figure 3. Fit of Transmission Function for 7 to 10 MeV Gammas Arriving in the 5 to 6.5 MeV Receiver Band (Points are taken from the SORS Monte Carlo results of Bigoni. Reciprocal variance weighting was used in performing this fit.)

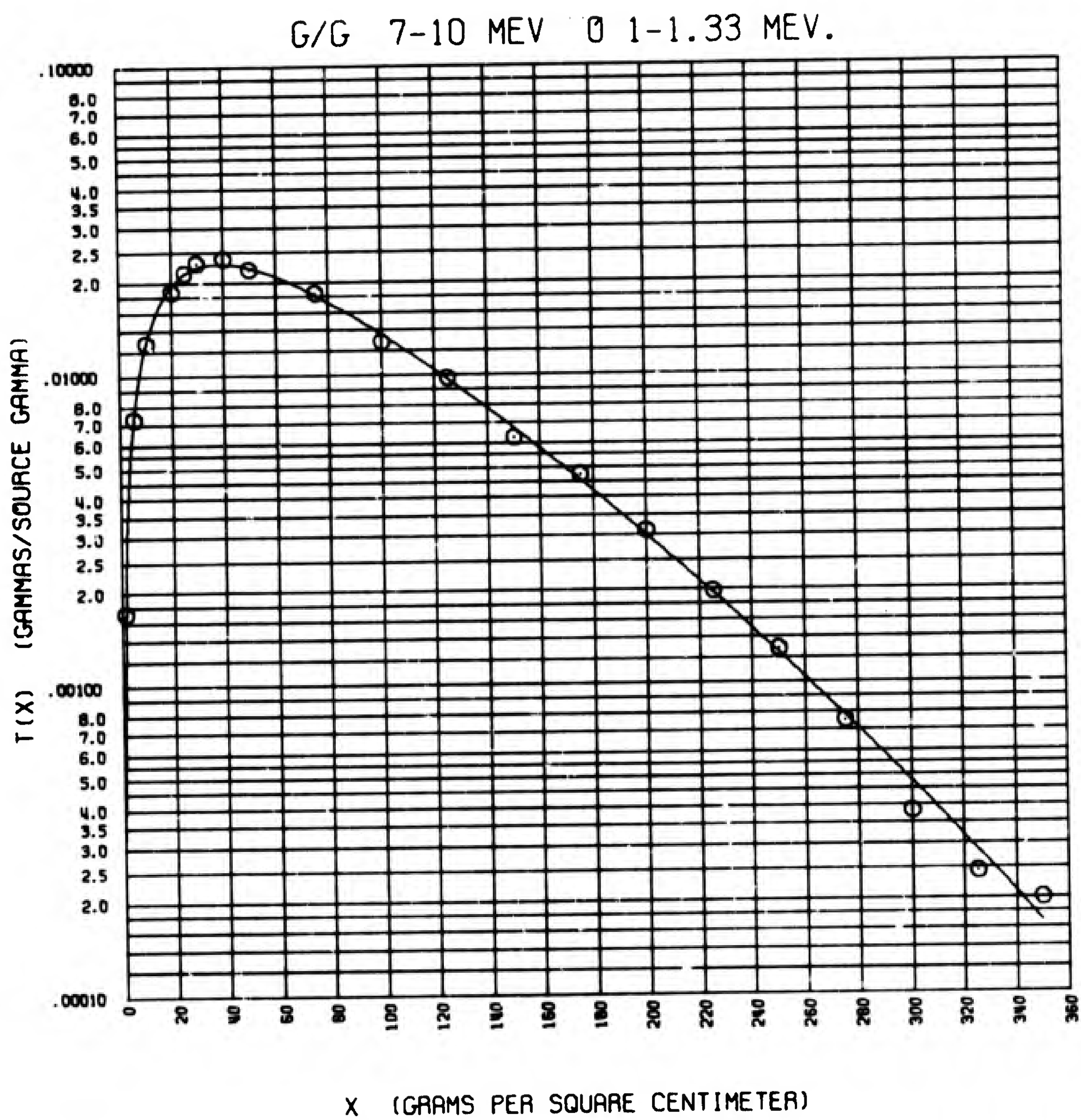

Figure 4. Fit of Transmission Function for 7 to 10 MeV Gammas Arriving in the 1 to 1.33 MeV Receiver Band (Points are taken from SORS Monte Carlo results of Bigoni. Reciprocal variance was used in performing this fit.)

where N_j is the number of photons in source band, j, and the factor of 10^{-4} accounts for the conversion from photons per square meter to photons per square centimeter.

4. SECONDARY GAMMA CALCULATION

SMAUG secondary gamma calculations are based on the use of transmission functions fit to neutron-induced secondary gamma data reported by Straker and Gritzner in ORNL-4464 (Ref. 8). This is the same report that is used for SMAUG's neutron data base.

The nine neutron source energies used are given in table I. The 18 gamma receiver energy banks are identical to those used in the SORS Monte Carlo calculations and are given in table IV.

A series of 162 transmission functions, $T_{i,j}(X)$, have been fit to this secondary gamma data set. The coefficients for this set are tabulated in appendix III of this report.

Figure 5 compares data points from reference 8 with the transmission function fit to those points for neutrons in the 12.2 to 15 MeV band resulting in secondary gamma photons in the 8 to 10 MeV receiver band.

In the previous cases of neutron and gamma transport, the actual number of transmission functions fitted was less than the product of the number of source bands and the number of receiver bands because such particles do not gain energy as they penetrate air. This is not the case for neutron-induced secondary gamma calculations. Because of the presence of exoenergetic n,γ reactions, neutrons in each source band can and do contribute secondary gammas to every one of the 18 gamma receiver bands. For this reason, more transmission functions have been used for the secondary gamma data set (162) than were used for the neutron or the gamma data sets (149 and 108 functions, respectively).

The secondary gamma spectrum at a point is computed by summing the contributions of neutrons in each of the nine neutron source bands to each of the 18 gamma receiver bands in a way exactly analogous to the neutron and the prompt photon calculations.

Except for their somewhat longer time of arrival at the receiver, there is no way of distinguishing the neutron-induced secondary gammas from the prompt gammas at the receiver. For this reason, the prompt and the secondary gamma spectra are combined in calculating the total gamma spectrum at the receiver.

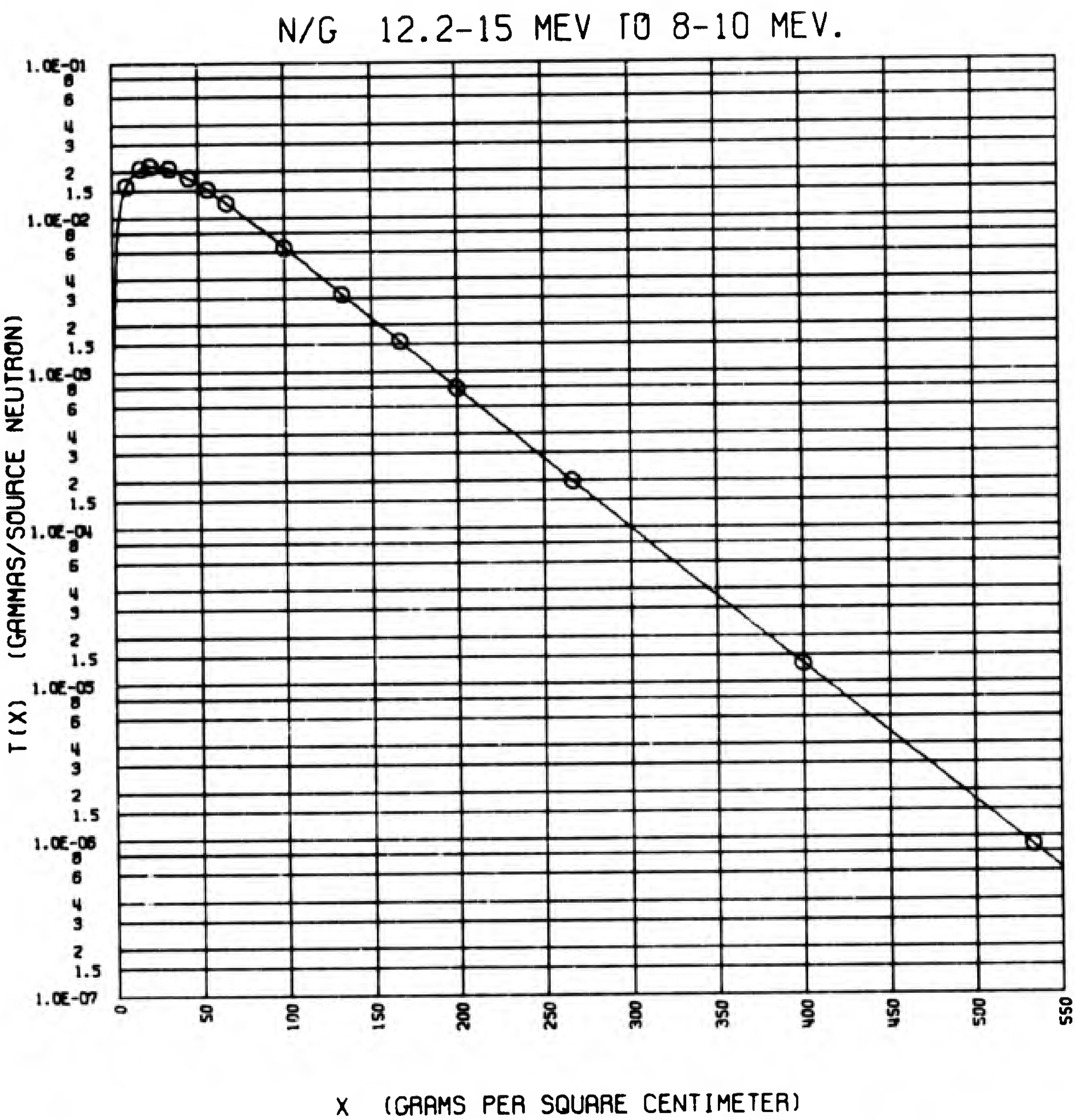

Figure 5. Fit of Transmission Function for 12.2 to 15.0 MeV Neutrons Resulting in Secondary Gammas in the 8 to 10 MeV Gamma Receiver Energy Band (Points are taken from ANISN results of Straker and Gritzner (Ref. 8))

5. EXTRAPOLATION

The ANISN neutron and secondary gamma data set of Straker and Gritzner is tabulated over ranges corresponding to 8.325 to 199.8 g/cm², with the data for the 12.2 to 15.0 MeV source further tabulated to a depth of 532.8 g/cm². Bigoni's SORS Monte Carlo gamma data set is tabulated to 350 g/cm². Frequently, solutions are needed for depths greater than these limits; if SMAUG was strictly held to these limits, the usefulness of the code would be severely reduced.

To permit extrapolation to greater depths, SMAUG takes advantage of the fact that--for deep penetration--the transmission functions can be well approximated by simple exponential functions of the form

$$T_{i,j}(x) = \exp\left(A_{i,j} + B_{i,j}(x)\right) \tag{11}$$

This transmission function is the same function defined in equation (8) with the exception that the four nonlinear terms of equation (8) are not retained. A point-slope form of equation (11) is used by SMAUG to calculate the transmission functions beyond the extrapolation point

$$T_{i,j}(x) = \exp\left(R_{i,j} + S_{i,j}(x-Xe)\right) \tag{12}$$

where $R_{i,j}$ is the value of the six-constant transmission function evaluated at the extrapolation point, Xe, and $S_{i,j}$ is the first derivative of the six-constant transmission function evaluated at the extrapolation point, Xe.

For neutron and secondary gamma calculations, the extrapolation point, Xe, is 200 g/cm². For ranges within 200 g/cm² SMAUG uses the six-constant transmission function; for ranges beyond 200 g/cm² SMAUG uses extrapolation.

For prompt gamma calculations, the extrapolation point is 300 g/cm².

Except for contour calculations, in each case where the results are based on extrapolation, SAMUG prints an advisory message. SMAUG aborts calculations beyond twice the maximum extrapolation point (i.e., beyond 600 g/cm²).

6. PEAK GAMMA DOSE RATE ESTIMATION

SMAUG estimates the peak prompt gamma dose rate if the user supplies the following information: (1) the fraction of the prompt gamma yield in the prompt gamma "spike;" and (2) the mean width of this spike. Given this information, SMAUG first calculates the uncollided peak gamma spectrum from the following:

$$\Phi_i = \frac{F\ N_i\ 10^{-4}}{4\pi r^2} e^{-\mu_i x} \qquad (13)$$

where

Φ_i is the uncollided gamma fluence in source band

N_i is the number of prompt gammas originating in source band

F is the fraction of the prompt gammas in the prompt "spike"

μ_i is the total gamma absorption coefficient for gammas in band

The dose in units of Roentgens and in rads(silicon) is computed by summing the contribution of photons in each of the energy bands.

A correction term is then computed to account for photons which undergo shallow-angle scattering, but which still arrive within the prompt gamma spike. This correction term is based on a series of SORS Monte Carlo runs made by Brown B. Rogers of the Air Force Weapons Laboratory who computed the number of photons arriving within 15 nanoseconds in each of 18 receiver energy bands, as a function of range in homogeneous, infinite, sea-level density air. This information, converted to Roentgens or rads(silicon) for each source band was fit by least-squares techniques to the six-constant transmission function. This scattered component of peak prompt gamma dose is computed in the usual way, with the addition of the following scaling function which accounts for the longer path lengths encountered in high-altitude situations:

$$\text{Scale} = \left(\frac{1.5 \cdot 10^{-8}\ Rs}{\Delta T\ S}\right)^{1/2} \qquad (14)$$

where

Rs is the equivalent range in meters at sea level, defined as 8.16327 times the depth in air in g/cm^2

ΔT is the mean width of the prompt gamma spike

S is the source-receiver slant range in meters

The scaled scattered dose and the direct dose are summed and divided by ΔT to obtain an estimate of the peak prompt gamma dose rate. In most cases, the direct dose rate accounts for roughly two-thirds of the total dose rate.

7. FLUENCE TO DOSE CONVERSION

Fundamentally, SMAUG is a program that computes neutron and photon fluences in a series of energy bands at the receiver. In some cases this is the information needed by the user, but more often the user wants dose values which can be more easily related to the personnel injury or equipment damage resulting from such exposures.

As an aid to the user, SMAUG calculates the following dose and dose-related values:

(1) Neutron energy fluence in MeV/cm^2

(2) Neutron mean energy in MeV

(3) Neutron tissue dose in rads

(4) Neutron phantom midline or gut dose in rads

(5) Neutron silicon dose in rads

(6) One-MeV (silicon) equivalent neutron fluence

(7) Gamma energy fluence in MeV/cm^2

(8) Gamma mean energy in MeV

(9) Gamma tissue dose in rads

(10) Gamma phantom midline or gut dose in rads

(11) Gamma air ionization dose in Roentgens

(12) Gamma silicon dose in rads

(13) Neutron plus gamma tissue dose in rads

(14) Neutron plus gamma phantom midline dose in rads

(15) Neutron plus gamma silicon dose in rads

Table V gives the factors used to convert neutron fluences in the 22 receiver bands to dose units. For each entry the value given is dose per unit neutron fluence at the average energy of the receiver band. The average energy is defined as the arithmetic mean of the lower and upper limits of the energy band.

Table V

NEUTRON DOSE CONVERSION FACTORS

	Neutron energy band (MeV)			Average energy (MeV)	Tissue dose (rads)	Phantom dose (rads)	Silicon dose (rads)	Silicon equiv fluence
	Lower		Upper					
1	0.0	to	4.140E-07	2.070E-07	8.259E-12	5.464E-11		2.170E-07
2	4.140E-07	to	1.120E-06	7.670E-07	4.339E-12	7.287E-11		8.050E-07
3	1.120E-06	to	3.060E-06	2.090E-06	2.667E-12	9.017E-11		2.190E-06
4	3.060E-06	to	1.070E-05	6.880E-06	1.546E-12	1.095E-10		7.220E-06
5	1.070E-05	to	2.900E-05	1.985E-05	1.084E-12	1.207E-10		2.090E-05
6	2.900E-05	to	1.010E-04	6.500E-05	1.153E-12	1.233E-10		6.820E-05
7	0.000101	to	0.000583	3.420E-04	3.659E-12	1.124E-10		3.590E-04
8	0.000583	to	0.003350	1.966E-03	1.958E-11	9.665E-11		2.060E-03
9	0.003350	to	0.111000	5.717E-02	4.259E-10	1.136E-10		5.990E-02
10	0.111000	to	0.550000	3.305E-01	1.292E-09	2.192E-10	3.400E-11	3.320E-01
11	0.550000	to	1.110000	8.300E-01	2.013E-09	3.881E-10	4.800E-11	6.760E-01
12	1.110000	to	1.830000	1.470E+00	2.619E-09	6.034E-10	5.500E-11	8.910E-01
13	1.830000	to	2.350000	2.090E+00	3.050E-09	8.192E-10	6.900E-11	1.000E+00
14	2.350000	to	2.460000	2.405E+00	3.154E-09	9.324E-10	7.700E-11	1.040E+00
15	2.460000	to	3.010000	2.735E+00	3.428E-09	1.053E-09	8.400E-11	1.070E+00
16	3.010000	to	4.070000	3.540E+00	4.066E-09	1.360E-09	1.020E-10	1.120E+00
17	4.070000	to	4.970000	4.520E+00	4.120E-09	1.755E-09	1.410E-10	1.170E+00
18	4.970000	to	6.360000	5.665E+00	4.486E-09	2.247E-09	2.150E-10	1.200E+00
19	6.360000	to	8.190000	7.275E+00	4.996E-09	2.990E-09	5.560E-10	1.240E+00
20	8.190000	to	10.000000	9.095E+00	5.153E-09	3.902E-09	8.740E-10	1.260E+00
21	10.000000	to	12.200000	1.110E+01	5.774E-09	4.990E-09	9.660E-10	1.270E+00
22	12.200000	to	15.000000	1.360E+01	6.255E-09	6.465E-09	9.350E-10	1.280E+00

Table VI gives the factors used to convert photon fluences in the 18 receiver bands to gamma doses. For each entry the value given is dose per unit photon fluence at the average energy of the receiver band.

A discussion of each of the 15 dose values follows:

a. Neutron Energy Fluence

The neutron energy fluence is computed by summing the product of the neutron fluence and mean energy of the 22 receiver bands. The unit for neutron energy fluence is MeV/cm^2.

$$\Phi(\text{MeV}) = \sum_{i=1}^{22} \Phi_i E_i \qquad (15)$$

b. Neutron Mean Energy

The neutron mean energy is calculated by dividing the neutron energy fluence by the total neutron fluence summed over all 22 receiver bands.

c. Neutron Tissue Dose

The neutron tissue dose is calculated on the basis of fluence-to-kerma factors reported by Ritts, Solomito, and Stevens in reference 12. Their report describes the results of making detailed calculations of kerma in an 11-element tissue corresponding to a standard man, while accounting for all significant neutron interactions, including neutron capture, n,n', n,p, n,d, n,t, n,α, n,2α, n,n'3α, n,n'p, and n,2n reactions. The calculations were performed for 131 neutron energies ranging from 0.0223 eV to 15.14 MeV. The tissue composition of their standard man is given in table VII.

The fluence to dose conversion factors shown in table V were obtained by performing four-point Lagrangian interpolation of the 131-point table given in their report. The values given here are in units of rads per unit fluence. (One rad corresponds to an absorbed dose of 100 ergs per gram or a kerma of 100, hence the dose represented is "first collision dose.")

The data set given in reference 12 was selected for use in SMAUG in preference to similar sets in references 13, 14, 15, and 16 for two reasons: (1) the set explicitly accounts for the effects of the minor elements calcium, phosphorus, sulphur, potassium, sodium, chlorine, and magnesium; and (2) the set evaluates in detail kerma over an unusually wide energy range, using the

Table VI

GAMMA DOSE CONVERSION FACTORS

	Gamma energy band (MeV)			Average energy (MeV)	Air dose (R)	Tissue dose (rads)	Phantom dose (rads)	Silicon dose (rads)
	Lower		Upper					
1	0.0200	to	0.0500	0.0350	5.925E-11	4.721E-11	1.174E-16	4.130E-10
2	0.0500	to	0.1000	0.0750	3.465E-11	3.203E-11	5.556E-13	9.750E-11
3	0.1000	to	0.2000	0.1500	7.195E-11	6.256E-11	1.651E-11	7.250E-11
4	0.2000	to	0.3000	0.2500	1.343E-10	1.226E-10	5.707E-11	1.170E-10
5	0.3000	to	0.4000	0.3500	1.956E-10	1.792E-10	9.800E-11	1.650E-10
6	0.4000	to	0.6000	0.5000	2.826E-10	2.601E-10	1.549E-10	2.370E-10
7	0.6000	to	0.8000	0.7000	3.912E-10	3.571E-10	2.267E-10	2.700E-10
8	0.8000	to	1.0000	0.9000	4.888E-10	4.462E-10	2.967E-10	4.100E-10
9	1.0000	to	1.3300	1.1650	6.045E-10	5.512E-10	3.874E-10	5.050E-10
10	1.3300	to	1.6600	1.4950	7.282E-10	6.647E-10	4.963E-10	6.100E-10
11	1.6600	to	2.0000	1.8300	8.392E-10	7.673E-10	6.008E-10	7.120E-10
12	2.0000	to	2.5000	2.2500	9.714E-10	8.838E-10	7.216E-10	8.400E-10
13	2.5000	to	3.0000	2.7500	1.122E-09	1.010E-09	8.502E-10	9.850E-10
14	3.0000	to	4.0000	3.5000	1.322E-09	1.181E-09	1.015E-09	1.200E-09
15	4.0000	to	5.0000	4.5000	1.568E-09	1.390E-09	1.191E-09	1.480E-09
16	5.0000	to	6.5000	5.7500	1.869E-09	1.644E-09	1.367E-09	1.830E-09
17	6.5000	to	8.0000	7.2500	2.215E-09	1.937E-09	1.546E-09	2.280E-09
18	8.0000	to	10.0000	9.0000	2.624E-09	2.258E-09	1.744E-09	2.800E-09

Table VII

TISSUE COMPOSITION

Element	Percent	Number density (atoms/g) x 10^{24}
H	10.00	0.05977
O	60.00	0.02259
C	24.00	0.01204
N	2.90	0.00125
Ca	1.20	0.177(-3)[a]
P	1.10	0.214(-3)
S	0.24	0.451(-3)
K	0.20	0.308(-4)
Na	0.20	0.524(-4)
Cl	0.20	0.340(-4)
Mg	0.03	0.743(-5)

[a](-n) represents (10^{-n}).

best cross-section data available in early 1969. However, differences between kerma values reported in the sets referenced above are not great over most of the energies of interest, amounting to 14 to 15 percent in the energy region above 10 MeV where such differences are most pronounced.

d. Neutron Phantom Midline or Gut Dose

The tissue dose discussed above represents the specific energy density in units of 100 ergs per gram, deposited by kinetic energy processes in an absorbing mass (in this case, tissue) so small that no sensible attenuation of the neutrons takes place and that no neutron makes more than a single collision--at most--in the mass. In the past this has frequently been referred to as "first-collision dose."

To provide the user with an estimate of the neutron dose to the gut of a man, SMAUG computes the mean tissue dose on the axis of a right circular cylinder of tissue 30 cm in diameter and 60 cm long. Such a phantom approximates the dimensions of a human torso without involving a welter of anthropomorphic detail.

The gut dose calculation is based on work by Auxier, Snyder, and Jones (Ref. 17), who used the ORNL 05R Monte Carlo computer code (Ref. 18) to calculate detailed neutron transport in a right circular cylinder of tissue of the dimensions given above. The cylinder was divided into 150 volume elements as shown in figure 6. The irradiating neutron beam was assumed to be uniform in intensity, monoenergetic, and directed as shown in figure 6. The mean dose in each volume element, including the dose from the $H^{1}(n,\gamma)H^{2}$ reaction, was computed per neutron per square centimeter for each neutron energy. Fourteen neutron energies ranging from 0.025 eV to 14 MeV were used.

The central cylinder, or gut, dose is not explicitly given in reference 17. To obtain such values for use by SMAUG, the mean dose in elements 1, 2, 3, and 4 of layer 3 of the phantom was computed, giving double weight to the

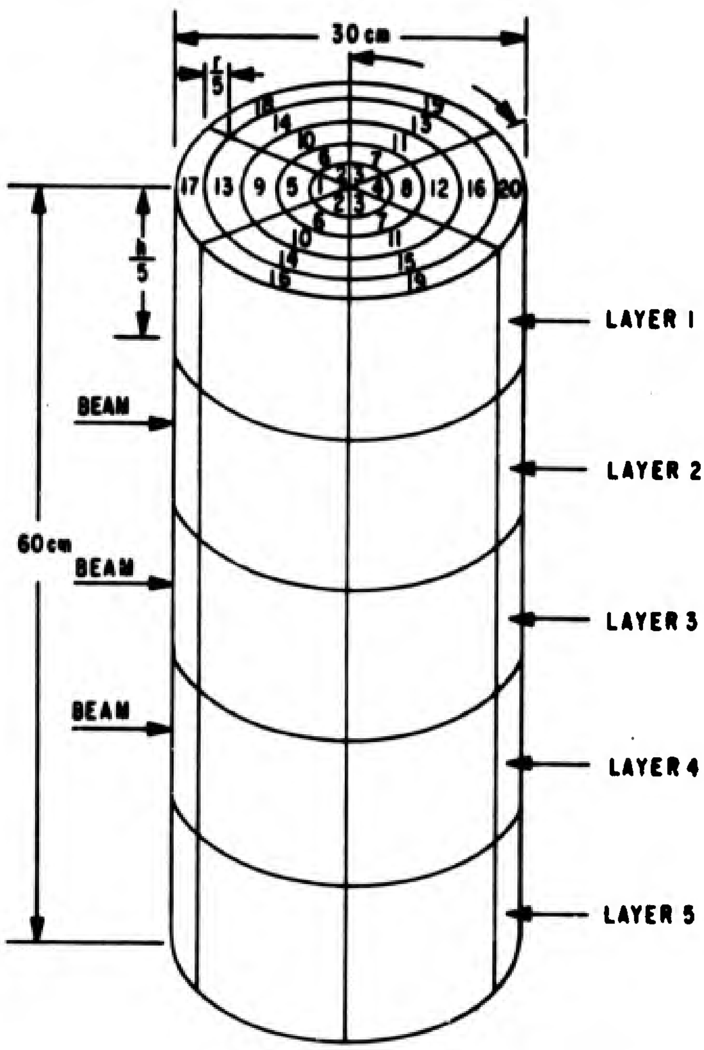

Figure 6. Phantom Geometry

symmetrically duplicated elements 2 and 3. This was done for each of the 14 neutron energies. The resultant data set was smoothed by fitting a fifth-order least-squares polynomial to the logarithm of the dose values as a function of logarithm of the neutron energy. The dose values given in table V were obtained by evaluating the polynomial for the SMAUG receiver band mean energies.

The smoothing polynomial used was

$$D(E) = \exp\left(a + bZ + cZ^2 + dZ^3 + eZ^4 + fZ^5\right) \qquad (16)$$

where

D(E) is the rad dose per unit fluence, evaluated at neutron energy, E MeV

Z is the natural logarithm of the neutron energy

a = -2.15333641E+01

b = 7.51236993E-01

c = 1.03569765E-01

d = 1.71455644E-03

e = -3.96747677E-04

f = -1.55681609E-05

e. Neutron Silicon Dose

The neutron silicon dose conversion factors given in table V are taken from table 4 in reference 8 and represent the total silicon dose, consisting of the sum of the ionizing and the nonionizing doses (see Ref. 19). Note that the contribution to the silicon dose from neutrons in the lower energy bands is assumed to be zero.

f. One-MeV Silicon Equivalent Neutron Fluence

The 1-MeV silicon equivalent neutron fluence purports to be the 1-MeV monoenergetic neutron fluence which will produce the same amount of permanent damage in silicon as the given polyenergetic neutron fluence. In some respects, this dose unit is similar to the "rem" dose unit formerly popular in reporting the results of nuclear radiation on biological materials.

The values shown in table V are derived from the ratio of the "1-MeV(S)" values to the fluence values given on page 17 of reference 20, which reports work using the same neutron receiver bands as are used by SMAUG. The ratios are based on Stein's measurements, reported in reference 21, which appear to yield a better estimate of equivalent damage in silicon than does Messenger's equation developed in reference 22.

g. Gamma Energy Fluence

The gamma energy fluence is computed by summing the product of the photon fluence (including both direct and secondary gammas) times the mean energy of the 18 receiver bands. The unit for gamma energy fluence is MeV/cm^2.

h. Gamma Mean Energy

The gamma mean energy is calculated by dividing the gamma energy fluence by the total photon fluence summed over the 18 receiver bands.

i. Gamma Tissue Dose

The gamma tissue dose calculation is based on the use of photon fluence-to-tissue dose factors given in table A-2 of NBS Handbook 75 (Ref. 14). The values used by SMAUG were obtained by performing four-point Lagrangian interpolation of that set of data. The dose is calculated in units of rads (tissue).

j. Gamma Phantom Midline or Gut Dose

To provide the user with an estimate of the gut dose resulting from a gamma exposure, SMAUG computes the mean tissue dose on the axis of the same cylindrical phantom as was used for the neutron gut dose calculation (figure 6).

The gamma calculation is based on the work of Richard W. Enz of the Air Force Weapons Laboratory, reported in reference 23, who used the SAMC Monte Carlo computer code described in references 24 and 25, to calculate the mean gamma dose per unit fluence for 11 monoenergetic gamma source energies, using the same geometry and volume elements as was used for Auxier's neutron calculations (figure 6). The gamma energies ranged from 0.1 to 10 MeV.

The gut dose was calculated by computing the weighted mean of the doses in elements 1, 2, 3, and 4 of layer 3, giving double weight to elements 2 and 3 and using reciprocal-variance statistical weighting to account for the relative error in the dose value calculated for each element. This was done for each of the 11 gamma energies. The resultant data set was smoothed by fitting a fifth-order least-squares polynomial to the logarithm of the dose as a function of the logarithm of the gamma energy, using reciprocal-variance statistical weighting in the fit. The dose values given in table VI were obtained by evaluating the polynomial for the SMAUG receiver and energies.

The smoothing polynomial used was

$$D(E) = \exp\,(a + bZ + cZ^2 + dZ^3 + eZ^4 + fZ^5) \qquad (17)$$

where

D(E) is the rad dose per unit photon fluence, evaluated at gamma energy, E, MeV

Z is the natural logarithm of the gamma energy

a = -2.18283865E+01

b = 1.03749623E+00

c = -6.82357453E-02

d = -1.08026000E-02

e = -3.90440527E-02

f = 1.43658019E-02

k. Gamma Air Ionization Dose

The gamma air ionization dose, in Roentgens, is computed by SMAUG so that the user can compare the tissue dose in rads with the older dose unit of Roentgens. The Roentgen is defined as that amount of X or gamma radiation which results in 1 esu of ions of either sign in 1.293 mg of air, and thus is a direct measure of the ionization of air resulting from a gamma fluence.

The Roentgen conversion factors shown in table VI are based on four-point Lagrangian interpolation of tabular data presented in reference 26.

l. Gamma Silicon Dose

The gamma silicon dose conversion factors given in table VI are taken from table 5 in reference 8.

m. Neutron Plus Gamma Tissue Dose

The total tissue dose is the arithmetic sum of the neutron tissue dose and the gamma tissue dose. No weighting of any kind has been done to account for possible differences in biological effectiveness of the radiations, and thus the value represents the total energy density in tissue resulting from the irradiation.

n. Neutron Plus Gamma Phantom Midline Dose

The total phantom midline dose is the arithmetic sum of the neutron and the gamma phantom midline doses, with no weighting applied to account for possible differences in biological effectiveness of the radiations.

o. Neutron Plus Gamma Silicon Dose

The total silicon dose is the sum of the neutron and the gamma silicon dose, with no weighting to account for possible differences in damage effectiveness of the radiations.

SECTION III

PROGRAM STRUCTURE

Program SMAUG is written entirely in ANSI FORTRAN (Ref. 1) and consists of the main routine, 15 subroutines, 5 function subroutines, and 9 BLOCK DATA routines. The code has been processed by the TIDY editing and resequencing code described in reference 27.

The program has a blank COMMON block of 539 words, and 14 labeled COMMON blocks whose length totals 5322 words. The total number of words in COMMON is, then, 5841 words. Communication between routines is done mainly through variables in blank COMMON rather than through the use of formal parameters. For the most part, the labeled COMMON blocks are used for constants loaded by the BLOCK DATA routines.

SMAUG input is assumed to consist of card images on Unit 5, output is written on Unit 6 and assumes a printer capable of accepting 120-character lines (including the control character). Only control characters 1 and (blank) are used. Page skipping and line counting are automatic.

Unit 1 is used only to load or save the information in the labeled COMMON blocks; this is done with the *LOAD or the *SAVE control cards described in reference 3.

Variable names have been chosen to have as high a mnemonic content as possible within the restrictions of FORTRAN implicit typing, a maximum of six characters in names, and the limits of human ingenuity. Variables in COMMON blocks have the further convention of having a minimum of three characters in their names. Logical variables, used as flags in SMAUG, start with the character "Q".

To preserve machine independence and to accomodate computers with short word size, all Hollerith character input has been limited to a maximum of four bytes per word. No assumptions are made as to the internal representations of such characters or bytes; however, the code does assume that characters can be matched by subtracting one word from another in the integer mode and testing for equality.

Comment cards have been used liberally within the program to explain the purpose of each routine and to document the major portions of each routine.

Although a source listing of the SMAUG program is not a part of this report nor reference 3, such a listing may be obtained upon request from the author of this report.

1. SMAUG, THE MAIN PROGRAM

The SMAUG main program contains and defines the major COMMON blocks, reads all input cards, and serves as an executive routine which calls other routines. A general outline of the main program follows.

At the start SMAUG sets all flags to their normal values and sets the maximum areal density, GMXX, to twice the maximum extrapolation point for the neutron, the gamma, or the secondary gamma calculations. The normal options, set at this point, are given in table VIII.

Table VIII

NORMAL OPTIONS SET ON INITIALIZATION

Flag	Value	Option
QDOT	FALSE	Do not perform peak gamma dose rate calculation
QEXEC	FALSE	Subroutine EXEC is not currently in control
QLST	TRUE	List input neutron and gamma source spectra
QPRG	TRUE	Print detailed gamma receiver spectra
QPRN	TRUE	Print detailed neutron receiver spectra
QRUN	FALSE	Do not accept receiver points; source spectra not yet defined
QTRAP	FALSE	A recursive call to subroutine CONTRL from EXEC has not been made
CDIST	1.0	Distance units in the output shall be labeled in meters
ALTMAX	50000.	Maximum altitude processed shall be 50,000 meters (not alterable by control cards)

As soon as execution gets under way, SMAUG checks one word in the last COMMON block to verify that the blocks have been loaded by BLOCK DATA routines; if they have not, SMAUG automatically calls the DATIO subroutines to load the blocks from Unit 1.

SMAUG then reads the name, or caption of the job, and tests the first four characters for "*LAS" or "*STO". If either are found, SMAUG stops; otherwise, SMAUG proceeds to read the neutron source spectrum control card.

When SMAUG reads the neutron source spectrum control card, it prints the card image and calls Subroutine CONTRL to check for the presence of a control card. CONTRL examines the card and returns a value, KON, containing a number ranging from 1 to 9, depending on the results of the scan. SMAUG then executes a multiway GO TO statement based on KON.

The nine values of KON and their meanings are given in table IX. Note that once Subroutine CONTRL identifies a control card, it ignores characters punched after the essential characters; thus a "*USE FI" control card might be punched "*USE FISSION SPECTRUM NEUTRONS."

Table IX

INTERPRETATION OF VALUES RETURNED BY SUBROUTINE CONTRL

Value	Interpretation
1	Card scanned was not a control card
2	Card scanned read: "*USEFI . . . "
3	Card scanned read: "*USETN . . . "
4	Card scanned read: "*READ . . . "
5	Card scanned read: "*DITTO . . . "
6	Card scanned read: "*GO . . . "
7	Card scanned read: "*LAST . . . "
8	Card scanned read: "*STOP . . . "
9	Card scanned was a control card directly executed by Subroutine CONTRL, such as setting or clearing a flag or calling a special routine such as CONTOR

If the control value, KON, is 2 or 3, SMAUG uses internal fission or thermonuclear neutron spectra taken from reference 8.

A typical fast neutron yield of 2.5×10^{23} neutrons per kiloton is used for the fission neutron source spectrum. This value is based on 1.45×10^{23} fissions per kiloton from reference 28 and a value of 2.75 neutrons per fission taken as the mean of 2.52 for U^{235} and 2.98 for Pu^{239} from reference 29. The mean leakage rate, accounting for the one neutron needed to sustain the chain reaction, is 2.75 - 1 = 1.75 neutrons per fission. This value should be reasonably accurate for critical assemblies, but is likely to be high for actual devices since this derivation does not account for neutron attenuation in materials around the fissioning assembly.

For the thermonuclear source, a typical neutron yield of 8.5×10^{23} neutrons per fusion kiloton is used for the source spectrum. This is based on 1.45×10^{24} neutrons per kiloton from reference 30 and an assumed fission fraction of 0.5 from reference 31.

If the control card value, KON, is 4, the neutron source spectrum is read from the next two cards, using the translating routine, VALUE.

If the control card value, KON, is 5, SMAUG checks to see if a neutron source spectrum is already loaded (from a previous calculation). If a spectrum is loaded, SMAUG goes on to read the next instruction; if not, SMAUG uses the fission source spectrum.

If the control card value, KON, is 6, 7, 8, or 9, SMAUG takes action appropriate to the particular control card.

Once the neutron spectrum has been loaded, SMAUG reads the prompt gamma source spectrum in essentially the same way.

Based on information presented in reference 32, the prompt photon yield for a fission source is assumed to be 2.9×10^{22} photons per fission emitted with a normalized spectrum given by

$$dN/dE(E) = 1.1\ e^{-1.1E} \text{ photons/MeV} \qquad (18)$$

or in absolute form

$$dN/dE(E) = 3.2 \cdot 10^{22}\ e^{-1.1E} \text{ photons/(MeV-kiloton)} \qquad (19)$$

where in both cases the energy, E, is in MeV.

The thermonuclear prompt photon source spectrum is assumed to bave the same shape as the fission prompt gamma spectrum with a photon yield of half that of the fission photon yield, namely 1.45×10^{22} photons per kiloton. This assumes that half the yield of a thermonuclear source comes from fission and that fusion reactions do not result in prompt gammas.

If "*DITTO" is specified for the gamma prompt source and no source has been loaded, SMAUG uses the fission source prompt gamma source.

If "*READ" is encountered, the prompt gamma source is read from the next two cards.

Once the gamma source is specified, SMAUG reads another card, checks it for the presence of a control phrase and--if it is not a control card--uses the VALUE routine to translate the first 10 columns into burst yield, in kilotons, and the second 10 columns into burst altitude, in meters.

If the burst altitude is outside the acceptable range of -5000 to +50,000 meters, or if an asterisk appears in column 11 of this card, SMAUG sets the burst altitude to the maximum altitude for appreciable local fallout as given by equation 2.118.1 on page 77 of reference 28.

$$H(\text{maximum for local fallout}) = 54.86W^{0.4} \text{ meters} \qquad (20)$$

where W is the burst yield in kilotons.

If the burst yield is zero, SMAUG assumes a yield of 1 kiloton detonated at 10,000 meters altitude.

Once SMAUG has a burst yield and altitude, it is ready to accept and process receiver point cards, and these cards are read next.

Each receiver point card is read and immediately checked by the CONTROL routine to detect and process possible control cards. If a control card is found, it is processed and another receiver card is read. If a *LAST card is read, SMAUG recycles to the beginning. If a *STOP card is read, SMAUG stops.

If the card is a receiver point specification, consisting of ground range in the first 10 columns and receiver altitude in the next 10 columns, a check is made for an "S" in column 1. If an "S" is found, the range is interpreted as slant range and the ground range is calculated by the Pythagorian Theorum.

SMAUG then calculates the areal density between the source and the receiver by means of subroutine function GMCMF. If the areal density is less than 0.1 g/cm^2, or if the slant range is less than the radius of the fireball for a sea-level detonation, SMAUG writes an advisory message and rejects the problem as calling for a receiver point too close to the source. The fireball radius, from equation 2.117.1 on page 77 of reference 28, is

$$R = 33.53W^{0.4} \text{ meters} \tag{21}$$

where W is the yield in kilotons.

If the areal density and slant range are sufficient, SMAUG calls the KERNEL routine to perform the necessary transport calculations and then the QUTPUT routine to print the results. SMAUG then loops to read another receiver point card.

2. SUBROUTINE QUTPUT

QUTPUT prints the results of a receiver point calculation, either as a result of a receiver point read by the SMAUG main program or as the result of an implicit receiver point generated by the FXTALT or FXTRAN routines.

QUTPUT computes the cumulative and normalized dose values from the neutron and gamma spectra calculated in subroutine KERNEL.

QUTPUT first prints the one-page summary output and then, depending on the QPRN and QPRG control flags, prints the detailed neutron and gamma outputs.

If the areal density exceeds the maximum value of GMXX (currently 600 g/cm^2), QUTPUT will abort printing dose values after printing a diagnostic message.

3. SUBROUTINES FXTALT, FXTRAN, AND CONTOR

These routines search for the point, or points, in the vicinity of a burst where, under user-specified constraints, certain dose values occur.

FXTALT locates the range, if any, at which a given dose occurs at a fixed altitude.

FXTRAN locates the altitudes, if any, at which a given dose occurs at a fixed range.

CONTOR computes the points around a burst in 10-degree increments at which a given dose occurs.

All three routines are executed as control card options. The control cards have the following format, where the asterisk is required to be in the first column while the remaining characters may appear anywhere on the card:

*ALTITUDE = *Alt* (*Mode*, *Dose*)

*RANGE = *Range* (*Mode*, *Dose*)

*CONTOUR = (*Mode*, *Dose*)

where

Alt is the receiver altitude constraint

Range is the receiver range constraint

Mode is the dose code from table X

Dose is the dose value constraint

Table X

DOSE MODES

Mode	Dose selected
1	Neutron fluence (n/cm^2)
2	Gamma fluence (photons/cm^2)
3	Neutron tissue dose (rads)
4	Gamma tissue dose (rads)
5	Neutron plus gamma tissue dose (rads)
6	Neutron silicon dose (rads)
7	Gamma silicon dose (rads)
8	Neutron plus gamma silicon dose (rads)
9	1-MeV silicon equivalent neutron fluence (n/cm^2)
10	Peak prompt gamma dose rate (rads(Si)/second)*
11	Peak prompt gamma dose rate (Roentgens/second)*
12	Neutron midline tissue dose (rads)
13	Gamma midline tissue dose (rads)
14	Neutron plus gamma midline tissue dose (rads)

*Requires prior use of *GAMMA DOT control card option.

On being called, both FXALT and FXTRAN scan the control card for the character "=", after which the altitude or range constraint is read by a call to the VALUE routine. The routines then scan the control card for the character "(", get the mode number by a second call to VALUE, scan for the character ",", and get the dose by a third call to VALUE.

Subroutine CONTOR similarly scans the control card looking for the mode and dose value.

Once the necessary parameters have been acquired from the calling control card, the dose value is located through application of the regula falsi iteration algorithm described in reference 33. This technique is used for inverse evaluation of an arbitrary function to obtain the argument for which the function has a particular value. The function is evaluated for two arbitrary arguments and inverse-interpolation is performed to obtain a new argument for which the function more nearly approximates the desired value. The above calculation is repeated, using the new result and one of the previous values, to obtain a better result, and the process is repeated again and again until the desired result is obtained to a sufficient degree of accuracy. For example, if one wishes to calculate the argument, x_0, for which the function F(x) takes on value Z, the function is evaluated at arbitrary arguments x_1 and x_2, and a better approximation for x_0 is calculated by

$$x_0^* = x_1 + (x_2 - x_1)\,(Z - F(x_1))/(F(x_2) - F(x_1)) \qquad (22)$$

The value obtained for x_0^* is then substituted for either x_1 or x_2, depending on which value is the poorer estimation of the solution, and equation (22) is re-solved for a new value of x_0^*. This process is repeated again and again until the process has converged to a value of x_0^* for which the corresponding function, $F(x_0^*)$ approximates the value Z to the required degree of accuracy.

The routine in SMAUG which corresponds to the function, F(x), is DXMOD, which calculates the dose corresponding to the current receiver position, according to the current value of MODE, and returns the result in the variable, DRX.

A trivial variation of the above outlined iteration technique is used by FXTALT, FXTRAN, and CONTOR, in which the logarithm is taken of the slant range and the dose, and iteration is performed for the logarithm of the distance. This is done to increase the speed of the iteration process, and is based on the observation that, over short distances, a log-log plot of dose as a function of distance is nearly linear.

The initial slant range tried for these routines is selected according to the following empiric rules: (1) the slant range must not be less than the minimum slant range implied by the range or altitude constraints; (2) the slant range should correspond to an areal density of approximately 10g/cm^2; (3) the slant range should not exceed 1000 meters. If ΔR and ΔH are the minimum slant ranges imposed by the range or altitude constraints, and if R_{10} is the slant range corresponding to an areal density of 10 g/cm^2, then the first slant range tried by the FXTALT routine is

$$R1 = \max(\Delta H, \min(R_{10},1000)) \text{ meters} \tag{23}$$

The first slant range tried by the FXTRAN routine is

$$R1 = \max(\Delta R, \min(R_{10},1000)) \text{ meters} \tag{24}$$

The first slant range tried by the CONTOR routine is

$$R1 = \min(R_{10},1000) \text{ meters} \tag{25}$$

CONTOR performs calculations for receiver points in 10-degree increments around the burst point. For the first calculation the receiver point is assumed to be directly above the burst point.

FXTRAN problems generally have two solutions, one for the receiver at an altitude above the burst altitude, and one for the receiver at an altitude below the burst altitude. For the first calculation, the receiver is assumed to be at the higher altitude.

For all three routines, increasing slant ranges are tried until a slant range is found which corresponds to a dose value which is less than the desired dose. At this point in the calculation the desired slant range is between the most recent slant range tried and its immediate predecessor. When this occurs, the desired slant range is located by application of the _regula falsi_ algorithm, iterating until the natural logarithm of the dose differs from the logarithm of the desired dose by less than one part in 256 (a relative error of approximately 0.4 percent), or until a maximum of 64 iterations have been performed.

Once the desired receiver point has been located, FXTALT and FXTRAN call the QUTPUT routine to print the results. After the call to QUTPUT, FXTALT returns control to the calling routine, CONTRL. Because of the bi-valued solution implied in the fixed range constraint, FXTRAN repeats the iterative calculations for the lower receiver altitude, providing that altitude is above sea level, and makes a second call to QUTPUT before returning to CONTRL.

Subroutine CONTOR prints the results for the receiver point directly above the burst and then repeats the iterative calculation for a receiver point whose angular position, relative to the burst point, is 10 degrees lower than the previous point. For each point, after the first, the starting slant range is the previous slant range computed by the iteration algorithm. In this way, successive receiver points are located at the expense of only one or two iterations.

4. SUBROUTINE DXMOD

This routine computes the dose according to the current value of MODE for the current receiver position and returns the result in DRX, where both MODE and DRX are contained in the blank COMMON block. The 14 dose modes and their dose interpretation are given in table X.

DXMOD calls the KERNEL routine to evaluate the neutron and gamma receiver spectra, and then applies the appropriate dose conversion factors to compute DRX. DXMOD returns with DRX set to zero if MODE is outside the range of 1 to 14.

5. SUBROUTINE KERNEL

This routine computes the neutron spectrum, the prompt gamma spectrum, the secondary gamma spectrum, and the combined prompt and secondary gamma spectrum for a source-receiver combination in which the burst yield, the neutron source spectrum, the prompt gamma source spectrum, the slant range, and the areal density are given.

Upon being called, KERNEL clears the neutron and the gamma receiver spectra to zero, computes a scaling factor, SCRR, which accounts for the burst yield and for the spherical divergence of the sources, and loads the six-word vector, RXG, with functions of the areal density corresponding to the terms of the transmission function. If X is the areal density in g/cm^2, the six terms of RXG are

RXG(1) = SLR (slant range; this word is not used in calculation of the transmission function)

RXG(2) = X

RXG(3) = X^2

RXG(4) = $X^{3/2}$

RXG(5) = $X^{1/2}$

RXG(6) = $X^{1/3}$

Since the above terms are used repeatedly in calculation of the transmission functions implicit in a single call to KERNEL, precalculation of the terms results in a significant saving in computer time.

If the areal density, GMGM2, is less than the extrapolation point, GMXG, the prompt gammas in each of the 18 gamma receiver bands resulting from gammas in each of the 10 gamma source bands are computed by the following 10 lines of FORTRAN coding:

```
   DO 7 K=1,10
   IF (SORG(K)) 7,7,4
4  JM=NCGG(K)
   DO 6 J=1,JM
   SUM=CONGG(1,J,K)
   DO 5 I=2,6
   IF (CONGG(I,J,K)) 5,6,5
5  SUM=SUM+RXG(I)*CONGG(I,J,K)
6  FLUXGG(J)=FLUXGG(J)+SORG(K)*SCRR*EXP(SUM)
7  CONTINUE
```

where

SORG(K) is the Kth prompt gamma source term

JM is the number of transmission functions associated with the Kth source term

CONGG(I,J,K) is the three-dimensional array containing the coefficients for the prompt gamma transmission functions

FLUXGG(J) is the Jth prompt gamma receiver band

Two things should be noted in the above coding. First, the simple coding that results through the use of the vector, RXG, rather than explicit coding of the powers of the areal density. Second, the prompt gamma fluence is accumulated in the array, FLUXGG(J), thus making the initial zeroing of this array essential.

The neutron and neutron-induced secondary gamma fluence calculations are performed in similar ways, with both calculations nested in a single DO-loop over each of the nine neutron source terms.

If the areal density, GMCM2, is greater than the gamma extrapolation point, GMXG, the gamma fluence in each of the 18 gamma receiver bands resulting from gammas in the 10 source bands is performed by linear extrapolation by the following eight lines of FORTRAN coding:

```
15   DX=GMCM2-GMXG
     DO 18 K=1,10
     IF (SORG(K)) 18,18,16
16   JM=NCGG(K)
     DO 17 J=1,JM
     SUM=FUNGG(J,K)+DX*DFXGG(J,K)
17   FLUXGG(J)=FLUXGG(J)+SORG(K)*SCRR*EXP(SUM)
18   CONTINUE
```

where

FUNGG(J,K) is the value of the transmission function for source band K and receiver band J, evaluated at GMXG g/cm^2

DFXGG(J,K) is the value of the first derivative of the transmission function for source band K and receiver band J, evaluated at GMXG g/cm^2

The neutron and secondary gamma calculations involving extrapolation are performed in similar ways, with both calculations nested in a single DO-loop.

6. SUBROUTINE SMERT

This routine calculates the direct and the scattered peak gamma dose rates, based on information supplied by the user through the *GAMMA DOT control card described in reference 3.

The calculations are carried out using two dose units, Roentgens per second and rads(silicon) per second. The Roentgen dose rate information is returned in the four-wood array, DOTR; the rads(Si) dose rate is returned in the four-word array, DOTS. The contents of each of the words in the arrays is described on the following page.

Direct peak dose rates are computed by simple exponential attenuation, using equation (13) of this report.

Roentgens/sec	Rads(Si)/sec	Contents
DOTR(1)	DOTS(1)	Direct peak dose rate
DOTR(2)	DOTS(2)	Scattered peak dose rate
DOTR(3)	DOTS(3)	Total peak dose rate
DOTR(4)	DOTS(4)	Percent of total peak dose rate from scattered

Scattered peak dose rates are computed by means of a series of transmission functions fit to scattered (Roentgens/second and rads(Si)/second) data generated by Monte Carlo calculations. The results of the scattered calculations are then scaled by application of equation (14) and the results combined in the four-word arrays.

7. SUBROUTINE CONTRL

This routine scans input card images previously read into the 80-character array, KARD, for control card statements and sets and clears flags or calls other routines, based on such cards.

SMAUG control cards contain an asterisk in column one, followed by a succession of characters with or without intermixed blank characters. The 24 control cards recognized by SMAUG are listed in table XI. The use and effects of these control cards is described in reference 3.

CONTRL is called with a single argument, KON, which is used to return to the calling routine the result of CONTRL's analysis. Table IX contains the interpretation of each of the nine values of KON returned by CONTRL.

Control card scanning is commenced by checking for the mandatory asterisk in column 1; if one is not present, the card cannot be a control card and CONTRL returns with KON set equal to 1.

If an asterisk is found in column 1 of the card, CONTRL tentatively assumes that the card contains a control phrase and attempts to match the card contents, character by character, ignoring blanks, with the characters of the 24 control phrases. If a match is not found, CONTRL returns with KON set to 9, causing SMAUG to ignore the unrecognizable card and its contents.

Table XI

SMAUG CONTROL CARDS**

*ALTITUDE=
*CALL EXEC
*CONTOUR(
*DITTO
*DO NOT LIST
*DO NOT PRINT Gamma
*DO NOT PRINT Neutron
*GAMMA DOT (
*GO
*LAST
*LIST
*LOAD (
*PRINT All
*PRINT Gamma
*PRINT Neutron
*PRINT Summary only
*RANGE=
*READ
*SAVE (
*STOP
*UNIT=
*UNITS=
*USE FIssion spectrum
*USE TN spectrum

**Lower-case letters are nulls and are not required as part of the control card.

If a match is made with a control card phrase and the phrase is one of the first seven scanned for which no action on CONTRL's part is required, CONTRL returns with KON set to the phrase number plus one (i.e., KON is in the range of 2 through 8, inclusive). If the match is with a phrase after the first seven, CONTRL executes a 17-way GO TO statement and branches to individual processing of the control cards, which may involve the setting of or clearing of logical flags, or which may cause CONTRL to call other routines such as FXTALT, FXTRAN, or CONTOR. In all cases, CONTRL returns with KON set at 9.

One control card, CALL EXEC, deserves special mention. This card causes the CONTRL routine to execute a call to subroutine EXEC, a dummy routine provided to enable the user to write his own specialized routines. Since EXEC is called from CONTRL, the subroutine return linkage is normally from EXEC to CONTRL to SMAUG's main program, which is the only routine that calls CONTRL. If, however, the user-supplied EXEC routine should call CONTRL, the return linkage would be destroyed, causing an endless loop in which EXEC would return to CONTRL, which would return to EXEC, which would return to CONTRL, ...

To prevent such a disaster, CONTRL sets a flag, QEXC, on calling EXEC, and clears the flag after EXEC returns. Each time CONTRL is called, it sets another flag, QTRAP, to the logical value of QEXC. Thus, if CONTRL is called directly or indirectly while EXEC is in control, QTRAP will be set to a logical value, TRUE. QTRAP is tested each time EXEC returns to CONTRL; if QTRAP is TRUE, an endless loop has been detected and CONTRL aborts with the following message:

> "RECURSIVE CALL TO SUBROUTINE CONTROL BY SUBROUTINE EXEC TRAPPED.
> BECAUSE OF THIS CALL, SUBROUTINE CONTROL CANNOT RETURN PROPERLY
> TO THE MAIN PROGRAM WITHOUT BECOMING CAUGHT IN AN ENDLESS LOOP.
> FURTHER COMPUTATION IS ABORTED AT THIS POINT."

8. FUNCTION CUBRT

CUBRT is a general purpose cube-root function which accepts positive or negative arguments.

The cube root of the argument, X, is approximated by

$$y = \exp\left(\ell n|X|/3\right) \tag{26}$$

Although exact mathematically, equation (26) is only approximate when executed on a digital computer as a result of the compounding of the approximations involved in the exponential and natural logarithm calculations. However, equation (26) results in an excellent first approximation and one Newton-Raphson iteration suffices to compute the magnitude of the cube root.

$$\left|\sqrt[3]{X}\right| = 1/3\left(2y + \frac{|X|}{y^2}\right) \tag{27}$$

CUBRT returns with the sign of the argument attached to the result of equation (27).

Function CUBRT is an essential part of SMAUG since each transmission function calculation involves the cube root of the areal density.

9. FUNCTIONS GMCMF, RHQF, AND GINT

These routines are used to compute the areal density, in g/cm^2, between the burst point and the receiver point. GMCMF is the function called to compute the areal density, RHQF is an ancillary routine called by GMCMF, and GINT is a general—purpose integration function called by GMCMF. Areal density is defined as the mass of air in a cylinder whose base area is 1 square centimeter which extends from the burst point to the receiver point, and is computed by integrating the air density in the cylinder. The relative air density at any altitude is supplied by Function AIRDEN.

Referring to figure 7, the areal density between a point at altitude Z1 and another point at altitude Z2, separated by ground range R, is calculated by the following call to the GMCMF function:

GMCM2 = GMCMF(R,Z1,Z2)

Upon being called, GMCMF computes DZ as the difference between altitudes Z1 and Z2, DR as the distance between the two points, and DZDR as the quotient of DZ and DR. DZDR is the derivative of altitude with respect to position along the line connecting the two points. Z1 is assumed to be the base altitude, and the integration is performed along the line connecting the point at Z1 with the point at Z2. Both Z1 and DZDR are supplied Function RHQF by means of the labeled COMMON block, RHQFDA. (Z1 is copied to ZB in the COMMON block.)

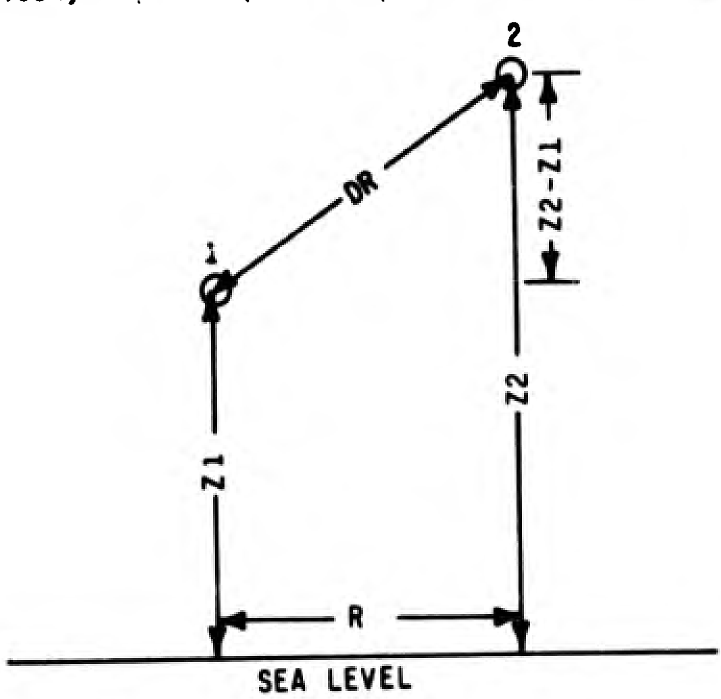

Figure 7. Calculation of Areal Density between Two Points

Function RHQF accepts a single argument, S, and computes the mass of air in a cylinder of base area 1 square centimeter and length 1 meter, where the cylinder is S meters from the point at altitude Z1 along the line connecting that point to the point at altitude Z2. Function RHQF consists of the following single executable FORTRAN statement:

```
RHQF = 0.12250*AIRDEN(ZB+S*DZDR)
```

The constant, 0.12250, is the mass of air in a 1-meter cylinder at sea level, assuming a standard air density of 1.225 mg/cm^3 from reference 34. AIRDEN computes the relative air density corresponding to the altitude (in meters) furnished as an argument.

Function GMCMF integrates Function RHQF along the line connecting the two points by passing RHQF as an EXTERNAL argument to the general purpose integration routine, GINT. The FORTRAN statement which does this is

```
GMCMF = GINT(RHQF,0.0,DR)
```

Function GINT performs 12-point Gauss-Legendre quadrature of the function supplied as the first argument (in this case, RHQF) over the range specified by the second and third arguments. The integration is carried out by forming the weighted sum of the function evaluated at 12 points over the integration range, and is much more accurate than either Simpson's Rule or trapezoidal integration over 12 increments.(Ref. 35). During the development of the SMAUG program, Gauss-Legendre quadrature using from 2 to 48 sample points for the computation of areal density was tested for a wide range of source and receiver altitude combinations. No significant improvement in accuracy was found when more than 12 sample points were used.

For co-altitude cases, GMCMF computes the areal density by the following simple FORTRAN statement:

```
GMCMF = 0.1225*DR*AIRDEN(ZB)
```

10. FUNCTION AIRDEN

Function AIRDEN accepts an altitude in meters above mean sea level and computes the relative air density at that altitude, based on equations and definitions of the standard atmosphere given in reference 34, the U.S. Standard Atmosphere, 1962. AIRDEN is valid for altitudes ranging from -5000 to +700,000 meters.

For altitudes between -5000 meters and sea level, AIRDEN uses the following cubic minimax polynomial expression which was fit by the author to tabular data in reference 39:

$$\rho/\rho_0 = \exp\,(c_0 + c_1 Z + c_2 Z^2 + c_3 Z^3) \tag{28}$$

where

Z is the altitude in meters

$c_0 = 1.25885682\text{E-}06$

$c_1 = -9.59950828\text{E-}05$

$c_2 = -1.06016969\text{E-}09$

$c_3 = -1.35266259\text{E-}14$

For altitudes above sea level, the relative air density is based on a computation of the air pressure, where the relative air density is related to the pressure by the following expression

$$\rho/\rho_0 = \left(\frac{M_0}{\rho_0 R^*}\right) = \frac{P}{T_M} \tag{29}$$

where

M_0 is the standard molecular weight of the atmosphere (28.9644 kilograms per kilogram-mole)

ρ_0 is the sea level air density (1.2550 kilograms per cubic meter)

R^* is the gas constant (8.31432 joules per °K per kilogram-mole)

P is the air pressure in Newtons per square meter

T_M is the molecular-scale temperature

Table I.4(e) of the U.S. Standard Atmosphere, 1962 lists 23 atmospheric-defining altitudes, and the molecular-scale temperature, the temperature gradient in degrees Kelvin per kilometer, the molecular weight, and the kinetic temperature for these altitudes. Other tables give the base pressure at these defining altitudes.

Function AIRDEN contains these defining values in tabular form and computes pressure values for these and intermediate values through the use of equations 1.2.10(1), 1.2.10(2), 1.2.10(5), and 1.2.10(6) of reference 39.

11. SUBROUTINES METRIC AND TIMUNT

These routines scan an input card image to detect whether a suffix has been appended to a numeric value to show that the value read is in nonstandard or nonmetric units. If a suffix is found, the routines convert the value read to a standard or metric unit. For example, if the receiver range is punched as "123F", the "F" following the numeric value would cause subroutine METRIC to convert the range from 123 feet to the equivalent value of 37.49 meters.

Subroutine METRIC scans for the following suffixes: "M", "F", and "Y", which are used to indicate units of meters, feet, and yards, respectively. Nonmetric inputs are converted to meters.

Subroutine TIMUNT scans for the following suffixes: "NS", "US", "MS", "S", or "SH" to indicate time values input in units of nanoseconds, microseconds, milliseconds, seconds, or shakes (10^{-8} seconds). All time units are converted to seconds.

12. SUBROUTINE VALUE

Except for data read by the DATIO routine, all SMAUG input is read as card images in the 80-word array, KARD, using a format of 80A1 which puts one BCD character in each word. Numeric information in these card images is translated by subroutine VALUE under rules much more liberal than those imposed by FORTRAN for numeric input using the "E", "F", or "I" input specifications. Because number translation is done in VALUE rather than a FORTRAN-supplied system routine, SMAUG will not abort as a result of mispunched input data.

If the 80-word array, KARD, contains a card image, the following call to VALUE will put the floating numeric value in columns 11 through 20 in X:

```
CALL VALUE (X,KARD(11),10)
```

The first argument tells VALUE where to put the result of the translation. The second argument tells where to start the scan and the third argument tells how many consecutive columns are to be scanned.

If the third argument is negative, VALUE returns an integer, otherwise VALUE returns a floating-point number. The following call to VALUE will put the integer value of the number in columns 1 through 5 in NSTAT:

```
CALL VALUE (NSTAT,KARD(1),-5)
```

The input rules for subroutine VALUE are

a. A number is defined as a collection of digits, with or without an embedded decimal point, preceded by an optional plus or minus sign and followed by an optional exponent. Leading blanks are ignored. Trailing blanks mark the end of the number.

b. Integer or floating-point conversion is set by the mode of the call to VALUE rather than by the form of the number. Decimal points and exponent fields are permitted for integer inputs; floating-point numbers are permitted which do not have decimal points.

c. If a plus or a minus sign follows digits in the numeric field, these signs are applied to the exponent of the number and mark the beginning of the exponent field.

d. Nonnumeric information in the numeric field stops the assembly of the number. If no number has been assembled at that point, a zero value is returned.

e. A single blank space is permitted in lieu of a plus sign following an "E" exponent indicator to conform with FORTRAN practice (e.g., "1.234E 05" or "1.234E 5" is treated as "1.234E+5").

Reference 3 contains a number of examples of inputs and the corresponding translation by VALUE.

A detailed description of the VALUE routine itself is not appropriate here; persons interested in the coding should study the well-commented FORTRAN source program. In general, VALUE scans the card image column by column, searching for certain characters by attempting to find matches between the characters and those contained in the card image. Numeric fields are assembled by comparing the characters in the card image array, KARD, with the digits (i.e., 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9) stored as BCD characters in the 10-word integer array, DIGIT. The following FORTRAN coding example demonstrates how a number, N, is compiled from columns KB through KM in the array KARD:

```
4  N = 0
   DO 6 K=KB,KM
   DO 5 J=1,10
   IF (KARD(K).EQ.DIGIT(J)) GO TO 6
5  CONTINUE
   GO TO 7
6  N = 10*N+J-1
7  CONTINUE
```

Note that if the DO loop on statement 5 fails to find a match between the character in KARD(K) and the characters in the BCD digit array, DIGIT, further scan is aborted and control is transferred to statement 7 with the results of the scan in N.

13. SUBROUTINE DIAGNO

This routine is called by other SMAUG routines with an integer argument in the range of 1 to 4 to print the most recently read card image and one of the following four commonly used diagnostic statements:

1. THE ABOVE CONTROL CARD CONTAINS EITHER AN ERROR IN SYNTAX OR AN ILLEGAL NUMERIC VALUE WHICH PREVENTS SMAUG FROM HONORING THE REQUEST. SMAUG IS PROCEEDING TO THE NEXT CARD.

2. THE ABOVE CONTROL CARD REQUESTS A DOSE VALUE WHICH CANNOT BE OBTAINED UNDER THE CONSTRAINTS IMPOSED BY THE PROBLEM.

   THE FOLLOWING OUTPUT IS OFFERED AS AN APPROXIMATION TO THE DESIRED PROBLEM.

3. THE DOSE VALUE REQUESTED BY THE ABOVE CONTROL CARD LIES BEYOND THE RANGE OF SMAUG VALIDITY.

   THE FOLLOWING OUTPUT IS OFFERED AS AN APPROXIMATION TO THE DESIRED PROBLEM.

4. THE ABOVE CONTROL CARD CANNOT BE HONORED SINCE THE SOURCE IS NOT YET FULLY DESCRIBED. SMAUG IS PROCEEDING TO THE NEXT CARD.

14. SUBROUTINE PAGE

PAGE is a utility routine which numbers and captions each page of SMAUG output and limits the number of printed lines on each page to 60.

PAGE is controlled by a single argument, N. If N is zero, PAGE checks to see if any information other than the page heading has been printed on the current page; if so, PAGE skips to a fresh page and captions and numbers it; otherwise PAGE simply returns. If N is 1 or greater, PAGE interprets the call to mean that N lines of output have been printed, checks to see if the page line limit has been reached or exceeded, and skips to a fresh page if necessary.

15. SUBROUTINE DATIO

SMAUG contains the capability of saving all information, loaded in labeled COMMON blocks by BLOCK DATA routines, on a selected tape unit by a control card, "*SAVE", as well as the capability of loading the labeled COMMON blocks from a tape unit by another control card, "*LOAD". Both these operations are performed in the DATIO subroutine.

The argument for DATIO determines whether a *SAVE or a *LOAD will be executed. If the argument is negative, a *SAVE will be executed; if the argument is zero, a *LOAD will be executed from the default unit (currently tape 1); if the argument is positive and nonzero, a *LOAD is executed.

For nonzero arguments, DATIO scans the control card for the unit number to be used, compares the unit number with a list of permitted unit numbers stored in the 10-word array L10 (currently limited to unit 1) and--if a match is found--proceeds to save or load the blocks.

If a match is not found during a save operation, DATIO generates a diagnostic message and returns to the calling routine without attempting the save operation. If no match is found during a load operation, DATIO generates a diagnostic message and aborts further computation by SMAUG.

When SMAUG starts execution, it checks to verify that the labeled COMMON blocks have been loaded by the BLOCK DATA routines. If it finds that the blocks are not loaded, it makes a call to DATIO with a zero argument which causes DATIO to generate a comment message and to attempt to load the blocks from tape unit 1.

16. SUBROUTINE EXEC

Subroutine EXEC is supplied as a dummy routine which may be expanded by the user to provide special computational capability in SMAUG.

Subroutine EXEC is called from subroutine CONTRL as a result of the *CALL EXEC control card.

Subroutine EXEC has access to all SMAUG routines; however, if EXEC calls the CONTRL routine, a flag will be set in CONTRL to prevent endless looping in the event EXEC attempts to execute a normal RETURN statement. If EXEC does call CONTRL, then EXEC should provide for terminating SMAUG.

17. THE BLOCK DATA ROUTINES

SMAUG contains nine separate BLOCK DATA routines which preload the labeled COMMON blocks with constants essential to the SMAUG calculations. Nine such routines were used instead of a single routine because it was found that the use of multiple BLOCK DATA routines resulted in a substantial reduction in the memory required to compile these routines by the RUN compiler on the AFWL CDC-6600 computer. The use of multiple BLOCK DATA routines does not appear to be prohibited by ANSI and--in fact--is implied by the wording of paragraph 8.5 of reference 1.

In those cases where it is not possible or practical to use BLOCK DATA, SMAUG can be run using DATIO to load the COMMON blocks automatically from tape unit 1.

Implicit equivalencing, which takes advantage of the fixed order of variable assignments in labeled COMMON blocks, has been done in the BLOCK DATA routines to permit the loading of multidimensioned arrays as a series of singly dimensioned equivalent arrays.

SECTION IV

INPUT DATA STRUCTURE

The input data requirements for SMAUG have been made as simple as possible for the user, even though this means that the internal coding in the program is made more complex. To ensure simplicity, an extensive set of control card options has been provided which permit the user to use internally stored "nominal" sources, to re-use previously defined sources, to execute iterative contouring calculations, or to print or suppress certain portions of the printed output. All user-supplied numerical information is translated by the VALUE routine which greatly relaxes the usual numeric input requirements associated with FORTRAN.

This section is not a full description of the input data requirements and capabilities of the SMAUG code; for that information the reader is referred to the SMAUG User's Guide (Ref. 3). A summary of the input data requirements and an example of an actual problem deck and its results follow.

Each SMAUG input data deck consists of one or more separate job decks.

Each job deck consists of a set of punched cards of which the first card is a job title card and the last card is a *LAST control card unless the job deck is the last one in the input data deck, in which case the last card is a *STOP control card.

Following the job title card, SMAUG expects the user to define the neutron source spectrum and the gamma source spectrum, in that order, through the use of the *READ, *USEFI, *USETN, or the *DITTO control cards.

Once the source spectra are defined, SMAUG expects the burst yield and burst altitude to be specified. The burst yield must be given in kilotons, the burst altitude is expected in meters, although a trailing F, Y, or M may be used to specify units of feet, yards, or meters at the user's option.

Following the burst yield and altitude specification, any number of receiver range-altitude cards may appear before a *LAST control card. The ground range is punched in the first 10 columns, the receiver altitude is punched in the second 10 columns. A trailing F, Y, or M may be used at the user's option to indicate inputs in feet, yards, or meters; otherwise, input is assumed to be in meters. An S punched in the first column of a range-altitude card will indicate that the value is slant range rather than ground range.

*ALTITUDE, *RANGE, and *CONTOUR control cards may be freely intermixed with range-altitude cards in this portion of the job deck.

All control cards except *READ, *USEFI, *USETN, *DITTO, *LIST, *NO LIST, and *GO may appear in this portion of the deck. The appearance of a *LAST or *STOP marks the end of the job deck.

The SMAUG control cards are listed in table XI. The use of the control cards is fully described in reference 3.

Figure 8 is an input deck for a typical SMAUG problem. The output resulting from this input deck is shown in figure 9.

```
KADATH TEST SITE DETONATION 37-KT AT 215 METERS.  (UNCLASSIFIED)
*READ (NEUTRON SOURCE SPECTRUM).
1.466+23  1.188+23  8.088+22  4.918+22  2.308+22  7.622+21  5.977+21  1.012+22
2.759+22
*READ (GAMMA SOURCE SPECTRUM).
2.085+21  3.540+21  4.044+21  2.907+21  3.146+21  1.815+21  1.651+21  7.326+20
8.118+19  9.742+18
37KT      215METERS
2000M     500M
*PRINT SUMMARY ONLY.
*ALTITUDE=500M(5,1000)
*CONTOUR(5,3000)
*STOP
```

Figure 8. Input Data Deck for a Typical SMAUG Problem

The first card of this deck contains the title "KADATH TEST SITE . . ." The title is used to caption the SMAUG printed output. SMAUG checks the title card for the presence of "*LAST" or "*STOP" in the first five columns; if either are found, SMAUG stops. Similarly, a blank title card will also cause SMAUG to stop. Otherwise, the contents of the card are ignored by SMAUG.

The next card is a *READ control card which causes SMAUG to read the neutron source spectrum from the next two cards. The source spectrum is read in terms of neutrons per kiloton with the nine neutron source terms read in order of ascending energy in fields of 10 columns each. The neutron source energy bands are given in table I.

The next card after the two neutron spectrum cards is another *READ control card which, because of its position in the input deck, causes SMAUG to read the gamma source spectrum from the next two cards. Like the neutron spectrum, the gamma source spectrum is read in units of prompt photons per kiloton in order of ascending energy. The 10 gamma source energy bands are given in table III.

Following the gamma source terms, the next card tells SMAUG that the source is a 37-kiloton detonation at an altitude of 215 meters above mean sea level. The "KT" following the yield is ignored by SMAUG, but the "M" following the burst altitude confirms that the input is in meters rather than yards or feet.

As the above information is read, SMAUG prints the card input together with commentary. The output for this example is given in figure 9. At this point SMAUG has all necessary source information and is ready to accept and process receiver range-altitude cards.

The next card specifies a receiver point at a ground range of 2000 meters and altitude 500 meters. The resulting SMAUG printout is shown on pages 57, 58, and 59. Page 57 is the summary page, page 58 is the detailed gamma output page, and page 59 is the detailed neutron output page.

The next card, *PRINT SUMMARY ONLY, is a SMAUG control card which limits further output to the summary page only.

The next card fixes the receiver altitude at an altitude of 500 meters and requests that SMAUG locate the ground range at which the mode 5 dose is 1000 rads. The dose modes are listed in table X. Mode 5 specifies neutron plus gamma tissue dose. Once the range is located, SMAUG acts just as if an ordinary receiver point card were read and prints the results of the calculation. Because in this example the *PRINT SUMMARY ONLY control card was used, only the summary page was printed. Page 60 is the resulting summary page.

The next card asks SMAUG to locate the isodose contours around the burst where the neutron plus gamma tissue dose (mode 5) is 3000 rads. The resulting contour printout is shown on page 61. SMAUG first locates the point directly overhead where the dose value is found, prints the results, and then proceeds in 10-degree increments around the burst point until either the point directly below the burst point has been calculated or until the next point would be below sea level.

The last card in this example, *STOP, terminates the input data set for this example and causes SMAUG to stop.

```
PAGE   1                                   *****   S M A U G   *****

KADATH TEST SITE DETONATION 37-KT AT 215 METERS.  {UNCLASSIFIED}

{*READ {NEUTRON SOURCE SPECTRUM}.                                                          }

NEUTRON SOURCE -  READ WITH INPUT DATA.

{1.446+23  1.188+23  8.088+22  4.918+22  2.308+22  7.622+21  5.977+21  1.012+22  }

{2.759+22                                                                          }

 1  3.3000E-03 TO  1.1100E-01 MEV.     1.4460E+23 NEUTRONS PER KILOTON.
 2  1.1100E-01 TO  1.1080E+00 MEV.     1.1880E+23 NEUTRONS PER KILOTON.
 3  1.1080E+00 TO  2.3500E+00 MEV.     8.0880E+22 NEUTRONS PER KILOTON.
 4  2.3500E+00 TO  4.0600E+00 MEV.     4.9180E+22 NEUTRONS PER KILOTON.
 5  4.0600E+00 TO  6.3600E+00 MEV.     2.3080E+22 NEUTRONS PER KILOTON.
 6  6.3600E+00 TO  8.1800E+00 MEV.     7.6220E+21 NEUTRONS PER KILOTON.
 7  8.1800E+00 TO  1.0000E+01 MEV.     5.9770E+21 NEUTRONS PER KILOTON.
 8  1.0000E+01 TO  1.2200E+01 MEV.     1.0120E+22 NEUTRONS PER KILOTON.
 9  1.2200E+01 TO  1.5000E+01 MEV.     2.7590E+22 NEUTRONS PER KILOTON.

{*READ {GAMMA SOURCE SPECTRUM}.                                                            }

{2.085+21  3.540+21  4.044+21  2.907+21  3.146+21  1.815+21  1.651+21  7.326+20  }

{8.118+19  9.742+18                                                                }

GAMMA SOURCE -  READ WITH INPUT DATA.

 1    0.10 TO    0.20 MEV.  2.0850E+21 GAMMAS PER KILOTON.
 2    0.20 TO    0.40 MEV.  3.5400E+21 GAMMAS PER KILOTON.
 3    0.40 TO    0.70 MEV.  4.0440E+21 GAMMAS PER KILOTON.
 4    0.70 TO    1.00 MEV.  2.9070E+21 GAMMAS PER KILOTON.
 5    1.00 TO    1.50 MEV.  3.1460E+21 GAMMAS PER KILOTON.
 6    1.50 TO    2.00 MEV.  1.8150E+21 GAMMAS PER KILOTON.
 7    2.00 TO    3.00 MEV.  1.6510E+21 GAMMAS PER KILOTON.
 8    3.00 TO    5.00 MEV.  7.3260E+20 GAMMAS PER KILOTON.
 9    5.00 TO    7.00 MEV.  8.1180E+19 GAMMAS PER KILOTON.
10    7.00 TO   10.00 MEV.  9.7420E+18 GAMMAS PER KILOTON.

{37KT      215METERS                                                               }
```

Figure 9. Output for a Typical SMAUG Problem

```
PAGE    2                                                  *****   S M A U G   *****                              PAGE   2

KADATH TEST SITE DETONATION 37-KT AT 215 METERS.  (UNCLASSIFIED)

PROBLEM STATEMENT - 2000M      500M

-------------------  SOURCE POSITION AND YIELD  -------------------

THE SOURCE IS     37.000 KILOTONS AT AN ALTITUDE OF     215.00 METERS.

NEUTRON SOURCE -  READ WITH INPUT DATA.

GAMMA SOURCE -  READ WITH INPUT DATA.

FAST NEUTRON   = 1.7310E+25 NEUTRONS, (1.3775E+24 NEUTRONS/STERADIAN.)

PRIMARY GAMMA = 7.4043E+23 PHOTONS,  (5.8921E+22 PHOTONS/STERADIAN.)

-----------------------  RECEIVER POSITION  -----------------------

RECEIVER ALTITUDE =      500.00 METERS.  RANGE =    2000.00 METERS.
SOURCE-RECEIVER SLANT RANGE =    2020.20 METERS,  ( 239.10 GRAMS/CM2).

RANGE BETWEEN 200. AND 300. G/CM2.  N AND S/G BY EXTRAPOLATION.

------------------------  NEUTRON RESULTS  ------------------------

THE NEUTRON FLUENCE   = 1.7070E+11 N/CM2, (5.1174E+10 MEV/CM2).
NEUTRON MEAN ENERGY   = 0.2998 MEV.

NEUTRON TISSUE  DOSE = 1.0449E+02 RADS,  (1.0449E+04 ERGS/GRAM).
NEUTRON MIDLINE DOSE = 3.5501E+01 RADS IN 30 CM DIA PHANTOM.
NEUTRON SILICON DOSE = 2.7017E+00 RADS, (2.8187E+10 N/CM2 (1-MEV EQ)).

------------------------  GAMMA RESULTS  ------------------------

THE GAMMA FLUENCE  = 2.6172E+11 PHOTONS/CM2, (2.7351E+11 MEV/CM2).
GAMMA MEAN ENERGY  = 1.0451 MEV.

GAMMA TISSUE  DOSE = 9.3087E+01 RADS.  ( 99.5 PCT N-G)
GAMMA MIDLINE DOSE = 6.9076E+01 RADS IN 30 CM DIA PHANTOM.
THE GAMMA AIR DOSE = 1.0442E+02 ROENTGENS  (ESU/CM3).
GAMMA SILICON DOSE = 1.0701E+02 RADS.

---------------------  NEUTRON/GAMMA RESULTS  ---------------------

THE NEUTRON/GAMMA FLUENCE RATIO =  0.652 (N/CM2)/(PHOTONS/CM2).
NEUTRON/GAMMA TISSUE DOSE RATIO =  1.123 RADS(N)/RAD(G).

NEUTRON+GAMMA TISSUE  DOSE = 1.9758E+02 RADS.
NEUTRON+GAMMA MIDLINE DOSE = 1.0458E+02 RADS IN 30 CM DIA PHANTOM.
NEUTRON+GAMMA SILICON DOSE   1.0972E+02 RADS.
```

Figure 9 (cont'd). Output for a Typical SMAUG Problem

KADATH TEST SITE DETONATION 37-KT AT 215 METERS. {UNCLASSIFIED}

PROBLEM STATEMENT - 2000M 500M

------------------- SOURCE POSITION AND YIELD -------------------

THE SOURCE IS 37.000 KILOTONS AT AN ALTITUDE OF 215.00 METERS.

RECEIVER ALTITUDE = 500.00 METERS. RANGE = 2000.00 METERS.
SOURCE-RECEIVER SLANT RANGE = 2020.20 METERS, { 239.10 GRAMS/CM2}.

NEUTRON SOURCE - READ WITH INPUT DATA.

NEUTRON YIELD = 1.7310E+25 NEUTRONS {4-PI}, OR 1.3775E+24 NEUTRONS PER STERADIAN.

NEUTRON FLUENCE = 1.7070E+11 N/CM2, {5.1174E+10 MEV/CM2}. NEUTRON MEAN ENERGY = 0.300 MEV.

NEUTRON TISSUE DOSE = 1.0449E+02 RADS. {1.0449E+04 ERGS/GRAM}.
NEUTRON MIDLINE DOSE = 3.5501E+01 RADS IN 30 CM DIA PHANTOM.
NEUTRON SILICON DOSE = 2.7017E+00 RADS, {2.8187E+10 N/CM2 {1-MEV EQ}}.

	NEUTRON ENERGY BAND -------- M E V -------- LOWER		UPPER	NEUTRON FLUENCE {N/CM2}	SUM NEUTRON FLUENCE	NORMAL NEUTRON FLUENCE	SUM NOR NEUTRON FLUENCE	TISSUE DOSE {RADS}	SUM TISSUE DOSE	NORMAL TISSUE DOSE	SUM NOR TISSUE DOSE
1	0.E+00	TO	4.140E-07	6.104E+09	6.104E+09	3.576E-02	3.576E-02	5.041E-02	5.041E-02	4.825E-04	4.825E-04
2	4.140E-07	TO	1.120E-06	6.726E+09	1.283E+10	3.940E-02	7.516E-02	2.918E-02	7.960E-02	2.793E-04	7.618E-04
3	1.120E-06	TO	3.060E-06	8.025E+09	2.086E+10	4.701E-02	1.222E-01	2.140E-02	1.010E-01	2.048E-04	9.666E-04
4	3.060E-06	TO	1.070E-05	1.106E+10	3.192E+10	6.481E-02	1.870E-01	1.710E-02	1.181E-01	1.637E-04	1.130E-03
5	1.070E-05	TO	2.900E-05	9.178E+09	4.110E+10	5.377E-02	2.408E-01	9.950E-03	1.281E-01	9.522E-05	1.226E-03
6	2.900E-05	TO	1.010E-04	1.161E+10	5.271E+10	6.802E-02	3.088E-01	1.339E-02	1.414E-01	1.281E-04	1.354E-03
7	1.010E-04	TO	5.830E-04	1.705E+10	6.976E+10	9.990E-02	4.087E-01	6.240E-02	2.038E-01	5.972E-04	1.951E-03
8	0.000583	TO	0.003350	1.693E+10	8.669E+10	9.920E-02	5.079E-01	3.316E-01	5.354E-01	3.173E-03	5.124E-03
9	0.003350	TO	0.111000	4.032E+10	1.270E+11	2.362E-01	7.441E-01	1.718E+01	1.771E+01	1.644E-01	1.695E-01
10	0.111000	TO	0.550000	2.237E+10	1.494E+11	1.311E-01	8.752E-01	2.897E+01	4.661E+01	2.766E-01	4.461E-01
11	0.550000	TO	1.110000	1.007E+10	1.595E+11	5.902E-02	9.342E-01	2.028E+01	6.689E+01	1.941E-01	6.401E-01
12	1.110000	TO	1.830000	4.129E+09	1.636E+11	2.419E-02	9.584E-01	1.081E+01	7.770E+01	1.035E-01	7.436E-01
13	1.830000	TO	2.350000	2.182E+09	1.658E+11	1.279E-02	9.712E-01	6.657E+00	8.436E+01	6.371E-02	8.073E-01
14	2.350000	TO	2.460000	5.827E+08	1.664E+11	3.413E-03	9.746E-01	1.838E+00	8.620E+01	1.759E-02	8.249E-01
15	2.460000	TO	3.010000	1.046E+09	1.674E+11	6.127E-03	9.807E-01	3.585E+00	8.978E+01	3.431E-02	8.592E-01
16	3.010000	TO	4.070000	8.409E+08	1.682E+11	4.926E-03	9.856E-01	3.419E+00	9.320E+01	3.272E-02	8.920E-01
17	4.070000	TO	4.970000	7.459E+08	1.690E+11	4.370E-03	9.900E-01	3.073E+00	9.628E+01	2.941E-02	9.214E-01
18	4.970000	TO	6.360000	8.490E+08	1.698E+11	4.973E-03	9.950E-01	3.808E+00	1.001E+02	3.645E-02	9.578E-01
19	6.360000	TO	8.190000	5.800E+08	1.704E+11	3.398E-03	9.984E-01	2.898E+00	1.030E+02	2.773E-02	9.855E-01
20	8.190000	TO	10.000000	1.892E+08	1.706E+11	1.108E-03	9.995E-01	9.749E-01	1.040E+02	9.329E-03	9.949E-01
21	10.000000	TO	12.200000	5.622E+07	1.707E+11	3.294E-04	9.998E-01	3.246E-01	1.043E+02	3.107E-03	9.980E-01
22	12.200000	TO	15.000000	3.366E+07	1.707E+11	1.972E-04	1.000E+00	2.105E-01	1.045E+02	2.015E-03	1.000E+00

FIGURE 9 (CONT'D). OUTPUT FOR A TYPICAL SMAUG PROBLEM

```
KADATH TEST SITE DETONATION 37-KT AT 215 METERS.  {UNCLASSIFIED}

PROBLEM STATEMENT - 2000M     500M

-------------------  SOURCE POSITION AND YIELD  -------------------

THE SOURCE IS    37.000 KILOTONS AT AN ALTITUDE OF    215.00 METERS.

RECEIVER ALTITUDE =    500.00 METERS.  RANGE =   2000.00 METERS.
SOURCE-RECEIVER SLANT RANGE =   2020.20 METERS, { 239.10 GRAMS/CM2}.

THE PRIMARY GAMMA YIELD = 7.4043E+23 PHOTONS {4-PI}, OR 5.8921E+22 PHOTONS PER STERADIAN.

GAMMA SOURCE -  READ WITH INPUT DATA.

THE NEUTRON YIELD = 1.7310E+25 NEUTRONS {4-PI}, OR 1.3775E+24 NEUTRONS PER STERADIAN.

NEUTRON SOU CE -  READ WITH INPUT DATA.

PRIMARY   GAMMA FLUENCE = 1.7864E+09 PHOTONS/CM2, {1.2718E+09 MEV/CM2}.  MEAN ENERGY =  0.7119 MEV.
SECONDARY GAMMA FLUENCE = 2.5993E+11 PHOTONS/CM2, {2.7224E+11 MEV/CM2}.  MEAN ENERGY =  1.0473 MEV.
THE TOTAL GAMMA FLUENCE = 2.6172E+11 PHOTONS/CM2, {2.7351E+11 MEV/CM2}.  MEAN ENERGY =  1.0451 MEV.

PRIMARY   TISSUE DOSE = 4.8814E-01 RADS  {4.8814E+01 ERGS/GRAM}.
SECONDARY TISSUE DOSE = 9.2598E+01 RADS  {9.2598E+03 ERGS/GRAM}.
THE TOTAL TISSUE DOSE = 9.3087E+01 RADS  {9.3087E+03 ERGS/GRAM}.
MIDLINE   TISSUE DOSE = 6.9076E+01 RADS IN 30 CM DIA PHANTOM.
AIR  IONIZATION  DOSE = 1.0442E+02 ROENTGENS {ESU/CM3}.
SILICON ABSORBED DOSE = 1.0701E+02 RADS.
```

	GAMMA ENERGY BAND ------- M E V -------- LOWER		UPPER	GAMMA FLUENCE {G/CM2}	SUM GAMMA FLUENCE	NORMAL GAMMA FLUENCE	SUM NOR GAMMA FLUENCE	TISSUE DOSE {RADS}	SUM TISSUE DOSE	NORMAL TISSUE DOSE	SUM NOR TISSUE DOSE
1	0.0200	TO	0.0500	1.345E+10	1.345E+10	5.139E-02	5.139E-02	6.349E-01	6.349E-01	6.821E-03	6.821E-03
2	0.0500	TO	0.1000	8.050E+10	9.395E+10	3.076E-01	3.590E-01	2.578E+00	3.213E+00	2.770E-02	3.452E-02
3	0.1000	TO	0.2000	5.389E+10	1.478E+11	2.059E-01	5.649E-01	3.371E+00	6.584E+00	3.622E-02	7.073E-02
4	0.2000	TO	0.3000	1.752E+10	1.654E+11	6.696E-02	6.318E-01	2.148E+00	8.732E+00	2.307E-02	9.381E-02
5	0.3000	TO	0.4000	9.456E+09	1.748E+11	3.613E-02	6.680E-01	1.694E+00	1.043E+01	1.820E-02	1.120E-01
6	0.4000	TO	0.6000	1.409E+10	1.889E+11	5.385E-02	7.218E-01	3.666E+00	1.409E+01	3.938E-02	1.514E-01
7	0.6000	TO	0.8000	6.673E+09	1.956E+11	2.550E-02	7.473E-01	2.383E+00	1.648E+01	2.560E-02	1.770E-01
8	0.8000	TO	1.0000	4.900E+09	2.005E+11	1.872E-02	7.660E-01	2.186E+00	1.866E+01	2.349E-02	2.005E-01
9	1.0000	TO	1.3300	6.237E+09	2.067E+11	2.383E-02	7.899E-01	3.437E+00	2.210E+01	3.693E-02	2.374E-01
10	1.3300	TO	1.6600	4.932E+09	2.117E+11	1.884E-02	8.087E-01	3.279E+00	2.538E+01	3.522E-02	2.726E-01
11	1.6600	TO	2.0000	4.283E+09	2.159E+11	1.636E-02	8.251E-01	3.286E+00	2.866E+01	3.530E-02	3.079E-01
12	2.0000	TO	2.5000	5.472E+09	2.214E+11	2.091E-02	8.460E-01	4.836E+00	3.350E+01	5.195E-02	3.599E-01
13	2.5000	TO	3.0000	4.735E+09	2.261E+11	1.809E-02	8.641E-01	4.783E+00	3.828E+01	5.139E-02	4.113E-01
14	3.0000	TO	4.0000	8.431E+09	2.346E+11	3.222E-02	8.963E-01	9.959E+00	4.824E+01	1.070E-01	5.182E-01
15	4.0000	TO	5.0000	7.243E+09	2.418E+11	2.767E-02	9.240E-01	1.007E+01	5.831E+01	1.082E-01	6.264E-01
16	5.0000	TO	6.5000	1.472E+10	2.565E+11	5.626E-02	9.802E-01	2.420E+01	8.251E+01	2.600E-01	8.864E-01
17	6.5000	TO	8.0000	3.463E+09	2.600E+11	1.323E-02	9.935E-01	6.708E+00	8.922E+01	7.206E-02	9.584E-01
18	8.0000	TO	10.0000	1.714E+09	2.617E+11	6.547E-03	1.000E+00	3.869E+00	9.309E+01	4.156E-02	1.000E+00

Figure 9 (cont'd). Output for a Typical SMAUG Problem

```
PAGE    5                                            *****   S M A U G   *****                      PAGE   5

KADATH TEST SITE DETONATION 37-KT AT 215 METERS.  {UNCLASSIFIED}

PROBLEM STATEMENT - *ALTITUDE=500M{5,1000}

-------------------  SOURCE POSITION AND YIELD  -------------------

THE SOURCE IS    37.000 KILOTONS AT AN ALTITUDE OF    215.00 METERS.

NEUTRON SOURCE -  READ WITH INPUT DATA.

GAMMA SOURCE -  READ WITH INPUT DATA.

FAST NEUTRON  = 1.7310E+25 NEUTRONS, {1.3775E+24 NEUTRONS/STERADIAN.}

PRIMARY GAMMA = 7.4043E+23 PHOTONS,  {5.8921E+22 PHOTONS/STERADIAN.}

----------------------  RECEIVER POSITION  ----------------------

RECEIVER ALTITUDE =    500.00 METERS.  RANGE =    1657.41 METERS.
SOURCE-RECEIVER SLANT RANGE =    1681.73 METERS,  { 199.04 GRAMS/CM2}.

-----------------------  NEUTRON RESULTS  -----------------------

THE NEUTRON FLUENCE  = 1.0633E+12 N/CM2, {3.2755E+11 MEV/CM2}.
NEUTRON MEAN ENERGY  = 0.3081 MEV.

NEUTRON TISSUE  DOSE = 6.6138E+02 RADS,  {6.6138E+04 ERGS/GRAM}.
NEUTRON MIDLINE DOSE = 2.2469E+02 RADS IN 30 CM DIA PHANTOM.
NEUTRON SILICON DOSE = 1.7414E+01 RADS, {1.7856E+11 N/CM2 {1-MEV EQ}}.

------------------------  GAMMA RESULTS  ------------------------

THE GAMMA FLUENCE  = 9.4329E+11 PHOTONS/CM2, {9.9835E+11 MEV/CM2}.
GAMMA MEAN ENERGY  = 1.0584 MEV.

GAMMA TISSUE  DOSE = 3.3834E+02 RADS.  { 99.3 PCT N-G}
GAMMA MIDLINE DOSE = 2.5155E+02 RADS IN 30 CM DIA PHANTOM.
THE GAMMA AIR DOSE = 3.7966E+02 ROENTGENS  {ESU/CM3}.
GAMMA SILICON DOSE = 3.8933E+02 RADS.

--------------------  NEUTRON/GAMMA RESULTS  --------------------

THE NEUTRON/GAMMA FLUENCE RATIO =  1.127 {N/CM2}/{PHOTONS/CM2}.
NEUTRON/GAMMA TISSUE DOSE RATIO =  1.955 RADS{N}/RAD{G}.

NEUTRON+GAMMA TISSUE  DOSE = 9.9972E+02 RADS.
NEUTRON+GAMMA MIDLINE DOSE = 4.7623E+02 RADS IN 30 CM DIA PHANTOM.
NEUTRON+GAMMA SILICON DOSE = 4.0674E+02 RADS.
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Figure 9 (cont'd). Output for a Typical SMAUG Problem

KADATH TEST SITE DETONATION 37-KT AT 215 METERS. {UNCLASSIFIED}

THE SOURCE IS 37.000 KILOTONS AT AN ALTITUDE OF 215.00 METERS.

THE NEUTRON YIELD = 1.7310E+25 NEUTRONS {4-PI}. THE PRIMARY GAMMA YIELD = 7.4043E+23 PHOTONS {4-PI}.

CONTOURS FOR AN ISODOSE VALUE OF 3.0000E+03 NEUTRON + GAMMA TISSUE RADS. {MODE 5}

ANGLE {DEG}	SLANT RANGE METERS	RANGE METERS	HEIGHT METERS	NEUTRON FLUENCE {N/CM2} {1}	GAMMA FLUENCE {G/CM2} {2}	NEUTRON TISSUE RADS {3}	GAMMA TISSUE RADS {4}	N + G TISSUE RADS {5}	NEUTRON SILICON RADS {6}	GAMMA SILICON RADS {7}	N + G SILICON RADS {8}
90.	1538.02	0.00	1753.02	3.57E+12	2.12E+12	2.23E+03	7.66E+02	2.99E+03	5.93E+01	8.83E+02	9.42E+02
80.	1536.22	266.76	1727.88	3.57E+12	2.13E+12	2.23E+03	7.68E+02	3.00E+03	5.94E+01	8.84E+02	9.44E+02
70.	1532.20	524.04	1654.80	3.57E+12	2.13E+12	2.23E+03	7.69E+02	3.00E+03	5.93E+01	8.86E+02	9.45E+02
60.	1525.71	762.85	1536.30	3.57E+12	2.13E+12	2.23E+03	7.72E+02	3.00E+03	5.93E+01	8.88E+02	9.48E+02
50.	1517.03	975.13	1377.11	3.57E+12	2.14E+12	2.23E+03	7.74E+02	3.00E+03	5.92E+01	8.92E+02	9.51E+02
40.	1506.53	1154.07	1183.38	3.56E+12	2.15E+12	2.22E+03	7.78E+02	3.00E+03	5.91E+01	8.96E+02	9.55E+02
30.	1494.63	1294.39	962.32	3.56E+12	2.16E+12	2.22E+03	7.82E+02	3.00E+03	5.90E+01	9.00E+02	9.59E+02
20.	1481.79	1392.42	721.80	3.55E+12	2.18E+12	2.22E+03	7.86E+02	3.00E+03	5.89E+01	9.05E+02	9.64E+02
10.	1468.44	1446.13	469.99	3.54E+12	2.19E+12	2.21E+03	7.90E+02	3.00E+03	5.88E+01	9.10E+02	9.69E+02
0.	1455.04	1455.04	215.00	3.54E+12	2.20E+12	2.21E+03	7.95E+02	3.00E+03	5.86E+01	9.15E+02	9.74E+02

FIGURE 9 (CONT'D). OUTPUT FOR A TYPICAL SMAUG PROBLEM

SECTION V

GENERAL REMARKS AND CONCLUSION

Early in the development work that eventually led to the writing of SMAUG, the following informal goals were set out for such a prompt radiation environment predicting computer code:

1. The code must produce reasonably accurate results consistent with the accuracies needed for analysis of the hazards of nuclear warfare.

2. The input data requirements must be simple and yet flexible so that input data can be prepared with a minimum of effort on the part of the user. Further, the user must never be required to rewrite portions of the code itself to produce a routine solution.

3. The printed output must be readable by a person unfamiliar with the inner workings of the code and must not consist of long lists of uncaptioned tables which have to be further processed by the user to obtain the results he needs. In addition, the user should be able to select or suppress detailed output as he desires.

4. The code must be fast and produce a solution in only a few seconds of computer time. The code must not, therefore, produce the solution by making a Monte Carlo or discrete ordinates calculation for each problem. Similarly, in the interests of speed and convenience, the code should not be encumbered with input data tapes.

5. The code must be machine-independent in that it can be run on any scientific computer and produce the same answers. This means that the code must not use instructions peculiar to one series of computers nor depend on the word size of the computer. As a further consequence of this requirement, the code must not contain any machine-language coding.

6. The code itself must be entirely unclassified, although, depending on the input data used, the problems and the answers obtained may sometimes be classified. This requirement is essential to permit the development, exchange, evaluation, and discussion of the code openly, free of unnecessary security encumbrances.

These goals have been satisfactorily met by the SMAUG code.

At this point it would be very desirable to quote some accuracy figure for the results produced by SMAUG. Unfortunately, such information is simply not available nor would it have much meaning in any case since there exists no absolutely known standard with which SMAUG can be compared. All that can be said is that SMAUG does reproduce the data base given in ORNL-4464 (Ref. 8) within 1 or 2 percent over the range spanned by the data base for constant density co-altitude problems. Thus, the first question to be resolved is not the accuracy of SMAUG, but that of the accuracy of the data base. Straker has compared a number of such data bases in reference 36 and shows that although there has been much progress in radiation transport since the mid 1940s, transport calculations made by different techniques and using different cross-section sets are still not in as good agreement as one would like.

The second question that must be answered is that of the validity of using mass integral scaling of data obtained in infinite, homogeneous air to non-co-altitude situations in exponential air. Certainly, such scaling cannot be accurate for problems in which either the source or the receiver is near the top of the atmosphere, for under such circumstances a significant amount of radiation must be leaking out of the atmosphere to reduce the dose level seen at the receiver. For more reasonable cases the same problem must exist--although to a lesser degree. This question deserves much more investigation.

A look at the current state of the art of air transport calculations can be obtained from the recently published proceedings of the Radiation Transport in Air Seminar held at Oak Ridge in November 1971, in which a number of computer codes, including SMAUG, are described (Ref. 37).

APPENDIX I

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 1 (3.300E-03 TO 1.110E-01 MEV).

I	A	B	C	D	E	F
1	-5.749E+00	-5.670E-01	-3.533E-04	2.100E-02	7.195E+00	-6.842E+00
2	-6.816E+00	-5.153E-01	-3.354E-04	1.945E-02	5.778E+00	-4.369E+00
3	-7.998E+00	-4.471E-01	-3.024E-04	1.712E-02	4.064E+00	-1.439E+00
4	-9.310E+00	-3.550E-01	-2.496E-04	1.373E-02	1.896E+00	2.202E+00
5	-1.157E+01	-2.228E-01	-1.655E-04	8.598E-03	-1.059E+00	7.066E+00
6	-1.261E+01	-1.091E-01	-8.350E-05	3.875E-03	-3.367E+00	1.069E+01
7	-1.272E+01	4.215E-03	7.336E-06	-1.148E-03	-5.370E+00	1.352E+01
8	-1.132E+01	1.126E-01	1.137E-04	-6.628E-03	-6.618E+00	1.448E+01
9	1.069E+00	-1.867E-01	-5.799E-05	3.995E-03	1.971E+00	-2.034E+00

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 2 (1.110E-01 TO 1.108E+00 MEV).

I	A	B	C	D	E	F
1	-9.494E+00	-2.665E-01	-1.004E-04	7.669E-03	2.610E+00	
2	-9.308E+00	-2.766E-01	-1.210E-04	8.476E-03	2.642E+00	
3	-1.244E+01	-9.762E-02	2.281E-05	7.466E-04	-1.216E+00	6.527E+00
4	-8.586E+00	-2.951E-01	-1.627E-04	1.006E-02	2.687E+00	
5	-1.372E+01	-1.844E-02	6.309E-05	-2.003E-03	-3.192E+00	9.883E+00
6	-1.208E+00	-6.319E-01	-4.357E-04	2.470E-02	1.002E+01	-1.269E+01
7	-1.431E+01	8.360E-02	1.294E-04	-6.007E-03	-5.412E+00	1.344E+01
8	-6.481E+00	-2.862E-01	-2.014E-04	1.087E-02	2.377E+00	
9	-1.074E+01	1.255E-01	1.725E-04	-8.282E-03	-5.446E+00	1.241E+01
10	-1.080E+00	-8.365E-02	3.682E-05	-4.691E-04	7.125E-01	
11	-7.073E-01	-4.668E-02	6.764E-05	-2.170E-03	3.035E-01	

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 3 (1.108E+00 TO 2.350E+00 MEV).

I	A	B	C	D	E	F
1	-9.784E+00	-1.836E-01	-2.497E-06	2.952E-03	2.220E+00	
2	-9.627E+00	-1.898E-01	-1.295E-05	3.391E-03	2.244E+00	
3	-9.403E+00	-1.962E-01	-2.426E-05	3.862E-03	2.270E+00	
4	-1.505E+01	1.315E-01	2.557E-04	-1.077E-02	-4.598E+00	1.158E+01
5	-1.533E+01	1.328E-01	2.486E-04	-1.057E-02	-4.772E+00	1.192E+01
6	-1.531E+01	1.427E-01	2.497E-04	-1.079E-02	-5.097E+00	1.250E+01
7	-8.297E+00	-2.267E-01	-8.292E-05	6.218E-03	2.365E+00	
8	-1.548E+01	1.780E-01	2.575E-04	-1.170E-02	-6.144E+00	1.430E+01
9	-6.718E+00	-2.372E-01	-1.168E-04	7.408E-03	2.319E+00	
10	-5.707E+00	-2.286E-01	-1.303E-04	7.601E-03	2.073E+00	
11	-6.337E+00	2.486E-02	1.082E-04	-4.515E-03	-2.213E+00	5.834E+00
12	-7.578E-01	-6.216E-02	4.337E-05	-1.048E-03	4.039E-01	
13	-3.070E-01	1.419E-02	1.247E-04	-5.109E-03	-2.179E-01	

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 4 (2.350E+00 TO 4.060E+00 MEV).

I	A	B	C	D	E	F
1	-1.053E+01	-1.563E-01	1.156E-05	2.047E-03	2.074E+00	
2	-1.037E+01	-1.600E-01	6.105E-06	2.292E-03	2.090E+00	
3	-1.016E+01	-1.641E-01	-4.437E-09	2.562E-03	2.108E+00	
4	-1.719E+01	2.429E-01	3.527E-04	-1.576E-02	-6.342E+00	1.422E+01
5	-1.723E+01	2.325E-01	3.395E-04	-1.515E-02	-6.223E+00	1.406E+01
6	-1.696E+01	2.297E-01	3.335E-04	-1.491E-02	-6.245E+00	1.413E+01
7	-9.158E+00	-1.849E-01	-3.444E-05	4.033E-03	2.190E+00	
8	-9.007E+00	-1.937E-01	-5.001E-05	4.680E-03	2.218E+00	
9	-1.543E+01	2.165E-01	3.001E-04	-1.362E-02	-6.365E+00	1.443E+01
10	-1.554E+01	2.100E-01	2.698E-04	-1.256E-02	-6.662E+00	1.499E+01
11	-7.126E+00	-2.377E-01	-1.503E-04	8.567E-03	2.181E+00	
12	-1.267E+01	1.613E-01	1.804E-04	-8.986E-03	-6.042E+00	1.325E+01
13	-7.104E+00	6.383E-02	1.086E-04	-5.134E-03	-3.048E+00	6.901E+00
14	-2.663E+00	-4.301E-02	4.394E-05	-1.289E-03	3.263E-01	
15	-6.788E-01	-5.332E-02	2.773E-05	-6.742E-04	4.469E-01	-4.197E-01
16	1.500E-01	9.712E-03	1.222E-04	-5.071E-03	-2.425E-01	

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 5 (4.060E+00 TO 6.360E+00 MEV).

I	A	B	C	D	E	F
1	-1.137E+01	-1.539E-01	-4.065E-06	2.497E-03	2.046E+00	
2	-1.983E+01	3.210E-01	4.090E-04	-1.893E-02	-7.784E+00	1.653E+01
3	-1.956E+01	3.152E-01	4.019E-04	-1.860E-02	-7.717E+00	1.644E+01
4	-1.061E+01	-1.630E-01	-1.833E-05	3.114E-03	2.084E+00	
5	-1.072E+01	-1.669E-01	-2.428E-05	3.377E-03	2.098E+00	
6	-1.042E+01	-1.699E-01	-2.924E-05	3.591E-03	2.109E+00	
7	-9.973E+00	-1.749E-01	-3.809E-05	3.955E-03	2.126E+00	
8	-9.792E+00	-1.784E-01	-4.478E-05	4.230E-03	2.129E+00	
9	-8.664E+00	-1.800E-01	-4.965E-05	4.411E-03	2.113E+00	
10	-1.563E+01	2.209E-01	2.946E-04	-1.353E-02	-6.247E+00	1.393E+01
11	-1.478E+01	1.766E-01	2.416E-04	-1.107E-02	-5.604E+00	1.280E+01
12	-7.823E+00	-2.180E-01	-1.301E-04	7.625E-03	2.040E+00	
13	-1.481E+01	1.870E-01	1.952E-04	-9.871E-03	-6.602E+00	1.438E+01
14	-1.345E+01	1.528E-01	1.724E-04	-8.606E-03	-5.400E+00	1.173E+01
15	-8.306E-01	-3.158E-02	4.736E-05	-1.640E-03	1.396E-01	
16	-1.281E+01	1.841E-01	1.818E-04	-9.503E-03	-6.392E+00	1.345E+01
17	-5.825E+00	1.756E-02	6.596E-05	-2.973E-03	-2.018E+00	4.921E+00
18	1.310E-01	1.983E-02	1.041E-04	-4.417E-03	-2.672E-01	

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 6 (6.360E+00 TO 8.180E+00 MEV).

I	A	B	C	D	E	F
1	-1.161E+01	-1.917E-01	-7.125E-05	5.411E-03	2.210E+00	
2	-1.918E+01	2.340E-01	2.978E-04	-1.376E-02	-6.614E+00	1.484E+01
3	-1.903E+01	2.355E-01	2.955E-04	-1.372E-02	-6.705E+00	1.501E+01
4	-1.887E+01	2.448E-01	2.996E-04	-1.402E-02	-6.960E+00	1.546E+01
5	-1.090E+01	-2.057E-01	-9.858E-05	6.499E-03	2.253E+00	
6	-1.907E+01	2.629E-01	3.069E-04	-1.459E-02	-7.455E+00	1.631E+01
7	-1.006E+01	-2.104E-01	-1.110E-04	6.952E-03	2.249E+00	
8	-1.893E+01	2.962E-01	3.258E-04	-1.581E-02	-8.228E+00	1.755E+01
9	-1.767E+01	3.089E-01	3.362E-04	-1.639E-02	-8.399E+00	1.768E+01
10	-1.551E+01	2.815E-01	3.197E-04	-1.545E-02	-7.407E+00	1.543E+01
11	-6.845E+00	-1.366E-01	-3.738E-05	3.184E-03	1.515E+00	
12	-6.730E+00	-1.309E-01	-2.930E-05	2.850E-03	1.425E+00	
13	-7.464E+00	-1.646E-01	-7.367E-05	4.898E-03	1.634E+00	
14	-8.787E+00	-1.842E-01	-1.081E-04	6.319E-03	1.726E+00	
15	-7.324E+00	-1.925E-01	-1.221E-04	6.906E-03	1.728E+00	
16	-1.264E+01	1.455E-01	1.581E-04	-7.941E-03	-5.441E+00	1.192E+01
17	-1.237E+01	1.715E-01	1.665E-04	-8.719E-03	-6.040E+00	1.276E+01
18	-7.344E+00	9.441E-02	1.089E-04	-5.651E-03	-3.697E+00	7.822E+00
19	6.278E-01	1.914E-02	9.246E-05	-3.966E-03	-2.680E-01	

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 7 (8.180E+00 TO 1.000E+01 MEV).

I	A	B	C	D	E	F
1	-1.754E+01	1.481E-01	2.413E-04	-1.034E-02	-4.794E+00	1.180E+01
2	-1.738E+01	1.436E-01	2.336E-04	-1.002E-02	-4.771E+00	1.179E+01
3	-1.100E+01	-2.012E-01	-7.137E-05	5.700E-03	2.264E+00	
4	-1.691E+01	1.435E-01	2.254E-04	-9.761E-03	-4.912E+00	1.208E+01
5	-1.719E+01	1.482E-01	2.241E-04	-9.809E-03	-5.099E+00	1.242E+01
6	-1.040E+01	-2.152E-01	-9.868E-05	6.792E-03	2.309E+00	
7	-1.680E+01	1.628E-01	2.262E-04	-1.015E-02	-5.557E+00	1.322E+01
8	-1.690E+01	1.771E-01	2.303E-04	-1.055E-02	-5.946E+00	1.386E+01
9	-1.578E+01	1.871E-01	2.335E-04	-1.086E-02	-6.161E+00	1.413E+01
10	-7.736E+00	-2.104E-01	-1.257E-04	7.440E-03	2.059E+00	
11	-6.867E+00	-1.897E-01	-1.186E-04	6.761E-03	1.778E+00	
12	-5.896E+00	-1.590E-01	-9.862E-05	5.479E-03	1.428E+00	
13	-9.814E+00	1.163E-01	1.653E-04	-7.732E-03	-3.650E+00	8.029E+00
14	-7.758E+00	-1.431E-01	-7.097E-05	4.331E-03	1.356E+00	
15	-6.067E+00	-1.291E-01	-5.177E-05	3.475E-03	1.220E+00	
16	-9.398E+00	6.198E-02	1.141E-04	-5.112E-03	-2.826E+00	6.812E+00
17	-1.219E+01	1.420E-01	1.651E-04	-8.115E-03	-4.991E+00	1.089E+01
18	-1.214E+01	1.708E-01	1.720E-04	-8.878E-03	-5.810E+00	1.225E+01
19	-7.902E+00	9.723E-02	1.046E-04	-5.549E-03	-3.890E+00	8.226E+00
20	6.552E-01	1.287E-02	8.298E-05	-3.600E-03	-2.741E-01	

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 8 (1.000E+01 TO 1.220E+01 MEV).

I	A	B	C	D	E	F
1	-1.128E+01	-1.935E-01	-5.594E-05	5.050E-03	2.234E+00	
2	-1.111E+01	-1.976E-01	-6.332E-05	5.353E-03	2.249E+00	
3	-1.089E+01	-2.018E-01	-7.108E-05	5.671E-03	2.265E+00	
4	-1.049E+01	-2.060E-01	-7.898E-05	5.990E-03	2.279E+00	
5	-1.059E+01	-2.113E-01	-8.944E-05	6.407E-03	2.295E+00	
6	-1.724E+01	1.723E-01	2.413E-04	-1.082E-02	-5.676E+00	1.340E+01
7	-1.700E+01	1.822E-01	2.437E-04	-1.108E-02	-5.959E+00	1.388E+01
8	-1.706E+01	1.986E-01	2.509E-04	-1.162E-02	-6.366E+00	1.453E+01
9	-1.582E+01	2.073E-01	2.548E-04	-1.192E-02	-6.513E+00	1.465E+01
10	-1.408E+01	1.812E-01	2.273E-04	-1.065E-02	-5.783E+00	1.297E+01
11	-1.263E+01	1.583E-01	1.990E-04	-9.405E-03	-5.204E+00	1.159E+01
12	-1.169E+01	1.463E-01	1.763E-04	-8.530E-03	-4.952E+00	1.084E+01
13	-1.214E+01	1.698E-01	1.920E-04	-9.479E-03	-5.398E+00	1.145E+01
14	-1.390E+01	1.959E-01	2.116E-04	-1.058E-02	-5.910E+00	1.227E+01
15	-1.053E+01	1.101E-01	1.381E-04	-6.753E-03	-4.077E+00	8.999E+00
16	-8.908E+00	6.812E-02	1.025E-04	-4.900E-03	-3.090E+00	7.083E+00
17	-8.294E+00	3.256E-02	8.821E-05	-3.805E-03	-2.076E+00	5.305E+00
18	-9.389E+00	7.319E-02	1.134E-04	-5.315E-03	-3.160E+00	7.322E+00
19	-8.180E+00	7.159E-02	1.102E-04	-5.215E-03	-3.013E+00	6.759E+00
20	-6.680E+00	2.026E-02	4.695E-05	-2.389E-03	-2.312E+00	5.536E+00
21	6.857E-01	9.269E-03	8.587E-05	-3.732E-03	-2.846E-01	

NEUTRON TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 9 (1.220E+01 TO 1.500E+01 MEV).

I	A	B	C	D	E	F
1	-1.395E+01	-9.128E-02	-2.410E-05	1.753E-03	-3.454E-01	4.554E+00
2	-1.394E+01	-8.578E-02	-2.233E-05	1.603E-03	-5.195E-01	4.868E+00
3	-1.387E+01	-8.002E-02	-2.036E-05	1.441E-03	-6.968E-01	5.184E+00
4	-1.366E+01	-7.329E-02	-1.802E-05	1.249E-03	-9.003E-01	5.546E+00
5	-1.399E+01	-6.414E-02	-1.458E-05	9.789E-04	-1.166E+00	6.010E+00
6	-1.384E+01	-5.652E-02	-1.171E-05	7.524E-04	-1.382E+00	6.379E+00
7	-1.355E+01	-4.690E-02	-7.766E-06	4.530E-04	-1.638E+00	6.802E+00
8	-1.347E+01	-3.586E-02	-3.009E-06	9.848E-05	-1.904E+00	7.197E+00
9	-1.203E+01	-3.326E-02	-1.281E-06	-1.472E-05	-1.881E+00	7.002E+00
10	-1.027E+01	-4.281E-02	-3.955E-06	2.222E-04	-1.343E+00	5.558E+00
11	-8.862E+00	-5.014E-02	-7.289E-06	4.640E-04	-9.611E-01	4.439E+00
12	-7.993E+00	-4.744E-02	-7.291E-06	4.275E-04	-9.196E-01	3.994E+00
13	-8.220E+00	-3.723E-02	-2.193E-06	7.553E-05	-1.116E+00	4.188E+00
14	-9.787E+00	-2.339E-02	4.220E-06	-3.935E-04	-1.424E+00	4.673E+00
15	-8.192E+00	-2.307E-02	2.811E-06	-3.266E-04	-1.491E+00	4.682E+00
16	-6.491E+00	-5.711E-02	-1.584E-05	9.252E-04	-5.838E-01	2.843E+00
17	-6.773E+00	-4.607E-02	-6.699E-06	3.790E-04	-6.935E-01	2.987E+00
18	-6.502E+00	-3.995E-02	-3.449E-06	1.501E-04	-7.713E-01	3.019E+00
19	-7.115E+00	-1.966E-02	5.135E-06	-4.826E-04	-1.342E+00	4.011E+00
20	-6.445E+00	-4.851E-02	-6.453E-06	3.900E-04	-6.611E-01	2.743E+00
21	-4.699E+00	-3.412E-02	3.215E-06	-3.491E-04	-8.459E-01	2.585E+00
22	1.759E-01	-2.821E-02	2.141E-05	-1.282E-03	-5.924E-02	

APPENDIX II

GAMMA TRANSMISSION FUNCTION COEFFICIENTS

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 1 (1.000E-01 TO 2.000E-01 MEV).

I	A	B	C	D	E	F
1	-1.276E+01	1.530E-01	4.139E-04	-1.755E-02	-6.216E+00	1.408E+01
2	-9.988E+00	5.651E-01	9.158E-04	-4.110E-02	-1.063E+01	1.819E+01
3	-7.293E-03	-1.985E-02	2.925E-04	-1.093E-02	6.302E-02	

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 2 (2.000E-01 TO 4.000E-01 MEV).

I	A	B	C	D	E	F
1	-8.638E+00	-4.933E-01	-4.068E-04	2.046E-02	3.583E+00	
2	-1.590E+01	5.941E-01	7.607E-04	-3.607E-02	-1.354E+01	2.480E+01
3	-7.583E+00	2.602E-01	4.028E-04	-1.950E-02	-6.390E+00	1.178E+01
4	-6.667E-01	-1.010E-02	1.885E-04	-7.932E-03		
5	-7.445E-01	-6.019E-02	6.868E-05	-3.043E-03		

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 3 (4.000E-01 TO 7.000E-01 MEV).

I	A	B	C	D	E	F
1	-1.532E+01	1.091E-01	1.361E-04	-7.746E-03	-6.464E+00	1.531E+01
2	-1.116E+01	-2.055E-02	-4.451E-05	-1.512E-04	-3.993E+00	1.071E+01
3	-6.102E+00	-1.441E-01	-2.222E-04	6.984E-03	-1.056E+00	4.642E+00
4	-8.982E+00	2.535E-01	3.166E-04	-1.657E-02	-6.420E+00	1.195E+01
5	-8.177E+00	6.725E-02	8.569E-05	-6.073E-03	-3.714E+00	8.054E+00
6	-3.683E-01	-5.291E-02	-5.843E-05			
7	-1.100E+00	-6.857E-02	-2.060E-05			

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 4 (7.000E-01 TO 1.000E+00 MEV).

I	A	B	C	D	E	F
1	-1.594E+01	7.877E-02	3.574E-05	-3.915E-03	-6.404E+00	1.549E+01
2	-1.372E+01	-1.761E-02	-1.799E-04	3.970E-03	-5.391E+00	1.377E+01
3	-1.046E+01	1.836E-01	2.093E-04	-1.116E-02	-6.237E+00	1.284E+01
4	-6.106E+00	-1.166E-01	-2.490E-04	7.049E-03	-1.092E+00	4.146E+00
5	-8.271E+00	-9.257E-02	-2.196E-04	5.987E-03	-1.940E+00	5.952E+00
6	-7.354E+00	-1.400E-01	-2.787E-04	8.795E-03	-1.208E+00	4.759E+00
7	-1.089E+00	-1.614E-02	9.814E-05	-4.099E-03		
8	-4.376E-01	-5.293E-02	5.335E-05	-1.183E-03		

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 5 (1.000E+00 TO 1.500E+00 MEV).

I	A	B	C	D	E	F
1	-1.596E+01	1.396E-01	1.158E-04	-7.185E-03	-6.851E+00	1.579E+01
2	-1.252E+01	2.631E-02	3.884E-06	-1.521E-03	-4.658E+00	1.187E+01
3	-1.298E+01	3.810E-01	4.303E-04	-2.124E-02	-9.330E+00	1.765E+01
4	-9.732E+00	4.323E-01	5.193E-04	-2.546E-02	-8.418E+00	1.439E+01
5	-8.992E+00	1.397E-01	2.238E-04	-1.039E-02	-4.105E+00	8.477E+00
6	-8.599E+00	8.759E-02	9.485E-05	-6.004E-03	-3.589E+00	7.799E+00
7	-1.183E+01	4.608E-01	6.248E-04	-2.830E-02	-9.011E+00	1.570E+01
8	-8.435E+00	4.291E-02	6.661E-05	-4.104E-03	-2.886E+00	6.684E+00
9	-3.958E-01	-4.579E-02	-1.921E-05			
10	-1.086E+00	-4.863E-02	6.852E-06	-3.114E-04		

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 6 (1.500E+00 TO 2.000E+00 MEV).

I	A	B	C	D	E	F
1	-1.001E+01	-3.897E-01	-3.916E-04	1.906E-02	2.503E+00	1.243E+00
2	-1.430E+01	1.382E-01	8.881E-05	-5.887E-03	-6.847E+00	1.539E+01
3	-1.169E+01	8.915E-02	-3.362E-05	-1.809E-03	-5.777E+00	1.286E+01
4	-7.834E+00	-1.378E-02	-1.002E-04	1.848E-03	-2.597E+00	6.567E+00
5	-8.047E+00	-7.022E-03	-6.037E-05	3.779E-04	-2.212E+00	5.744E+00
6	-9.324E+00	6.589E-02	2.276E-05	-3.258E-03	-3.690E+00	8.284E+00
7	-1.103E+01	1.667E-01	9.037E-05	-7.388E-03	-5.632E+00	1.130E+01
8	-9.634E+00	1.631E-01	2.193E-04	-1.067E-02	-4.385E+00	8.783E+00
9	-8.339E+00	-9.860E-02	-2.136E-04	6.687E-03	-1.371E+00	4.880E+00
10	-1.144E+00	-2.763E-02	-1.353E-05	-5.745E-04		
11	-4.009E-01	-4.294E-02	-3.233E-06			

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 7 (2.000E+00 TO 3.000E+00 MEV).

I	A	B	C	D	E	F
1	-1.690E+01	1.528E-02	-1.174E-04	2.914E-03	-5.993E+00	1.525E+01
2	-1.123E+01	-1.171E-01	-1.626E-04	6.957E-03	-2.185E+00	8.015E+00
3	-1.187E+01	9.116E-02	6.005E-06	-2.506E-03	-5.527E+00	1.245E+01
4	-6.519E+00	-8.757E-02	-1.150E-04	4.389E-03	-7.587E-01	3.462E+00
5	-4.317E+00	-1.582E-01	-7.281E-05	4.698E-03	1.861E+00	-1.414E+00
6	-7.387E+00	-6.024E-02	-1.025E-04	3.352E-03	-1.305E+00	4.361E+00
7	-1.059E+01	1.714E-01	2.214E-04	-1.033E-02	-4.804E+00	9.747E+00
8	-1.017E+01	4.016E-02	-3.716E-05	-8.152E-04	-3.329E+00	7.756E+00
9	-1.110F+01	2.346E-01	2.510E-04	-1.284E-02	-5.959E+00	1.147E+01
10	-8.969E+00	-9.148E-02	-1.611E-04	5.714E-03	-1.241E+00	4.697E+00
11	-8.622E+00	-3.681E-02	-4.968E-05	1.535E-03	-1.619E+00	4.884E+00
12	-6.797E-01	-3.603E-02	-1.915E-05	4.240E-04		
13	-6.890E-01	-3.683E-02	-1.504E-05	3.050E-04		

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 8 (3.000E+00 TO 5.000E+00 MEV).

I	A	B	C	D	E	F
1	-2.092E+01	3.636E-01	2.317E-04	-1.404E-02	-1.203E+01	2.457E+01
2	-1.129E+01	-1.347E-01	-1.871E-04	8.351E-03	-1.871E+00	7.540E+00
3	-1.297E+01	1.685E-01	1.014E-04	-6.508E-03	-6.692E+00	1.426E+01
4	-9.509E+00	9.756E-02	9.357E-05	-4.853E-03	-4.078E+00	8.879E+00
5	-1.209E+01	2.167E-01	1.678E-04	-9.676E-03	-6.570E+00	1.300E+01
6	-7.556E+00	-1.427E-02	-5.639E-05	1.428E-03	-2.023E+00	5.342E+00
7	-1.245E+01	2.469E-01	2.163E-04	-1.187E-02	-6.581E+00	1.274E+01
8	-1.152E+01	1.469E-01	1.300E-04	-7.246E-03	-4.720E+00	9.815E+00
9	-1.009E+01	4.874E-02	-1.928E-05	-1.248E-03	-3.206E+00	7.433E+00
10	-1.294E+01	2.318E-01	1.910E-04	-1.084E-02	-6.492E+00	1.275E+01
11	-1.005E+01	7.210E-02	1.070E-04	-4.860E-03	-2.896E+00	6.684E+00
12	-1.092E+01	1.203E-01	1.199E-04	-6.447E-03	-4.065E+00	8.723E+00
13	-9.408E+00	-4.977E-02	-9.835E-05	3.367E-03	-1.541E+00	4.946E+00
14	-7.077E-01	-2.451E-02	7.240E-06	-2.610E-04		
15	-6.894E-01	-2.876E-02	-1.165E-05	2.619E-04		

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 9 (5.000E+00 TO 7.000E+00 MEV).

I	A	B	C	D	E	F
1	-1.023E+01	-4.786E-01	-5.448E-04	2.610E-02	3.495E+00	
2	-1.976E+01	3.257E-01	1.537E-04	-1.085E-02	-1.166E+01	2.397E+01
3	-1.163E+01	2.599E-02	-7.464E-05	1.589E-03	-4.406E+00	1.078E+01
4	-9.543E+00	2.057E-02	-2.251E-05	7.103E-05	-3.057E+00	7.573E+00
5	-7.670E+00	-1.721E-01	-1.666E-04	8.536E-03	5.708E-01	1.874E+00
6	-6.991E+00	-1.035E-02	-4.525E-05	1.376E-03	-1.999E+00	5.133E+00
7	-1.060E+01	1.016E-01	8.647E-05	-4.972E-03	-3.717E+00	8.106E+00
8	-1.164E+01	1.215E-01	1.184E-04	-6.034E-03	-4.259E+00	9.160E+00
9	-1.126E+01	1.585E-01	1.381E-04	-7.690E-03	-4.639E+00	9.461E+00
10	-1.091E+01	3.016E-02	-4.429E-05	8.372E-05	-2.961E+00	7.200E+00
11	-1.466E+01	3.285E-01	2.961E-04	-1.564E-02	-8.052E+00	1.517E+01
12	-9.127E+00	-6.134E-02	-3.648E-05	2.126E-03	-5.994E-01	3.261E+00
13	-8.522E+00	-7.214E-02	-5.774E-05	2.876E-03	-2.810E-01	2.523E+00
14	-1.039E+01	1.086E-01	9.576E-05	-5.399E-03	-3.727E+00	8.039E+00
15	-9.544E+00	-4.691E-02	-9.821E-05	3.432E-03	-1.547E+00	5.009E+00
16	-2.850E-01	-2.477E-02	-1.087E-05	2.561E-04		
17	-1.386E+00	-2.347E-02	1.162E-06			

GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR GAMMAS IN SOURCE BAND 10 (7.000E+00 TO 1.000E+01 MEV).

I	A	B	C	D	E	F
1	-2.160E+01	3.147E-01	1.503E-04	-1.030E-02	-1.174E+01	2.457E+01
2	-1.700E+01	1.794E-01	3.308E-05	-4.282E-03	-8.560E+00	1.873E+01
3	-1.448E+01	1.816E-01	5.185E-05	-5.078E-03	-7.681E+00	1.629E+01
4	-9.365E+00	-9.349E-02	-1.756E-04	7.057E-03	-1.724E+00	5.958E+00
5	-8.129E+00	-1.646E-01	-2.007E-04	9.270E-03	1.591E-01	2.631E+00
6	-7.960E+00	7.187E-02	8.319E-06	-1.885E-03	-3.652E+00	7.774E+00
7	-1.121E+01	1.453E-01	1.139E-04	-6.720E-03	-4.406E+00	9.101E+00
8	-1.071E+01	1.940E-03	-5.228E-05	1.181E-03	-2.377E+00	6.273E+00
9	-1.018E+01	2.186E-02	-2.476E-05	-2.645E-05	-2.546E+00	6.339E+00
10	-1.044E+01	5.059E-02	6.873E-05	-3.150E-03	-2.441E+00	5.974E+00
11	-1.218E+01	1.576E-01	1.560E-04	-7.955E-03	-4.543E+00	9.381E+00
12	-1.152E+01	1.564E-01	1.474E-04	-7.807E-03	-4.396E+00	8.985E+00
13	-1.296E+01	1.652E-01	1.177E-04	-7.139E-03	-5.154E+00	1.063E+01
14	-1.019E+01	3.725E-02	2.184E-05	-1.625E-03	-2.513E+00	6.222E+00
15	-1.089E+01	1.292E-01	1.352E-04	-6.873E-03	-3.767E+00	7.965E+00
16	-9.772E+00	1.318E-03	-1.829E-05	2.816E-04	-1.947E+00	5.403E+00
17	-1.087E+00	-2.155E-02	-1.923E-05	4.521E-04		
18	-4.140E-01	-1.987E-02	-2.510E-06			

APPENDIX III

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 1 (3.300E-03 TO 1.110E-01 MEV).

I	A	B	C	D	E	F
1	-1.347E+01	-2.655E-01	-1.405E-04	9.765E-03	2.600E+00	
2	-1.165E+01	-2.692E-01	-1.477E-04	1.005E-02	2.614E+00	
3	-1.196E+01	-3.061E-01	-2.152E-04	1.282E-02	2.768E+00	
4	-1.302E+01	-3.402E-01	-2.824E-04	1.549E-02	2.900E+00	
5	-1.362E+01	-3.420E-01	-2.853E-04	1.562E-02	2.910E+00	
6	-1.316E+01	-3.662E-01	-3.299E-04	1.744E-02	3.007E+00	
7	-1.417E+01	-3.177E-01	-2.597E-04	1.424E-02	2.782E+00	
8	-1.450E+01	-3.179E-01	-2.628E-04	1.432E-02	2.780E+00	
9	-1.427E+01	-3.177E-01	-2.643E-04	1.435E-02	2.776E+00	
10	-1.453E+01	-3.194E-01	-2.683E-04	1.450E-02	2.782E+00	
11	-1.468E+01	-3.203E-01	-2.696E-04	1.456E-02	2.787E+00	
12	-1.446E+01	-3.222E-01	-2.722E-04	1.469E-02	2.797E+00	
13	-1.459E+01	-3.241E-01	-2.742E-04	1.479E-02	2.808E+00	
14	-1.322E+01	-4.623E-01	-4.904E-04	2.430E-02	3.420E+00	
15	-1.364E+01	-4.433E-01	-4.746E-04	2.333E-02	3.317E+00	
16	-1.215E+01	-4.660E-01	-4.766E-04	2.405E-02	3.454E+00	
17	-1.458E+01	-4.711E-01	-4.989E-04	2.483E-02	3.465E+00	
18	-1.503E+01	-4.721E-01	-5.053E-04	2.504E-02	3.467E+00	

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 2 (1.110E-01 TO 1.108E+00 MEV).

I	A	B	C	D	E	F
1	-1.346E+01	-1.938E-01	-4.056E-05	5.088E-03	2.254E+00	
2	-1.164E+01	-1.959E-01	-4.385E-05	5.234E-03	2.263E+00	
3	-1.195E+01	-2.183E-01	-7.816E-05	6.765E-03	2.367E+00	
4	-1.304E+01	-2.398E-01	-1.130E-04	8.280E-03	2.462E+00	
5	-1.363E+01	-2.409E-01	-1.146E-04	8.348E-03	2.467E+00	
6	-1.318E+01	-2.552E-01	-1.358E-04	9.305E-03	2.532E+00	
7	-1.427E+01	-2.318E-01	-1.136E-04	8.044E-03	2.414E+00	
8	-1.460E+01	-2.325E-01	-1.163E-04	8.132E-03	2.416E+00	
9	-1.439E+01	-2.333E-01	-1.188E-04	8.221E-03	2.418E+00	
10	-1.465E+01	-2.341E-01	-1.201E-04	8.286E-03	2.422E+00	
11	-1.480E+01	-2.353E-01	-1.220E-04	8.369E-03	2.428E+00	
12	-1.457E+01	-2.359E-01	-1.226E-04	8.407E-03	2.431E+00	
13	-1.469E+01	-2.369E-01	-1.233E-04	8.454E-03	2.437E+00	
14	-1.313E+01	-3.021E-01	-1.923E-04	1.214E-02	2.755E+00	
15	-1.367E+01	-3.000E-01	-2.024E-04	1.234E-02	2.736E+00	
16	-1.198E+01	-2.948E-01	-1.691E-04	1.128E-02	2.728E+00	
17	-1.446E+01	-3.054E-01	-1.920E-04	1.227E-02	2.774E+00	
18	-1.492E+01	-3.085E-01	-1.993E-04	1.258E-02	2.788E+00	

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 3 (1.108E+00 TO 2.350E+00 MEV).

I	A	B	C	D	E	F
1	-1.373E+01	-1.598E-01	-1.016E-05	3.262E-03	2.081E+00	
2	-1.828E+01	1.924E-01	2.974E-04	-1.266E-02	-5.194E+00	1.223E+01
3	-1.220E+01	-1.728E-01	-2.496E-05	4.028E-03	2.145E+00	
4	-1.327E+01	-1.843E-01	-3.958E-05	4.746E-03	2.201E+00	
5	-1.386E+01	-1.849E-01	-4.014E-05	4.776E-03	2.204E+00	
6	-1.340E+01	-1.917E-01	-4.703E-05	5.152E-03	2.238E+00	
7	-1.454E+01	-1.833E-01	-4.837E-05	4.943E-03	2.189E+00	
8	-1.486E+01	-1.832E-01	-4.925E-05	4.967E-03	2.187E+00	
9	-1.465E+01	-1.841E-01	-5.134E-05	5.050E-03	2.191E+00	
10	-1.491E+01	-1.843E-01	-5.135E-05	5.067E-03	2.192E+00	
11	-1.506E+01	-1.851E-01	-5.230E-05	5.116E-03	2.196E+00	
12	-1.482E+01	-1.854E-01	-5.256E-05	5.133E-03	2.198E+00	
13	-1.494E+01	-1.855E-01	-5.177E-05	5.115E-03	2.199E+00	
14	-1.327E+01	-2.107E-01	-5.594E-05	5.941E-03	2.339E+00	
15	-1.383E+01	-2.131E-01	-6.815E-05	6.358E-03	2.345E+00	
16	-1.211E+01	-2.036E-01	-4.032E-05	5.247E-03	2.309E+00	
17	-1.458E+01	-2.116E-01	-5.310E-05	5.920E-03	2.346E+00	
18	-1.504E+01	-2.142E-01	-5.755E-05	6.146E-03	2.358E+00	

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 4 (2.350E+00 TO 4.060E+00 MEV).

I	A	B	C	D	E	F
1	-1.363E+01	-1.813E-01	-9.736E-05	6.066E-03	2.053E+00	
2	-1.173E+01	-1.774E-01	-9.213E-05	5.835E-03	2.024E+00	
3	-1.135E+01	-1.522E-01	-6.122E-05	4.386E-03	1.816E+00	
4	-1.127E+01	-9.306E-02	2.078E-05	7.392E-04	1.390E+00	
5	-2.165E+01	4.282E-01	4.729E-04	-2.273E-02	-9.477E+00	1.838E+01
6	-1.187E+01	-1.018E-01	2.508E-05	8.536E-04	1.505E+00	
7	-1.265E+01	-1.117E-01	-1.602E-05	2.208E-03	1.487E+00	
8	-2.298E+01	4.518E-01	4.764E-04	-2.330E-02	-1.008E+01	1.938E+01
9	-2.265E+01	4.551E-01	4.772E-04	-2.339E-02	-1.013E+01	1.941E+01
10	-1.263E+01	-1.068E-01	-2.047E-05	2.216E-03	1.404E+00	
11	-1.270E+01	-1.129E-01	-3.522E-05	2.763E-03	1.418E+00	
12	-2.450E+01	8.461E-01	6.988E-04	-3.798E-02	-1.834E+01	3.172E+01
13	-2.475E+01	8.480E-01	6.885E-04	-3.771E-02	-1.855E+01	3.213E+01
14	-1.233E+01	-8.256E-02	1.038E-04	-1.700E-03	1.531E+00	
15	-1.438E+01	-1.736E-01	-3.049E-05	4.190E-03	2.144E+00	
16	-1.270E+01	-1.661E-01	-1.247E-05	3.385E-03	2.113E+00	
17	-1.514E+01	-1.711E-01	-1.925E-05	3.798E-03	2.137E+00	
18	-1.561E+01	-1.755E-01	-2.914E-05	4.184E-03	2.157E+00	

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 5 (4.060E+00 TO 6.360E+00 MEV).

I	A	B	C	D	E	F
1	-1.249E+01	-3.146E-01	-2.843E-04	1.473E-02	2.656E+00	
2	-1.570E+01	-2.406E-02	-3.079E-05	1.578E-03	-3.283E+00	9.907E+00
3	-1.670E+01	7.810E-02	3.826E-05	-2.555E-03	-5.320E+00	1.297E+01
4	-1.636E+01	1.309E-01	8.910E-05	-5.236E-03	-5.787E+00	1.299E+01
5	-1.767E+01	1.467E-01	9.875E-05	-5.816E-03	-6.239E+00	1.388E+01
6	-1.748E+01	1.839E-01	1.391E-04	-7.801E-03	-6.727E+00	1.450E+01
7	-1.727E+01	1.066E-01	7.937E-05	-4.421E-03	-5.246E+00	1.217E+01
8	-1.734E+01	1.011E-01	7.323E-05	-4.136E-03	-5.123E+00	1.192E+01
9	-1.690E+01	9.352E-02	6.315E-05	-3.679E-03	-5.017E+00	1.174E+01
10	-1.024E+01	-2.724E-02	-3.363E-05	1.398E-03	-1.637E+00	4.725E+00
11	-7.951E+00	-1.655E-01	-1.558E-04	7.700E-03	1.186E+00	
12	-6.989E+00	-1.831E-01	-1.723E-04	8.672E-03	1.238E+00	
13	-7.593E+00	-1.870E-01	-1.853E-04	9.111E-03	1.270E+00	
14	-8.706E+00	-3.052E-02	5.665E-05	-1.744E-03	6.714E-01	
15	-1.574E+01	3.327E-01	2.718E-04	-1.500E-02	-8.414E+00	1.565E+01
16	-6.534E+00	-2.849E-02	2.213E-05	-9.585E-04	4.897E-01	
17	-2.323E+01	2.438E-01	3.304E-04	-1.472E-02	-6.285E+00	1.405E+01
18	-1.635E+01	-1.636E-01	-2.636E-05	3.771E-03	2.086E+00	

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 6 (6.360E+00 TO 8.180E+00 MEV).

I	A	B	C	D	E	F
1	-1.586E+01	-1.927E-02	-3.746E-06	6.755E-04	-3.169E+00	9.687E+00
2	-1.399E+01	-1.135E-02	2.928E-06	3.127E-04	-3.289E+00	9.826E+00
3	-1.468E+01	6.853E-02	5.401E-05	-2.829E-03	-4.896E+00	1.220E+01
4	-8.098E+00	-2.378E-01	-2.098E-04	1.079E-02	1.958E+00	
5	-8.872E+00	-2.462E-01	-2.216E-04	1.131E-02	2.019E+00	
6	-8.156E+00	-2.278E-01	-2.010E-04	1.030E-02	1.875E+00	
7	-9.376E+00	-2.294E-01	-1.924E-04	1.009E-02	1.952E+00	
8	-9.602E+00	-2.270E-01	-1.909E-04	9.993E-03	1.928E+00	
9	-9.266E+00	-2.264E-01	-1.920E-04	1.002E-02	1.912E+00	
10	-1.002E+01	4.605E-02	6.292E-05	-2.968E-03	-2.707E+00	6.482E+00
11	-1.018E+01	4.328E-02	5.876E-05	-2.787E-03	-2.681E+00	6.457E+00
12	-5.876E+00	-1.492E-01	-1.162E-04	6.152E-03	1.135E+00	
13	-9.757E+00	3.159E-02	4.239E-05	-2.057E-03	-2.524E+00	6.177E+00
14	-8.928E+00	5.722E-02	4.980E-05	-2.823E-03	-3.105E+00	6.992E+00
15	-9.783E+00	6.531E-02	6.021E-05	-3.273E-03	-3.212E+00	7.216E+00
16	-9.520E+00	1.080E-01	9.415E-05	-5.195E-03	-4.031E+00	8.515E+00
17	-1.839E+01	4.668E-01	4.549E-04	-2.318E-02	-9.865E+00	1.753E+01
18	-2.337E+01	1.941E-01	2.627E-04	-1.166E-02	-5.645E+00	1.314E+01

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 7 (8.180E+00 TO 1.000E+01 MEV).

I	A	B	C	D	E	F
1	-1.501E+01	-3.909E-02	-2.120E-05	1.618E-03	-2.803E+00	9.095E+00
2	-1.310E+01	-3.336E-02	-1.680E-05	1.365E-03	-2.883E+00	9.169E+00
3	-1.382E+01	4.758E-02	3.439E-05	-1.802E-03	-4.519E+00	1.159E+01
4	-1.344E+01	8.423E-02	6.998E-05	-3.691E-03	-4.735E+00	1.127E+01
5	-1.462E+01	9.726E-02	7.667E-05	-4.131E-03	-5.124E+00	1.203E+01
6	-1.374E+01	1.103E-01	9.236E-05	-4.894E-03	-5.154E+00	1.183E+01
7	-1.481E+01	1.125E-01	1.065E-04	-5.362E-03	-5.061E+00	1.172E+01
8	-1.530E+01	1.163E-01	1.063E-04	-5.424E-03	-5.200E+00	1.199E+01
9	-1.360E+01	5.858E-02	6.027E-05	-2.950E-03	-3.880E+00	9.639E+00
10	-5.798E+00	-1.445E-01	-1.145E-04	5.999E-03	1.118E+00	
11	-9.288E+00	3.900E-02	4.464E-05	-2.268E-03	-2.673E+00	6.371E+00
12	-8.701E+00	2.591E-02	3.206E-05	-1.611E-03	-2.500E+00	6.116E+00
13	-8.811E+00	2.317E-02	2.313E-05	-1.300E-03	-2.468E+00	6.030E+00
14	-5.894E+00	-1.559E-01	-1.295E-04	6.674E-03	1.228E+00	
15	-9.250E+00	4.993E-02	4.627E-05	-2.520E-03	-2.981E+00	6.930E+00
16	-8.372E+00	7.192E-02	6.423E-05	-3.536E-03	-3.422E+00	7.589E+00
17	-1.019E+01	5.299E-02	3.624E-05	-2.268E-03	-3.130E+00	7.066E+00
18	-1.330E+01	1.521E-01	1.222E-04	-6.828E-03	-4.908E+00	9.906E+00

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 8 (1.000E+01 TO 1.220E+01 MEV).

I	A	B	C	D	E	F
1	-9.754E+00	-3.142E-01	-2.650E-04	1.425E-02	2.661E+00	
2	-7.795E+00	-3.098E-01	-2.615E-04	1.405E-02	2.619E+00	
3	-7.179E+00	-2.971E-01	-2.713E-04	1.400E-02	2.406E+00	
4	-1.207E+01	3.792E-02	2.365E-05	-1.360E-03	-3.938E+00	9.929E+00
5	-1.332E+01	4.932E-02	2.867E-05	-1.714E-03	-4.319E+00	1.071E+01
6	-1.266E+01	6.774E-02	4.807E-05	-2.688E-03	-4.490E+00	1.078E+01
7	-6.077E+00	-1.408E-01	-8.176E-05	5.030E-03	1.224E+00	
8	-8.445E+00	-2.383E-01	-2.090E-04	1.084E-02	1.948E+00	
9	-6.487E+00	-1.623E-01	-1.130E-04	6.406E-03	1.366E+00	
10	-7.828E+00	-8.536E-03	-6.750E-06	2.378E-04	-1.924E+00	5.146E+00
11	-5.361E+00	-1.579E-01	-1.381E-04	7.019E-03	1.147E+00	
12	-4.922E+00	-1.620E-01	-1.436E-04	7.291E-03	1.154E+00	
13	-4.902E+00	-1.612E-01	-1.457E-04	7.356E-03	1.123E+00	
14	-9.319E+00	6.649E-02	6.325E-05	-3.342E-03	-3.275E+00	7.429E+00
15	-5.097E+00	-1.579E-01	-1.437E-04	7.173E-03	1.149E+00	
16	-4.349E+00	-1.555E-01	-1.365E-04	6.870E-03	1.146E+00	
17	-5.453E+00	-1.642E-01	-1.581E-04	7.781E-03	1.138E+00	
18	-6.679E+00	-1.541E-01	-1.496E-04	7.323E-03	1.072E+00	

NEUTRON-INDUCED SECONDARY GAMMA TRANSMISSION FUNCTION COEFFICIENTS
FOR NEUTRONS IN SOURCE BAND 9 (1.220E+01 TO 1.500E+01 MEV).

I	A	B	C	D	E	F
1	-1.364E+01	-9.378E-02	-7.501E-05	4.422E-03	-1.975E+00	7.792E+00
2	-1.158E+01	-9.237E-02	-7.338E-05	4.331E-03	-1.936E+00	7.640E+00
3	-1.147E+01	-3.656E-02	-4.204E-05	2.218E-03	-2.933E+00	8.865E+00
4	-1.023E+01	-2.987E-02	-2.975E-05	1.581E-03	-2.415E+00	7.198E+00
5	-1.169E+01	-1.248E-02	-2.182E-05	1.022E-03	-2.959E+00	8.283E+00
6	-1.059E+01	-1.239E-02	-1.822E-05	8.621E-04	-2.723E+00	7.634E+00
7	-4.939E+00	-1.093E-01	-4.897E-05	3.434E-03	9.248E-01	
8	-7.611E+00	-1.734E-01	-9.383E-05	6.242E-03	1.563E+00	
9	-5.216E+00	-1.155E-01	-5.452E-05	3.742E-03	9.812E-01	
10	-4.440E+00	-1.114E-01	-5.943E-05	3.853E-03	8.440E-01	
11	-4.786E+00	-1.102E-01	-5.748E-05	3.753E-03	8.556E-01	
12	-5.633E+00	-1.290E-01	-6.637E-05	4.424E-03	1.090E+00	
13	-4.265E+00	-1.204E-01	-6.983E-05	4.412E-03	8.753E-01	
14	-7.692E+00	-3.096E-03	8.656E-07	-1.738E-04	-1.749E+00	4.738E+00
15	-4.318E+00	-1.077E-01	-5.692E-05	3.673E-03	8.387E-01	
16	-6.075E+00	-2.134E-02	-7.657E-06	4.783E-04	-1.359E+00	3.944E+00
17	-4.340E+00	-1.098E-01	-6.225E-05	3.933E-03	8.151E-01	
18	-8.213E+00	-1.319E-02	-1.508E-05	6.380E-04	-1.642E+00	4.396E+00

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