3 3679 00060 2476

BNWL-236
UC-34, Physics

ISOSHL D - A COMPUTER CODE FOR
GENERAL PURPOSE ISOTOPE SHIELDING ANALYSIS

R. L. Engel
Scientific Programming
COMPUTER SCIENCE CORPORATION

J. Greenborg
Engineering Development Department
BATTELLE-NORTHWEST

M. M. Hendrickson
Research and Engineering Section
Hanford Atomic Products Department
GENERAL ELECTRIC COMPANY

June 1966

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in USA. Price \$4.00. Available from the
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards
U.S. Department of Commerce
Springfield, Virginia

ABSTRACT

ISOSHL D is a computer code to perform gamma ray shielding calculations for isotope sources in a wide variety of source and shield configurations. Attenuation calculations are performed by point kernel integration; for most geometries by Simpson's rule numerical integration. Source strength in uniform or exponential distribution (where applicable) may be calculated by the linked fission product inventory code RIBD or by other options as desired. Buildup factors are calculated by the code based on the number of mean free paths of material between the source and detector points, the effective atomic number of a particular shield region (the last unless otherwise chosen), and the point isotropic NDA buildup data available as Taylor coefficients in the effective atomic number range of 4 to 82. Other data needed to solve most isotope shielding problems of practical interest are linked to ISOSHL D in various libraries.

TABLE OF CONTENTS

INTRODUCTION	1
THEORY.	3
Point Kernel Integration	3
Calculation of the Volumetric Source Strength.	5
Mixed Mass Attenuation Coefficients	7
The Buildup Factor	8
ISOSHL D PROGRAM AND SUBROUTINES	10
ISOSHL D Main Program	10
Subroutine RIBD	10
Subroutine CONTRL	13
Subroutine ADJUST	13
Subroutine BFUNC	14
The Attenuation Routines	14
RECOMMENDATIONS	15
ACKNOWLEDGEMENT	15
APPENDIX A INPUT PREPARATION	16
Use of Code.	16
Source Type	16
Choice of Source Type	17
Data Sequence.	18
Data Card Descriptions	19
Geometry Selections	25
APPENDIX B ISOSHL D ATTENUATION EQUATIONS	31
Point Source-Slab Shields.	31
Line Source-Slab Shields	31
Spherical Source	32
Shperical Shields	32
Slab Shields.	34

Truncated Cone Source-Slab Shields	35
Disc Source (Detector on Center Line)- Slab Shields	36
Cylindrical Source	37
Cylindrical Shields	38
Slab Shields.	39
Cylinder with Detector at End on Center Line-Slab Shield.	39
Rectangular Solid-Slab Shield	40
APPENDIX C CODE LISTING	41
APPENDIX D ISOSHL D LIBRARIES	96
RIBD Isotope Library	96
Photon Probability Library	97
Mass Attenuation Coefficient Library	98
Buildup Factor Library	99
APPENDIX E SAMPLE PROBLEMS	131
Activity of Co ⁶⁰ BNL Standard Strip.	131
Dose Rates from Aqueous-filled Cylinders	134
REFERENCES	137

ISOSHLD - A COMPUTER CODE FOR
GENERAL PURPOSE ISOTOPE SHIELDING ANALYSIS

INTRODUCTION

Shielding calculations associated with design and operation of atomic energy installations have traditionally been hand calculations which are time consuming and very approximate. This computer program, ISOSHLD (pronounced Isoshield), attempts to fill the need for a convenient semirigorous calculational method to handle the majority of these problems.

The program was also designed to include most basic data required for these calculations. Thus, considerable effort has been expended in compiling isotopic decay, material attenuation, buildup factor, and other required basic data for these types of shielding calculations. These data were placed in libraries chained to the code so that for most calculations all basic data are supplied.

For most problems the user need only supply:

- The geometry and material composition of the source
- The geometry and materials of the shields.

Optional modes of data entry are available for solving special problems.

The method used in the attenuation calculation is point kernel integration, i.e., the dose at the exposure point is the contribution from a large number of individual point sources. A numerical integration is carried out over the source volume to obtain the total dose.

The code obtains solutions for any combination of the variables listed below:

Shield and Source Geometry

1. Point
2. Line
3. Sphere
4. Sphere with slab shields
5. Truncated cone
6. Disc
7. Cylinder
8. Cylinder with slab shields
9. Cylinder end
10. Rectangular solid
11. Infinite slab and plane
12. Exponential source distribution where applicable

Isotope Selection from Calculated Fission Products

1. Noble gases
2. Halogens
3. Volatile solids
4. All except the above 3
5. All fission products
6. Individual isotopes by individual specification.

Source Type

1. Calculated source strength from known fuel irradiation exposure (See Note.)
2. Specify curies of isotopes in library--both fission products and activation products
3. Source strength in photons of specific energies for source volume.

Note: If Source Type 1 is specified, the irradiation history of the fuel must be described by supplying:

1. Initial conversion ratio
2. Fuel exposure time
3. Fast fission in U-238 per thermal fission
4. Reactor power history
5. Cooling time
6. Proper choice of above variables also approximates fuel irradiation in a fast reactor.

Shield Region Geometry and Materials

1. Number of regions - up to 5
2. Material in each region-choice of 18 (maximum of 20) materials in library
3. Material density in each region - 5 materials allowed in a region
4. Region and material for which buildup is most important.

THEORY

Point Kernel Integration

Figure 1 illustrates a point source, S_o (in this example within a large cylindrical volume, S_v), of gamma ray photons which emits with equal intensity in all directions.

FIGURE 1. Point Source Within a Finite Volume

The dose rate at point P from photons originating at S_o is given by:

$$D = \frac{S_o B e^{-b_1}}{K 4 \pi \rho^2} \quad (1)$$

where:

$$b_1 = \sum_{i=1}^N \mu_i t_i$$

D = dose rate, R/hr

S_o = emission rate of gamma rays, photons/sec

B = buildup factor, dimensionless

μ_i = linear absorption coefficient of the i th shield, cm^{-1}

t_i = slant distance through the i th shield, cm

K = conversion of gamma ray flux to dose rate

ρ = distance from source to dose point, cm

N = number of shields.

The dose rate at point P from photons of all initial energies originating at all points within the source volume, S_v , is given by

$$D_{\text{tot}} = \int_E \int_V \frac{S_o(E,V) B(E,b_1) e^{-b_1}}{K(E) 4\pi\rho^2(V)} dV dE \quad (2)$$

Equation 2 may be analytically integrated for a few simple geometries, and this technique is used to obtain some of the extended source dose formulas given in the shielding handbooks.^(1,2,3)

Equation 2 may be numerically integrated for virtually any source geometry; however, only regular geometric shapes are normally considered suitable for computer integration. Complex geometric shapes are generally constructed by synthesis of simple shapes.

This numerical integration technique (commonly referred to as point kernel integration) consists of dividing the source volume into a number of differential volumes. The source energy is divided into a number of energy groups narrow enough to consider the buildup factors, attenuation coefficients, and dose conversion

factors constant over the energy range of the group. Each monoenergetic differential volume source is then treated as a point source and the dose from each of these point sources [Equation (1)] is calculated. For each point source, new values of B , μ_i , t_i , ρ , S_0 , b_1 and K are needed and are calculated using trigonometric relationships and basic data appropriate to the system geometry, source photon energies, and materials. Integration over source volume and source energy is then obtained by summing the dose contributions from all differential source volumes over all source energies. The overall calculation is handled as described above; however, it is necessary to describe in greater detail portions of these calculations.

Calculation of the Volumetric Source Strength

ISOSHLTD allows three methods (modes) of evaluating source strength and source distribution.

Method 1

If the source consists of fission nuclides and other decay and neutron activation products in fuel irradiated under known conditions, the subroutine RIBD⁽⁴⁾ may be used. RIBD is a fission product inventory code that calculates the quantity of all radioisotopes in a fuel sample at various times after exposure. A choice can be made of one, any, several groupings, or all of these isotopes; and a factor representing a recovery efficiency may be applied.

The library of RIBD at the time of this publication contains 450 isotopes. A gamma photon abundance library is also chained to the code which contains these 450 fission products plus 48 activation products. This library contains the energy yield and abundance of all principal gamma rays emitted by each isotope during decay. At the completion of the

RIBD calculation, ISOSHL D calculates the photon yield from each isotope using the RIBD results (in curies) and the data from the photon library. During the process of calculating photon yield, photon energies are examined; and photon yields (photons/sec) are summed into 16 energy groups. The group structure is indicated in Table I.

TABLE I. Energy Structure Used in Mode 1 and 2 Source Strength Calculations.

<u>Group No.</u>	<u>Group Upper Energy Limit, MeV</u>	<u>Group Average Energy, MeV</u>
1	0.2	0.15
2	0.3	0.25
3	0.4	0.35
4	0.55	0.475
5	0.75	0.65
6	0.9	0.825
7	1.1	1.0
8	1.35	1.225
9	1.6	1.475
10	1.8	1.7
11	2.0	1.9
12	2.2	2.1
13	2.4	2.3
14	2.6	2.5
15	2.8	2.7
16	∞	3.0

The attenuation calculations are based on energy flux, the product of flux and photon energy. The result is that the source energy and flux are effectively corrected to the average group energy (the energy used for flux to dose conversion, buildup factors, attenuation coefficients, etc.). Error can develop in Groups 1 and/or 16 if there are source photons significantly less than 0.15 MeV or greater than 3.0 MeV.

Method 2

If a source consists of a known quantity (in curies) of some isotopes contained in the photon abundance library, the code may be

operated to specify the isotopes (by library number) and the curies of each. The code will then evaluate the photon abundance per energy group.

Method 3

If only photon generation rates and photon energies are known, then these are read in. In this type of operation ISOSHL D does the attenuation calculations at the specified photon energies. Attenuation coefficients, buildup factors, etc., are interpolated from the 16 group point data in the material and buildup factor libraries.

For the truncated cone (including slab), disc, cylinder on end, and line source, an exponential source distribution may be specified. The formula is:

$$S(x) = Ce^{ax} \quad (3)$$

where a is a positive or negative number specified as input variable SSV1. If SSV1 is not specified, ISOSHL D assumes a zero value; hence, a uniform source distribution is created. The constant C is evaluated by ISOSHL D using the value of " a " and the total source strength.

Mixed Mass Attenuation Coefficients

Linked to ISOSHL D is a library of mass attenuation coefficients in 16 energy groups for 18 common materials. The materials are ¹water, ²tissue, ³air, ⁴hydrogen, ⁵lithium, ⁶carbon, ⁷aluminum, ⁸titanium, ⁹iron, ¹⁰zirconium, ¹¹tin, ¹²tungsten, ¹³lead, ¹⁴uranium, and ordinary ¹⁵magnetite, and ¹⁶ferrophosphorous concretes. The attenuation coefficients are listed for materials of unit density. For each source and shield region the code input requires the library material number and the material density. Up to five materials per region are allowed. Thus ISOSHL D calculates region mixed mass

attenuation coefficients, μ_i , for each region, i , by

$$\mu_i = \sum_{j=1} d_j \mu_j \quad (4)$$

where j is the index of materials specified to be in region i . If a combination of the 18 materials above will not adequately describe a desired shield material, the code user may add additional materials to this library.

The Buildup Factor

Linked to ISOSHLD is a buildup factor library which contains, for 16 photon energies, the coefficients A , α_1 , and α_2 of Taylor's equation⁽¹⁾

$$B = A e^{-\alpha_1 b_1} + (1-A) e^{-\alpha_2 b_1}, \quad (5)$$

for dose buildup from a point isotropic source in five materials: water, aluminum, tin, tungsten, and lead. This material range covers the effective atomic numbers (EAN) from 4 to 82. The data in this library were taken from Goldstein⁽⁵⁾, page 376.

In the process of kernel integration, the buildup factor for each differential source volume is calculated for all of the materials between source point and dose point. Values of t_i , the source point to dose point line of sight distance through the source and shield regions are calculated for each new source point by trigonometric relationships. Values of μ_i for each shield region are obtained from Equation (4). ISOSHLD then calculates b_1 for the line of sight from the source point to dose point and b_1 is used in Equation (5) to obtain the correct buildup, B .

There are several considerations to be discussed in regard to how A , α_1 , α_2 (from the buildup factor library) are used. The

method of selection is by effective atomic number. The effective atomic number (EAN) has been defined in a number of ways (discussed in Reference 6); however, within ISOSHL D it is defined as

$$EAN = \frac{\sum_j \frac{d_j Z_j}{A_j}}{\sum_j \frac{d_j}{A_j}}$$

where

Z_j = atomic number of species j in the shield

A_j = atomic weight of species j in the shield

d_j = density of species j in the shield.

A particular shield region should be chosen whose characteristics will be used in calculating buildup through all shields in the system. This region is usually the last shield region, provided the region is thick compared to the sum thickness of the other regions. If no buildup region choice is made, the code will use the last defined region. The EAN is then calculated for the chosen region. ISOSHL D brackets this effective atomic number in the buildup factor table, calculates the buildup factors for both effective atomic numbers available in the library and then interpolates between these to obtain the final buildup factor for use in the numerical integration.

Since the atomic weight for each material in the library is required for use in evaluating EAN, an effective atomic weight (EAW) was defined for the mixed elemental materials given in the library. These were calculated by:

$$EAW = \frac{\sum_k N_k A_k}{\sum_k N_k}$$

where

N_k = atomic density of species k in the mix

A_k = atomic weight of species k in the mix.

In summary, the buildup treatment in ISOSHLD includes all mean free paths in material between the source point and dose point and has the buildup characteristics of the last (or a particular specified shield region). Treatment of buildup for multiregion shields has been discussed in the literature^(5,7) and a number of approaches are suggested for various shield configurations. The approach used by ISOSHLD is believed to be the most general and gives a good approximation for most shield configurations.

ISOSHLD PROGRAM AND SUBROUTINES

The following is a brief description of the ISOSHLD program and its subroutines. The reader is referred to Appendix A for Input Instructions; Appendix B for definitions of geometry and variables and for equations solved by ISOSHLD; and to Appendix C for a FORTRAN IV listing.

ISOSHLD Main Program

The main program is a control which calls in the links of ISOSHLD. To fit a 32 k memory computer, it was necessary to link the subroutine RIBD to the rest of ISOSHLD. The main program calls RIBD if necessary and then enters subroutine CONTRL, the main routine, to calculate attenuation.

Subroutine RIBD

Radio-Isotope Buildup and Decay (RIBD) is the name given to a Hanford-developed computer program which has been linked to ISOSHLD for the calculation of in-reactor fission product inventories.

RIBD is a general purpose, multiple path, multiple chain, grid processor. When used for fission product calculations, RIBD includes a library containing pertinent nuclear data for 450 nuclides including both ground states and isomeric states where they are known to exist, whether formed directly from fissions of U^{235} , U^{238} , and Pu^{239} or subsequent to fission as a result of neutron capture and/or chain decay.

RIBD organizes the various members described by the library into a grid with the various linkages established from the chain branching data, yield data and neutron capture cross sections with their branching ratios. Chain decay includes not only the simple member-to-member cascade but also the more complex form where branching may partially or completely skip one or two intervening members.

A sample of a portion of the grid is shown in Figure 2. Upper boxes of a pair, where they exist, refer to isomeric states, lower boxes refer to ground states. Y235 and Y239 refer to variable direct yield rates from U^{235} and Pu^{239} respectively. Horizontal transitions between boxes are by neutron capture; vertical transitions are by beta decay and/or isomeric transition. Ground states are allowed to have up to seven source paths, isomeric states up to five source paths. Since time factors and neutron flux levels exert competing influences on each other, inventories of nuclides are affected to varying degrees by the reactor mode of operation. Consequently, RIBD was designed to follow the operating history of the fuel in detail as closely as the user desires through the entire residence period including power level changes, shutdowns, and outages.

RIBD was modified for inclusion in ISOSHL D to calculate only the amount (in curies) of final products at up to five

different times after irradiation is complete; however, the original program calculates activity levels (expressed in curies), concentrations (expressed in gram-atoms), heat generation rates (both beta and gamma), and integrated energy releases between time points for any set of times (up to 90) following shutdown.

FIGURE 2. Sample Reaction Grid Used in RIBD

Subroutine CONTRL

Subroutine CONTRL is the main program to calculate gamma attenuation for various source and shield configurations. CONTRL programs the following functions in the approximate order shown:

1. Reads in all library data other than the RIBD data.
2. Reads all problem data other than data used for RIBD calculation.
3. Builds a source isotope selection table based on input.
4. Calculates mixed mass attenuation coefficients for all regions and the effective atomic number for the characteristic buildup region.
5. Builds source strength table in 16 groups for MODE 1 or 2 operation and up to 16 groups for MODE 3 operation.
6. Extracts 2 sets of Taylor's coefficients from the buildup library in 16 energy groups based on effective atomic number of the characteristic region.
7. Calls the appropriate subroutine (based on input information) to perform kernel integration in the given source geometry.
8. Converts flux to dose and writes the problem report, i.e., the results.

Subroutine ADJUST

ADJUST is called by various geometry routines to reduce the thickness of the last shield or add an additional air shield as necessary to make the total shield thickness equal the specified source point to dose point distance.

Subroutine BFUNC

BFUNC is called by all attenuation routines to interpolate (on effective atomic number) the buildup factors as calculated from data in the library.

The Attenuation Routines

The attenuation routines evaluate the equations given in Appendix B. Table II indicates the relation between these subroutines and the equations of Appendix B. The reader should examine the portion of Appendix B applicable to a particular subroutine of interest.

TABLE II. Source Attenuation Geometry Subroutine Index

<u>Subroutine (or Function)</u>	<u>Geometry Called for</u>	<u>Appendix B Reference</u>
CYL	Cylindrical source (slab & cyl. shields)	Sect. 6 a, b
DSIC	Disc source	Sect. 5
DSCSRC	Disc source	Sect. 5
ENDCYL	Cylindrical source (end shields)	Sect. 7
E1(ARG)	Truncated cone and infinite slab	Sect. 4
E1(ARG)	Truncated cone and infinite slab	Sect. 4
F1(T,A)	Truncated cone and infinite slab	Sect. 4
LINE	Line source	Sect. 2
POINT	Point source	Sect. 1
RECT	Rectangular source	Sect. 8
SPHERE	Spherical source (slab & spher. shields)	Sect. 3 a,b
SPHSRC	Spherical source (slab & spher. shields)	Sect. 3 a,b
TCONE	Truncated cone and infinite slab and plane	Sect. 4
SIMPS	Generalized Simpsons Integration Used in DSIC, Line, and SPHERE	
TERP	Generalized Interpolation Routine Used in CONTRL	

RECOMMENDATIONS

1. ISOSHL D may be used for routine solution of radiation problems associated with isotopes handling, production, and use. Only those isotopes (or isotope mixtures) which are pure beta emitters or yield a significant quantity of neutrons via spontaneous fission, (γ, n) , or (α, n) reactions may not be treated adequately by ISOSHL D. A radionuclide which yields a significant fraction of photons of energy higher than 3 MeV will also require special consideration.
2. The capability of performing bremsstrahlung calculation (source spectra, source strength, and dose rate) should be added to ISOSHL D. This modification requires the addition of a new energy group structure, 0.01 to 2 MeV, suitable for low energy "beta only" decay. A bremsstrahlung source generator would be linked to the code either in the form of a calculational scheme or a table of resolved spectra. Additional library data would be added to handle the wider range of problems within the code capability. At the time of publication of this report, this work has been started.
3. The capabilities of the code should be further extended by the addition of a neutron attenuation routine.

ACKNOWLEDGEMENT

The authors are indebted to R. O. Gumprecht for use of his unpublished RIBD code and data library. Also appreciated are the many discussions with Mr. Gumprecht regarding the use of this code and interpretation of the input and output. The authors are also indebted to R. L. Junkins, Manager, Nuclear Safeguards and Engineering, Battelle Northwest. Work on this code commenced under the sponsorship of General Electric and Mr. Junkins' organization before Hanford's diversification under several contractors. Since diversification, the code has been completed as a joint effort.

APPENDIX A

INPUT PREPARATION

APPENDIX A

INPUT PREPARATION

USE OF THE CODE

The user has the option of choosing one of three types of source specifications and one of 10 source geometries. Up to five shields (the source is always the first shield), composed of up to 18 materials each may be used. The code adds a sixth air shield if the user requests a calculation at some distance beyond the fifth shield.

The amount and kind of input data required by the code depends upon which of the three source specification options is chosen. The source geometry and shield composition are not affected by the way one wishes to specify the source strength. The selection of source type is described below:

Source Type

The Isoshield code has three source input options. The selection of these options is controlled by the input variable MODE. If MODE = 1, a fission product inventory is calculated internally. With this option numerous input parameters are required which specify the burnup and decay history of the fuel. The required parameters include the conversion ratio, reactor power, exposure time, flux time, the U^{235} absorption cross section, the ratio of fast fissions in U^{238} to thermal fissions in fuel, and the fuel cooling times after shutdown at which one desires the dose calculations to be made. Four cooling times after shutdown are allowed. The code always includes an additional calculation at zero time after shutdown.

If MODE = 2, the user arbitrarily specifies the source strength (in curies) of a given isotope or isotopes. A source of any mixture of isotopes is permitted. If MODE = 3, the user specifies the source in terms of the photon abundance and photon energy.

Any geometry option may be used with any of the three source input options.

Choice of Source Type

Typical problems the code would handle are given in Examples 1 and 2.

Example 1. Gamma Radiation Dose in Tissue at Some Distance from a Cloud of Fission Gases.

The following options are available:

- Request the code to calculate the fission product inventory, and by using the weighting factor GROUP, adjust the inventory of fission products in the cloud to account for various removal factors such as retention in the fuel, plateout in the confiner, removal by fog sprays, etc.
- If the fission product inventory is available, specify the number of curies of each isotope contained in the cloud.
- The source may also be described in terms of the number of photons emitted per second from the cloud at given energies.

In all of the above cases it would be necessary to specify the geometry of the cloud, the density of air in the cloud, and the density in air intervening between the cloud and the point at which the dose was to be calculated. If, in addition, it is desired that the dose be calculated in tissue, an additional shield of tissue would be specified and the dose calculated at some depth in this shield.

Example 2. Gamma Radiation Dose in Tissue Some Distance from a Co^{60} Cylindrical Source Enclosed in a Lead Shielded Cask with a Steel Inner and Outer Liner

Specify the source (in curies) of Co^{60} contained.
(MODE = 2, WEIGHT (472) = curies of Co^{60})

Shield region 1 is the source itself, and appropriate materials are specified to describe this region. The second shield is the steel inner liner, the third the lead shielding, and the fourth the steel outer liner. The fifth shield is the air between the tissue and the cask, and the sixth shield the tissue in which the dose is to be calculated. In this example the number of shields exceeds the amount allowable, which is five, thus the steel inner liner and source must be lumped together and considered as one shield, or the thickness of the steel inner liner must be added to the outer to reduce the number of shields.

DATA SEQUENCE

The number of data cards required is variable depending on the source mode and whether multiple cases are desired.

The card sequence is given in Table A-I. All isotope data except the source strength is contained in the Isoshld library and input on tape unit A5.

A description of each data card and the required card sequence follow. (Several tape handling cards are required in addition to cards listed below. These, however, are dependent on the computer system used. Hanford Code users will be supplied with this information as necessary upon contacting any of the authors.)

TABLE A-I. Data Card Sequence

<u>Card Number</u>	<u>Use</u>
1	MODE Card specifies the type of source.
1a, 1b, 1c	RIBD parameter cards - Used only when MODE = 1.
2	Title Card - the title is printed out at the top of each output page
3...N	Namelist Cards - as many may be used as are required. Usually 3 will suffice.
N+1...N+20	Up to 20 cards describing the density of up to 20 materials in the 5 allowable shields. One card is used for each material if it is present in any or all of the 5 shields.

DATA CARD DESCRIPTIONSCard 1 - MODE Card

Card 1 is the MODE Card and determines the manner in which the source will be specified.

- MODE = 1: an internally calculated fission product inventory based on a specified quantity of fuel and input parameters describing the burn-up history of the uranium fuel.
- MODE = 2: arbitrary specification of the source strength in curies of a given isotope. A source of mixed isotopes is permitted.
- MODE = 3: arbitrary specification of the source in terms of the photon abundance and photon energy.

Card 1

<u>Column</u>	<u>Format</u>
11	I1

Cards 1a, 1b, 1cRIBD Cards

These cards are used only if MODE = 1 on Card 1.

Card 1a

<u>Column</u>	<u>Format</u>	<u>Variable</u>	<u>Use</u>
1-36	6A6	CASER	Title on RIBD pages
41-50	E10.4	CON	Conversion ratio of fuel, grams of plutonium produced per megawatt day at beginning of cycle.

Card 1b

1-10	E10.4	PO	Power, megawatts
11-20		TIME	Irradiation time, days
21-30		T	Exposure = $\phi \sigma_a t$ ϕ = neutron flux, neutrons/(cm) ² (sec) σ_a = U ²³⁵ absorption cross section, cm ² t = fuel irradiation time, sec
31-40	E10.4	SIGA25	U ²³⁵ absorption cross section in barns (absolutely necessary that flux be correctly related to power, PO)
41-50		DEL	$\Delta = \frac{\text{fast fissions in U}^{238}}{\text{thermal fission in fuel}}$

Card 1c

1-8	E8.3	DT(1)	Cooling times, sec
9-16		DT(2)	
17-24		DT(3)	
25-32		DT(4)	

Card 2 - Title Card

<u>Column</u>	<u>Format</u>	<u>Variable</u>	<u>Use</u>
1-72	12A6	TITLE	Words entered here are reprinted as a title at the head of a case. Each case requires a title card or blank card.

Cards 3 to N - Namelist Cards

(one or more namelist cards)

The data for each attenuation calculation consists of one title card (Card 2) and one or more cards using the Namelist format (Cards 3 to N). The first Namelist card (Card 3) must be blank in column 1, \$INPUT in column 2-7, followed by at least one blank, followed by data items. Additional cards must have a blank in column 1. The data items are separated by a comma, and the last data item must be followed by a \$. Data items must have one of the three following forms:

1. Variable name = constant, where variable name may be either subscripted or not.
2. Array name = set of constants (separated by commas).
The number of constants must be equal to the number of elements in the array. The constants must be in the same order as the array is in storage, i.e., the first subscript changes most rapidly. Example: If A is dimensioned 2x2, the constants must be in the following order: A(1), A(2,1), A(1,2), A(2,2).
3. Subscripted variable = set of constants (separated by commas). This form results in the set of constants being placed in consecutive array elements, starting with the element designated by the subscripted variable. The number of constants cannot exceed the

number of elements in the array between the given element in the array and the last element in the array.

The principal advantage of the namelist format is that all values that are not changed do not need to be specified for subsequent attenuation calculations. The variables that may be input in the namelist are given in Table A-II.

TABLE A-II. Table of Namelist Variables

<u>Variable</u>	<u>Array Size</u>	<u>Use</u>	<u>Value Units</u>	<u>Values</u>
NEXT		Program Control - Next Case Options		
GROUP (I)	(5)	Selects isotope group and weight factor	MODE 1 - none MODE 2 - not used MODE 3 - not used	any constant
WEIGHT (J)	(500)	Selects isotopes and weight factor or quantity	MODE 1 - none MODE 2 - curies MODE 3 - not used	any any
SOURCE (L,M)	(3,16)	Selects photon strength L = 1, value specifies number of photons L = 2, value specifies photon energy	MODE 1,2 - not used MODE 3 MeV	 any any
IGEOM		Program Control - Selects geometry	None	1 to 10
NSHLD		Specifies number of shields in problem		1 to 5
JBUF		Specifies the shield for which buildup is characteristic		1 to 5
T(K)		Thickness of shields 1 to 5, K = shield number	cm	any
SLTH	}	Geometry variables: For use see <u>Geometry Section</u>	cm	any
X			cm	any
Y			cm	any
ANG1			degrees	0° to 180°
ANG2			degrees	0° to 180°
ANG3			degrees	0° to 180°
NTHETA	}	Numerical Integration Control variables: For use see <u>Integration Control</u>		
NPSI				
DELR				
SSV1		Exponent for exponential source distribution	none	-10 ≤ SSV1 ≤ 10

NEXT

NEXT is a variable controlling attenuation calculations that instructs the program what to do after reading a set of data. It controls isotope selection and material in shields, not shielding geometry. There are 6 options corresponding to NEXT = 1,2,3,...,6.

- NEXT = 1 New isotope selection and new shield material compositions will be made; geometry may be changed.
- NEXT = 2 New isotope selection; geometry may be changed.
- NEXT = 3 New shield material compositions; geometry may be changed.
- NEXT = 4 Geometry change only may be made.
- NEXT = 5 Reinitialize all namelist input variables. In this case no calculation is made. A new set of namelist variable values must be specified in the following case.
- NEXT = 6 End of run. In this case no attenuation calculation is performed. NEXT may be set equal to 6 to accomplish a normal exit on the IBM 7090.

When NEXT = 1, 2, 3 or 4 any variables describing the geometry and dimensions may be changed. NEXT must be specified as 1 in the first case. In succeeding cases WEIGHT and GROUP are not initialized unless NEXT = 5. When NEXT = 1, shield materials are initialized and added isotopes are allowed, but the previous isotopes are carried over to the new case. They may be set to zero by setting their WEIGHT value equal to zero.

WEIGHT, GROUP, AND SOURCE

Any combination of the isotopes contained in the photon library may be selected for a particular case, using the two arrays GROUP and WEIGHT. GROUP has a dimension of 5 and WEIGHT has a dimension of 500. The subscript in the WEIGHT array corresponds to the location of the desired isotope in the photon library, i.e., WEIGHT (100) corresponds to the 100th isotope

in the library. The weight array is used to select individual isotopes and the group array is used to specify all isotopes, or a group of isotopes, contained in the library.

GROUP (1) Noble gases (Xe, Kr)

GROUP (2) Halogens (I, Br)

GROUP (3) Volatile Solids (Se, Te, Cs)

GROUP (4) All elements not included in first 3 groups

GROUP (5) All isotopes in the library

The value specified by the GROUP and WEIGHT arrays has a different meaning, depending on the value of program variable MODE. If MODE = 1, a value specified by group or weight is a weighting factor. The source activity (in curies) calculated by RIBD for a given isotope is in this case multiplied by the weighting factor specified for that isotope. When MODE = 2, the value specified by WEIGHT represents the total curies for a given isotope to be distributed throughout the source. When MODE = 3, WEIGHT and GROUP are replaced by SOURCE to define the total source strength.

Geometry Selections

The various geometries handled by Isoshield are described here along with the input parameters required for each geometry

Point Source - Slab Shields

INPUT VARIABLES

IGEOM = 1
X
Y

Line Source - Slab Shields

INPUT VARIABLES

IGEOM = 2
X = Dist to detector
ANG1 = Shield normal angle
ANG2 = Detector angle
SLTH = Source length
SSV1 = Exponent for exponential source strength distribution

NOTE: If the source is not completely contained in the first shield region, the thickness of the first shield region will be increased so the complete source is in the first shield region.

Spherical Source and Shields

INPUT VARIABLES

IGEOM = 3

X = Dist from center
to detector

T(1) = Source radius

NOTE: Constant source strength distribution only for spherical source

Spherical Source - Slab Shields

INPUT VARIABLES

IGEOM = 4

X = Dist from center
to detector

T(1) = Source radius

NOTE: Constant source strength distribution only for spherical source

NOTE: Shield region 2 surrounds the source

Truncated Cone Source - Slab Shields

INPUT VARIABLES

IGEOM = 5
 ANG1 = Cone angle
 T(1) = Source Thickness
 X = Dist to detector from opposite face of source
 SSVI = Exponent for exponential source strength distribution

NOTES: If $ANG1 = 90.0^\circ$ (Infinite slab source), then the source strength is input in curies per cm^3 .

If $T(1) = 0$ and $ANG1 = 90.0^\circ$ (Infinite plane source), then the source strength is input in curies per cm^2 .

Disc Source - Detector on Center Line - Slab Shields

INPUT VARIABLES

IGEOM = 6
 SLTH = Dis radius
 X = Dist from center to detector
 SSVI = Exponent for radial exponential source strength distribution

Cylindrical Source

INPUT VARIABLE

IGEOM = 7 for cylindrical shields

IGEOM = 8 for slab shields

T(1) = Radius of source

SLTH = Length of source

X = Radial distance to detector from center line of source

Y = Vertical distance from end of source to detector

NTHETA = Number of horizontal angle intervals for numerical integration

NPSI = Number of vertical angle intervals for numerical integration

DELR = Length of radial intervals for numerical integration (in cm)

End View of Slab Shields

NOTE: With slab shield, the second shield region surrounds the source

Cylinder With Detector at End on Center Line - Slab Shields

INPUT VARIABLES

IGEOM = 9

SLTH = Radius

T(1) = Cylinder length

NTHETA = Number of angle intervals for numerical integration

DELR = Length of radial interval for numerical integration

X = Distance to detector from opposite end

SSV1 = Exponent for radial exponential source strength distribution

Rectangular Solid With Detector on Center Line - Slab Shield

INPUT VARIABLES

IGEOM = 10

X = Distance to detector from opposite face of source

Y = Height of source

SLTH = Length of source

T(1) = Thickness of source

NTHETA = Number of horizontal angle intervals for numerical integration

NPSI = Number of vertical angle intervals for numerical integration

DELR = Length of radial interval for numerical integration

NOTE: Constant source strength distribution only for rectangular solid source

Cards N + 1 to N + 18 - Shield Materials Cards

Each card specifies the density of one material in each of the five allowable shields. The materials which may be used (18 in the library) and the appropriate number designating the material (1 to 18) are listed in Appendix D.

<u>Column</u>	<u>Format</u>	<u>Variable</u>	<u>Use</u>
9-10	I2	MN	Material number corresponding to library material number (Material numbers from 1 to 20)
11-20	E10.4	ρ	Density of this material (if any) in shield 1
21-30	E10.4	ρ	Density of this material (if any) in shield 2
31-40	E10.4	ρ	Density of this material (if any) in shield 3
41-50	E10.4	ρ	Density of this material (if any) in shield 4
51-60	E10.4	ρ	Density of this material (if any) in shield 5
72	I1		= 1 for last material card. Left blank on all preceding cards.

Cards N + 19, etc. - Additional cases

Additional cases may be run by using as few as two additional cards.

Card 1 (following last Material card above) - Title card for second case.

This card signals that additional cases are to be run and changes from the previous case will be described on cards to follow, N+20, etc.

Card 2 - First Namelist card for second case.

Card 3, etc. Additional cards as needed to describe the next case.

Cards.....New material specification if desired. See use of variable NEXT, the program control which determines whether new material specification cards are expected.

APPENDIX B

ISOSHLD ATTENUATION EQUATIONS

APPENDIX B

ISOSLD ATTENUATION EQUATIONS

The kernel integration equations for specific geometries are stated below.

1. POINT SOURCE - SLAB SHIELDS

$$\phi = \frac{B S e^{-b_1 \sec \theta}}{4 \pi \rho^2}$$

where B = buildup factor

S = source strength

$$\theta = \tan^{-1}(Y/X)$$

$$b_1 = \sum_{i=1}^N \mu_i t_i$$

N = number of shields

2. LINE SOURCE SLAB SHIELDS

$$\phi = \int_0^{SLTH} \frac{S_L B e^{-b}}{4 \pi \rho^2} d\ell$$

$$\text{where } \rho^2 = \ell^2 + x^2 - 2\ell x \cos \beta$$

$$\sin \omega = \frac{\ell \sin \beta}{\rho}$$

$$\cos \omega = \frac{x^2 + \rho^2 - \ell^2}{2x\rho}$$

$$\omega = \tan^{-1}(\sin \omega / \cos \omega)$$

$$\theta = |\alpha - \beta - \omega|$$

$$\omega + \theta = \frac{\pi}{2} - \left(\frac{\pi}{2} - \alpha + \beta \right) = \alpha + \beta$$

$$b = \mu_1 \left(\rho - \sec \theta \sum_{i=2}^N t_i \right) +$$

$$\sec \theta \sum_{i=2}^N \mu_i t_i$$

N = number of shield regions

B = build up factor
 S_L = Source strength
 energy per unit
 length

NOTE: If $SSV1 \neq 0$, indicating exponential source strength distribution,

$$S_L = [C][e^{(L)}(SSV1)]$$

$$\text{where } SSV2 = \frac{(S)(SSVL)}{(e^{SSV1 \cdot SLTH} - 1)}$$

where S = total source strength

3. SPHERICAL SOURCE

a. Spherical Shields

$$dv = 2\pi\rho\sin\theta\rho d\rho d\theta$$

$$\phi dv = \frac{BS_v e^{-b} dv}{4\pi\rho^2}$$

$$\phi = \int \frac{BS_v \sin\theta e^{-b} dv}{2} =$$

$$\frac{1}{2} \int_0^{\theta_2} \sin\theta d\theta \int_{M_1}^L BS_v e^{-b} d\rho$$

$$\text{where } \theta_2 = \tan^{-1}(R/\sqrt{x^2 - R^2})$$

$$L = x\cos\theta + \sqrt{R^2 - (x\sin\theta)^2}$$

$$M_1 = x\cos\theta - \sqrt{R^2 - (x\sin\theta)^2}$$

$$M_2 = x\cos\theta -$$

$$\sqrt{(R + t_2)^2 - (x\sin\theta)^2}$$

$R = t_1$ = Radius of source

$$M_N = \frac{x \cos \theta - \sqrt{(R + \sum_{i=2}^N t_i)^2 - (x \sin \theta)^2}}{x \sin \theta}$$

N = number of shield regions

$$B = A_1 e^{-\alpha_1 b} + A_2 e^{-\alpha_2 b}$$

$$b = (\rho - M_1) \mu_1 + \sum_{i=2}^N (M_{i-1} - M_i) \mu_i$$

S_v = volumetric source strength

$$\begin{aligned} \phi &= \frac{S_v}{2} \int_0^{\theta_2} \sin \theta d\theta \int_{M_1}^L (A_1 e^{-b(1 + \alpha_1)} + A_2 e^{-b(1 + \alpha_2)}) d\rho \\ \phi &= \frac{S_v}{2} \int_0^{\theta_2} \sin \theta \left[A_1 e^{(1 + \alpha_1)(M_1 \mu_1 - \sum_{i=2}^N (M_{i-1} - M_i) \mu_i)} \int_{M_1}^L e^{-(1 + \alpha_1) \rho \mu_1} d\rho \right. \\ &\quad \left. + A_2 e^{(1 + \alpha_2)(M_1 \mu_1 - \sum_{i=2}^N (M_{i-1} - M_i) \mu_i)} \int_{M_1}^L e^{-(1 + \alpha_2) \rho \mu_1} d\rho \right] d\theta \\ \phi &= \frac{S_v}{2} \int_0^{\theta_2} \sin \theta \left(A_1 e^{(1 + \alpha_1)C} \left\{ \frac{-1}{\mu_1(1 + \alpha_1)} \left[e^{-(1 + \alpha_1)L\mu_1} - e^{-(1 + \alpha_1)M_1\mu_1} \right] \right\} \right. \\ &\quad \left. + A_2 e^{(1 + \alpha_2)C} \left\{ \frac{-1}{\mu_1(1 + \alpha_2)} \left[e^{-(1 + \alpha_2)L\mu_1} - e^{-(1 + \alpha_2)M_1\mu_1} \right] \right\} \right) d\theta \end{aligned}$$

where $C = M_1 \mu_1 - \sum_{i=2}^N (M_{i-1} - M_i) \mu_i$, function of θ only.

$$\begin{aligned} \phi &= \frac{S_v}{2} \int_0^{\theta_2} \sin \theta \left\{ \frac{-A_1}{\mu_1(1 + \alpha_1)} \left[e^{(1 + \alpha_1)(C - L\mu_1)} - e^{(1 + \alpha_1)(C - M_1\mu_1)} \right] \right. \\ &\quad \left. - \frac{A_2}{\mu_1(1 + \alpha_2)} \left[e^{(1 + \alpha_2)(C - L\mu_1)} - e^{(1 + \alpha_2)(C - M_1\mu_1)} \right] \right\} d\theta \end{aligned}$$

$$- e^{(1 + \alpha_2)(c - M_1 \mu_1)} \Big] \Big\} d\theta$$

b. Slab Shields

R = radius

$$L = x \cos \theta + \sqrt{R^2 - (x \sin \theta)^2}$$

$$M_1 = x \cos \theta - \sqrt{R^2 - (x \sin \theta)^2}$$

$$M_n = \sec \theta \sum_{i=n+1}^N t_i$$

for $n = 2, 3, \dots, N-1$

N = Number of shield regions

$$M_N = (x - \sum_{i=1}^N t_i) \sec \theta$$

$$\theta_2 = \tan^{-1}(R/\sqrt{x^2 - R^2})$$

S_v = volumetric source strength

$$\phi = \int \frac{BS_v \sin \theta e^{-b}}{2} dv$$

$$\text{where } b = (\rho - M_1) \mu_1 + (M_1 - \sum_{i=3}^N t_i \sec \theta) \mu_2 + \sum_{i=3}^N \mu_i t_i \sec \theta$$

$$\phi = \frac{S_v}{2} \int_0^{\theta_2} \sin \theta \left\{ \frac{-A_1}{\mu_1 (1 + \alpha_1)} \left[e^{(1 + \alpha_1)(c - L \mu_1)} - e^{(1 + \alpha_1)(c - M_1 \mu_1)} \right] \right.$$

$$\left. - \frac{-A_2}{\mu_1 (1 + \alpha_2)} \left[e^{(1 + \alpha_2)(c - L_2 \mu_1)} - e^{(1 + \alpha_2)(c - M_1 \mu_1)} \right] \right\} d\theta$$

$$\text{where } c = M_1 \mu_1 - \sec \theta \sum_{i=3}^N \mu_i t_i - (M_1 - \sec \theta \sum_{i=3}^N t_i) \mu_2$$

4. TRUNCATED CONE SOURCE - SLAB SHIELD

See Reference 8

If $SSV1 = 0$, indicating constant source strength distribution

$$\phi = \frac{S_v}{2\mu_1} \sum_{i=1}^2 \frac{A_i}{1 + \alpha_i} \left[E_2(b_{1i}) - E_2(b_{2i}) - \frac{E_2(b_{1i} \sec \theta)}{\sec \theta} + \frac{E_2(b_{2i} \sec \theta)}{\sec \theta} \right]$$

$$\text{where } S_v = \frac{\text{total source strength}}{\text{source volume}}$$

$$b_{1i} = (1 + \alpha_i) \sum_{j=2}^N \mu_j t_j, \quad N = \text{Number of shield regions}$$

$$b_{2i} = (1 + \alpha_i) \sum_{j=1}^N \mu_j t_j$$

$$E_2(y) = y \int_y^{\infty} t^{-2} e^{-t} dt$$

If $SSV1 \neq 0$, indicating exponential source strength distribution

$$\phi = \frac{S_v(0)}{2\mu_1} e^{\left(\frac{SSV1}{\mu_1} \sum_{i=1}^N \mu_i t_i \right)} \sum_{j=1}^2 \frac{A_j}{1 + \alpha_j} \left[F_1(b_{2j}, \alpha_j) - F_1(b_{1j}, \alpha_j) - \frac{F_1(b_{2j} \sec \theta, \alpha_j)}{\sec \theta} + \frac{F_1(b_{1j} \sec \theta, \alpha_j)}{\sec \theta} \right]$$

$$\text{where } F_1(y, \alpha) = \int_0^y e^{\alpha b} E_1(b) db$$

$$E_1(b) = \int_b^{\infty} \frac{e^{-t}}{t} dt$$

$$S_v(0) = S / \left\{ \pi \tan^2 \theta \left[\frac{D^2 e^{CT}}{C} - \frac{D^2}{C} - \frac{2De^{CT}(CT-1)}{C^2} - \frac{2D}{C^2} + \frac{T^2 e^{CT}}{C} - \frac{2e^{CT}(CT-1)}{C^3} - \frac{2}{C^3} \right] \right\}$$

where S = Total source strength

D = Distance to detector from opposite side of source

C = SSV1

T = Source thickness

5. DISC SOURCE (DETECTOR ON CENTER LINE) SLAB SHIELDS

R = radius

$$dA = r dr d\theta$$

$$\phi = \int_0^R \int_0^{2\pi} \frac{BS_A e^{-b} r d\theta dr}{4\pi \rho^2}$$

$$\phi = \int_0^R \frac{BS_A e^{-b} r dr}{2(x^2 + r^2)}$$

B = Buildup factor

$$b = \sum_{i=1}^N \mu_i t_i, \quad N = \text{number of shield regions}$$

S_A = source strength per unit area

if $SSV1 = 0$, indicating constant source strength

$$S_A = \frac{S}{\text{Area}},$$

where S = total source strength

if $SSV1 \neq 0$, indicating exponential source strength distribution

$$S_A = C e^{(SSV1)(r)}$$

$$\text{where } C = \frac{(S)(C^2)}{2\pi(e^{CR}(CR - 1) + 1)}$$

$$C = SSV1$$

$$R = \text{radius}$$

6. CYLINDRICAL SOURCE

$$dv = \rho^2 d\theta d\psi d\rho$$

$$\phi = \int_v \frac{BS_v e^{-b_1}}{4\pi\rho^2} dv$$

$$b_1 = \sum_{i=1}^N \mu_i t_i$$

θ = horizontal angle

ψ = vertical angle

R = radius of cylinder = t_1

$$\begin{aligned} \phi = & \frac{2}{4\pi} \int_0^{\theta_2} d\theta \left[2 \int_0^{\psi_1} d\psi \int_{R_1}^{R_2} B(b \sec \psi) S_v e^{-b \sec \psi} d\rho \right. \\ & \left. + \int_{\psi_1}^{\psi_2} d\psi \int_{R_1}^{R_3} B(b \sec \psi) S_v e^{-b \sec \psi} d\rho \right] \end{aligned}$$

B = Buildup factor

S_v = Volumetric source strength

$$L_1 = x \cos \theta - \sqrt{R^2 - (x \sin \theta)^2}$$

$$L_2 = x \cos \theta + \sqrt{R^2 - (x \sin \theta)^2}$$

$$R_1 = L_1 \sec \psi$$

$$R_2 = \min(L_2 \sec \psi, \min(Y, SLTH - Y) \csc \psi)$$

$$R_3 = \min(L_2 \sec \psi, \max(Y, SLTH - Y) \csc \psi)$$

$$\psi_1 = \tan^{-1} \left[\frac{\min(Y, SLTH - Y)}{L_1} \right]$$

$$\psi_2 = \tan^{-1} \left[\frac{\max(Y, SLTH - Y)}{L_1} \right]$$

$$\theta_2 = \tan^{-1} (R / \sqrt{x^2 - R^2})$$

a. Cylindrical Shields

$$b = (\rho \cos \psi - L_1) \mu_1 + \sum_{i=1}^{N-1} (m_i - m_{i+1}) \mu_{i+1} + 1$$

where $m_1 = L_1$

$$m_2 = x \cos \theta - \sqrt{(t_1 + t_2)^2 - (x \sin \theta)^2}$$

⋮

$$m_N = x \cos \theta - \sqrt{\left(\sum_{i=1}^N t_i \right)^2 - (x \sin \theta)^2}$$

N = Number of shield regions

b. Slab Shields

$$b = (\rho \cos \psi - L_1) \mu_1 + (L_1 - \sec \theta \sum_{i=3}^N t_i) \mu_2 + \sum_{i=3}^N \mu_i t_i \sec \theta$$

NOTE: The view of the cylinder from the end is the same as the sphere

If $SSV1 = 0$, specifying constant source strength distribution,

$$S_v = S/\text{volume},$$

S = Total source strength

If $SSV1 \neq 0$, specifying exponential source strength distribution,

$$S_v = b e^{SSV1(r)},$$

$$\text{where } r = \sqrt{x^2 - 2x\rho \cos \theta \cos \psi + \rho^2 \cos^2 \psi}$$

$$\text{and } b = \frac{(S)(C^2)}{2\pi h e^{CR}(CR - 1) + 2\pi h}$$

where h = cylinder length,

C = $SSV1$,

R = radius

7. CYLINDER WITH DETECTOR AT END ON CENTER LINE - SLAB SHIELDS

r = radius

$$dv = 2\pi r \rho d\theta d\rho = 2\pi \rho^2 \sin \theta d\theta d\rho$$

$$\phi = \int \frac{BS_v e^{-b}}{4\pi \rho^2} dv$$

$$\phi = 1/2 \int_0^{\theta_2} d\theta \int_{R_1}^{R_2} BS_v e^{-b} \sin \theta d\theta d\rho$$

where

B = Buildup

S_v = volumetric energy source strength rate (same as previous cylinder cases)

$$b = \left(\rho - \sec \theta \sum_{i=2}^N t_i \right) \mu_1 + \sum_{i=2}^N \mu_i t_i \sec \theta$$

$$\theta_2 = \tan^{-1} \left(\frac{R}{x - t_1} \right)$$

$$R_1 = \sec \theta \sum_{i=2}^N t_i$$

$$R_2 = \min(x \sec \theta, R \csc \theta)$$

8. RECTANGULAR SOLID - SLAB SHIELDS

$$dv = ds dy dx$$

$$\phi = \int \frac{BS_v e^{-b}}{4\pi\rho^2} dv$$

$$\phi = \frac{1}{\pi} \int_0^{\frac{SLTH}{2}} ds \int_0^{\frac{V}{2}} dy \int_0^{\frac{t_1}{2}} \frac{BS_v e^{-b}}{\rho^2} dt$$

where

B = Buildup

S_v = volumetric source strength rate = $\frac{S}{\text{volume}}$,
 S = total source strength

$$\rho^2 = \left(t + \sum_{i=2}^N t_i \right)^2 + s^2 + y^2$$

$$\sec \theta = \rho / \left(t + \sum_{i=2}^N t_i \right)$$

$$b = \left(\rho - \sec \theta \sum_{i=2}^N t_i \right) \mu_1 + \sum_{i=2}^N \mu_i t_i \sec \theta$$

APPENDIX C

CODE LISTING


```

C      MAIN PROGRAM - CALLS IN OTHER LINKS
      COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1     SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
      COMMON SSV1,SSV2,      SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1     JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2     SECANT, BUIF,B1
      COMMON      CASER(6),FMWD,TET,TLN(5),TLH(5)
      COMMON NTHETA, NPSI, DELR ,VOLUME
      DIMENSION FZ(7)
      CALL SETDAR (5,0,FZ)
      CALL SETIO(2,1)
      CALL SETIO(3,2)
      READ (2,10) MODE
10     FORMAT ( 10XI1)
      GO TO (11,13,13 ),MODE
11     CALL RIBD
      GO TO 15
C      READ PAST RIBD LIBE
13     READ (5,20) NCD
      DO 14 I=1,NCD
      READ(5,20) J
14     CONTINUE
15     CALL CONTRL(MODE)
20     FORMAT(I3)
      RETURN
      END

```

```

SUBROUTINE RIBD
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1 SOURCE(3,16), MU(6,16),MUE(6,16), NDT,DATA2(5,450)
COMMON SSV1,SSV2, SLTH,TOTAL(4),TT(6),NSHLDA,X,YY,ANG1,ANG2,ANG3,
1 JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2 SECANT, BUIF,B1
COMMON CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR, VOLUME
DIMENSION ISO(450), LISTM(10,96), LISTA(25,40), NRM(96), NRA(40),
1 DT(5), DATA1(10,450)
DIMENSION Y(5), TERM(13), SUM2(13), SUM3(13), FX(15), TM(15),
1 WL(15),WM(15), FM(13), FR(13), TF(14), TX(14), FXT(14),FLM(6),
2 SEMLT(9), EMLT(9,9), PAR2(14,10,2), PAR3(13,10,2), FEED3(450),
3 FEED4(450), FEED5(450), FEED6(450), FEED7(450), FEED8(450),
4 FEED9(450), FEED10(450), DG1(6), DG2(6), FLAM(9), PDN(6)
DATA KA,KM,MP,NAT/4*0/
DATA DG1/2.046E-4,1.3578E-3,1.2152E-3,2.449E-3,7.13E-4,2.604E-4/
DATA DG2/7.0E-5,5.96E-4,4.22E-4,6.52E-4,1.72E-4,8.8E-5/
DATA FLM/1.075E+3,2.635E+3,9.626E+3,2.603E+4,9.816E+4,2.603E+5/
LOGICAL L6
1001 FORMAT(6A6,4X,2E10.4,2I1,10X/5E10.4,I1)
1010 FORMAT(1H16A6,2X,1P2E11.3,2X, I1,19H EXTRA DECAY LISTS,,5H TYPEI2
1,7H OPTION/1H 1P5E15.4, I5)
1050 FORMAT(1H+102X,4HSTEP13)
1060 FORMAT(1H A3,I3,2X,1P11E10.3,I2)
1070 FORMAT(2E10.4,30X,I1)
1080 FORMAT(1H 1P2E15.4,45X, I5)
1090 FORMAT(9E8,3)
1091 FORMAT(1H 1P9E10.3,23H DECAY POINTS - SECONDS)
1000 FORMAT(I3,I2, 4E9,3,4F5.3,7X,A3,I1)
1002 FORMAT(1H1,3X,24HLIBRARY OUT OF ORDER AT A3,I4/(28X,A3,I4))
1021 FORMAT(I3)

```

42

BNWL-236


```

X=1.E-37
DO 111 I=1,5
111 A=X*1.E-5
READ (5,1021)NCD
READ (5,1000)(ML(J),LA(J),FEED3(J),FEED4(J),FEED5(J), FEED6(J),
1FEED7(J),FEED8(J),FEED9(J),FEED10(J),REC(J),ISO(J),J=1, NCD)
LOWA=LA(1)-1
DO 4 J=1,10
DO 4 K=1,450
4 DATA1(J,K) = 0.
DO520 I=1,96
520 NRM(I) = 0
DO521 I=1,40
521 NRA(I) = 0
DO522 I=1,NCD
522 DATA1(1,I) = 0.
U9I = 0.
PNI = 0.
DO 23 I=1,6
23 PDN(I) = 0.
DO 3 J=1,NCD
FEED3(J)=.693/FEED3(J)
FEED9(J)=FEED9(J)*5.9274E-9
FEED10(J)=FEED10(J)*5.9274E-9
IF (MP-ML(J))5,1,6
5 MP=ML(J)
KM=KM+1
1 KA=LA(J)-LOWA
IF (KA)6,6,2
6 WRITE (3,1002) REC(J=1),ML(J-1),REC(J),ML(J),REC(J+1),ML(J+1)
CALL EXIT
2 NRM(KM)=NRM(KM)+1
NRA(KA)=NRA(KA)+1
JM=NRM(KM)
JA=NRA(KA)
LISTM(JM,KM)=J
LISTA(JA,KA)=J

```

06971
06981
06991
07101
07201
07301

07401
07501
07601
07602
07801
07901
08001
08101
08201
08301
08401
08501
08601
08701
08801
08901
09001

```

09101 NAT=MAX0(NAT,KA)
09201
09301
0950
09601
09701
09801
09901
10001
10101
10201
10301
10401
10501
10601
10701
1080
10901
11001
11101
11201
11301
11401
11501
11601
11701
11801
11901
12001
12101
12201
12301
12401
12501
12601
12701
12801

3 CONTINUE
NMA=KM
9 READ (2,1001)CASER,CON,BIGL,NEDL,KEY,PO,TIME,T,SIGA25, DEL,NSIG
FLUX=T/(SIGA25*TIME)
THETA=TIME
XBAR=EXP(-T)
PXBAR=XBAR
P=PO*8.436E+5
TFISS=P*TIME
X=FLUX*SIGA25
RATIO=FLUX/PO
NSTEP=1
TET=TIME
FMWD=PO*TIME
P25=P/(1.0+DEL)
WRITE (3,1010)CASER,CON,BIGL,NEDL,KEY,PO,TIME,T,SIGA25, DEL,NSIG
BIGL=BIGL*86400.0
IF(NSIG)31,31,32
31 JS1=2
GO TO 33
32 WRITE (3,1050)NSTEP
JS1=1
33 FX(1)=-X
ADD=1.0
TM(1)=THETA
WL(1)=THETA
SSUM=THETA
DO 8 L=2,15
ADD=ADD+1.0
TM(L)=TM(L-1)*THETA/ADD
FX(L)=-FX(L-1)*X
WL(L)=-T/ADD*WL(L-1)
8 SSUM=SSUM+WL(L)
TX(1)=SSUM
DO 11 L=2,14
ADD=L

```

```

12901 SSUM=0.0
13001 DO 12 I=1,15
13101   WL(I)=WL(I)*THETA/ADD
13201   ADD=ADD+1.0
13301   12 SSUM=SSUM+WL(I)
13401   11 TX(L)=SSUM
13501   IO=1
13601   IN=2
13701   DO 290 K=1,NMA
13801     RET=0.0
13901     13 N1=0
14001     N2=0
14101     N3=0
14201     JM=NRM(K)
14301     DO 2900 J=1,JM
14401       Y(1)=0.0
14501       Y(2)=0.0
14601       Y(3)=0.0
14701       Y(4)=0.0
14801       Y(5)=0.0
14901       KI=LISTM(J,K)
15001       IS=ISO(KI)
15101       AT=LA(KI)
15201       KA=LA(KI)-LOWA
15301       LM=NR(KA)
15401       F=FLUX*FEED6(KI)+FEED3(KI)
15501       I1=KI
15601       I2=KI
15701       I3=KI
15801       I4=KI
15901       I5=KI
16001       MP=ML(KI)-1
16101       PAR2(14,J,IN)=AT
16201       DO 10 L=1,LM
16301       NP=LISTA(L,KA)
16401       IF(ML(NP)-MP)10,100,170
16501       10 CONTINUE

```

```

100 I4=NP
    I5=I4+1
    DO 101 L=1,10
        L4=L
        IF(PAR2(I4,L,IO)-AT)101,102,101
101 CONTINUE
102 L5=L4+1
    IF(IS,GT,1) GO TO 140
110 IF(ISO(NP)-2)120,130,130
120 Y(4)=FLUX*FEED6(I4)*FEED7(I4)
    GO TO 135
130 I5=NP
    L5=L4
135 Y(5)=FLUX*FEED6(I5)*FEED7(I5)
    GO TO 170
140 IF(ISO(NP)-2)150,160,160
150 Y(4)=FLUX*FEED6(I4)*(1.0-FEED7(I4))
    GO TO 165
160 I5=NP
    L5=L4
165 Y(5)=FLUX*FEED6(I5)*(1.0-FEED7(I5))
170 IF(N1-1)240,180,210
180 I1=KI-1
    L1=J-1
    Y(1)=FEED3(I1)*(1.0-FEED8(I1))
    IF(N2-1)240,185,190
185 WRITE (3,1002)REC(KI),ML(KI)
    GO TO 240
190 I2=I1-1
    L2=L1-1
    Y(2)=FEED3(I2)*(1.0-FEED8(I2))
    IF(N3-1)240,200,240
200 I3=I2-1
    L3=L2-1
    Y(3)=FEED3(I3)*FEED8(I3)
    GO TO 240
210 I2=KI-1

```

16601
16701
16801
16901
17001
17101
17201
17301
17401
17501
17601
17701
17801
17901
18001
18101
18201
18301
18401
18501
18601
18701
18801
18901
19001
19101
19201
19301
19401
19501
19601
19701
19801
19901
20001
20101
20201

20301
20401
20501
20601
20701
20801
20901
21001
21101
21201
21301
21401
21501
21601
21701
21801
21901
22001
22101
22201
22301
22401
22501
22601
22701
22801
22901
23001
23101
23201
23301
23401
23501
23601
23701
23801
23901

```

L2=J-1
IF (IS.GT.1) GO TO 230
220 Y(2)=FEED3(I2)*FEED8(I2)
GO TO 240
230 Y(2)=FEED3(I2)*(1.0-FEED8(I2))
IF (N2-1) 240,200,240
240 N3=N2
N2=N1
N1=IS
A=P*FEED5(KI)/100.0
B=P25*(FEED4(KI)-FEED5(KI))/100.0
DO 241 L=1,13
SUM2(L)=Y(1)*PAR2(L,L1,IN)+
1 Y(2)*PAR2(L,L2,IN)+
2 Y(3)*PAR2(L,L3,IN)+
3 Y(4)*PAR2(L,L4,IO)+
4 Y(5)*PAR2(L,L5,IO)
241 SUM3(L)=Y(1)*PAR3(L,L1,IN)+
1 Y(2)*PAR3(L,L2,IN)+
2 Y(3)*PAR3(L,L3,IN)+
3 Y(4)*PAR3(L,L4,IO)+
4 Y(5)*PAR3(L,L5,IO)
F1=A/F
F2=B/(F-X)
F3=F2*XBAR
F4=DATA1(1,KI)-F1-F2
ARG=F*THETA
SUM=0.0
FM(1)=1.0
FR(1)=1.0/F
DO 242 L=2,13
FM(L)=-FM(L-1)*F
FR(L)=-FR(L-1)/F
242 TERM(L)=0.0
IF (ARG-79.0) 260,243,243
243 NT=1
DO 244 L=1,10

```

TERM(L)=SUM2(L)*FR(L)	24001
SUM=SUM+TERM(L)	24101
IF(.0001-ABS(TERM(L)/SUM))244,245,245	24201
244 CONTINUE	24301
245 DATA2(1,KI)=F1+F3+SUM	24401
PAR2(1,J,IN)=DATA2(1,KI)	24501
EMFT=0.0	24601
DO 247 L=2,13	24701
SSUM=0.0	24801
PT=ABS(FR(1)*SUM2(L))	24811
N=0	24821
DO 246 I=L,13	24901
N=N+1	25001
ADD=FR(N)*SUM2(1)	25011
TEST=ABS(ADD)	25021
IF(TEST.GT.PT) GO TO 247	25031
PT=TEST	25041
246 SSUM=SSUM+ADD	25101
247 PAR2(L,J,IN)=F3*FX(L-1)+SSUM	25201
249 FMULT=(1.0-EMFT)/F	25301
SSUM=SUM	25401
DO 250 L=1,13	25501
SSUM=(SUM3(L)-SSUM)/F	25601
FA=TM(L)	25701
PAR3(L,J,IN)=FMULT*F4+FA*F1+F2*TX(L)+SSUM	25801
250 FMULT=(FA-FMULT)/F	25901
GO TO 300	26001
260 EFT=EXP(ARG)	26101
EMFT=1.0/EFT	26201
F5=F4*EMFT	26301
IF(ARG-1.0)261,261,291	26401
261 NT=2	26501
267 DO 265 L=1,10	26601
TERM(L)=SUM3(L)*FM(L)	26701
SUM=SUM+TERM(L)	26801
IF(.0001-ABS(TERM(L)/SUM))265,266,266	26901
265 CONTINUE	27001

```

266 SS2=THETA
   SSUM=THETA
   Q=THETA
   WL(1)=THETA
   ADD=1.0
   WM(1)=THETA
   DO 262 L=2,15
     ADD=ADD+1.0
     Q=-T/ADD*Q
     WL(L)=-ARG/ADD*WL(L-1)+Q
     SSUM=SSUM+WL(L)
     WM(L)=-ARG/ADD*WM(L-1)
262 SS2=SS2+WM(L)
   FXT(1)=SSUM
   TF(1)=SS2
   DO 264 L=2,14
     SSUM=0.0
     SS2=0.0
     ADD=L
     DO 263 I=1,15
       WL(I)=WL(I)*THETA/ADD
       WM(I)=WM(I)*THETA/ADD
       ADD=ADD+1.0
       SSUM=SSUM+WL(I)
263 SS2=SS2+WM(I)
     FXT(L)=SSUM
     TF(L)=SS2
264 DATA2(1,KI)=DATA1(1,KI)*EMFT+A*TF(1)+B*FXT(1)+SUM
     PAR2(1,J,IN)=DATA2(1,KI)
269 DO 272 L=2,13
     SSUM=0.0
     DO 270 I=2,L
       N=L-I+1
270 SSUM=SSUM+FM(I-1)*SUM2(N)
     DO 271 I=L,13
       N=I-L+1
271 SSUM=SSUM+FM(I)*SUM3(N)

```

27101
27201
27301
27401
27501
27601
27701
27801
27901
28001
28101
28201
28301
28401
28501
28601
28701
28801
28901
29001
29101
29201
29301
29401
29501
29601
29701
29801
29901
30001
30101
30201
30301
30401
30501
30601
30701

```

30801
30901
31001
31101
31201
31301
31401
31501
31601
31701
31801
31901
32001
32101
32201
32301
32401
32501
32601
32701
32801
32901
33001
33101
33201
33301
33401
33601
33501
33701
33801
33901
34001
34101
34201
34301
34401

272 PAR2(L,J,IN)=FM(L)*F5+F3*FX(L-1)+SSUM
    DO 281 L=1,13
    LIM=13-L
    IF(LIM)281,281,282
282 SSUM=0.0
    DO 280 I=1,LIM
    N=I+L
280 SSUM=SSUM+FM(I)*SUM3(N)
281 PAR3(L,J,IN)=DATA1(1,KI)*TF(L)+A*TF(L+1)+B*FXT(L+1)+SSUM
    GO TO 300
291 FA=1.0
    ADD=1.0
    NT=3
    FNUM=EFT-1.0
    SS2=0.0
    WL(1)=1.0
    DO 294 L=1,13
    TF(L)=FNUM/EFT
    FA=FA/ADD*ARG
    FNUM=FNUM-FA
    WL(L+1)=WL(L)+FA
    SS2=-F*SS2+WL(L)*SUM2(L)
    WM(L)=EMFT*SS2
294 ADD=ADD+1.0
    DO 292 L=1,10
    TERM(L)=FR(L)*TF(L)*SUM2(L)
    SUM=SUM+TERM(L)
292 CONTINUE
    IF(.00001.GT.ABS(TERM(L)/SUM)) GO TO 293
293 IF(ABS(TERM(10)/SUM)=.001)298,298,296
296 IF(ARG=2.0)297,297,298
297 NT=4
    SUM=0.0
    DO 299 L=1,10
299 TERM(L)=0.0
    GO TO 267
298 DATA2(1,KI)=DATA1(1,KI)*EMFT+F1*(1.0-EMFT)+F2*(XBAR-EMFT)+SUM

```


PAR2(1,J,IN)=DATA2(1,KI)	34501
DO 295 L=2,13	34601
SSUM=0.0	34701
PT=ABS(FR(1)*SUM2(L)*TF(L))	34711
N=0	34721
DO 2950 I=L,13	34801
N=N+1	34901
ADD=FR(N)*SUM2(I)*TF(I)	34911
TEST=ABS(ADD)	34912
IF(TEST.GT,PT) GO TO 295	34913
PT=TEST	34914
2950 SSUM=SSUM+ADD	35001
295 PAR2(L,J,IN)=FM(L)*F5+F3*FX(L-1)+WM(L-1)+SSUM	35101
GO TO 249	35201
300 IF(DATA2(1,KI))302,302,301	35301
301 IF(ABS(TERM(10)/DATA2(1,KI))-0.001)305,305,302	35401
302 IF(RET)303,303,304	35501
303 RET=1.0	35601
GO TO 13	35701
304 WRITE (3,1060)REC(KI),ML(KI),(TERM(I),I=1,10),	35801
1,NT	35901
305 FLAM(J)=FEED3(KI)	36001
SSUM=0.0	36101
LIM=J-1	36201
IF(LIM)403,403,400	36301
400 DO 402 L=1,LIM	36401
401 DATA1(L+1,KI)=(Y(1)*DATA1(L+1,I1)+Y(2)*DATA1(L+1,I2)+Y(3)*	36501
1DATA1(L+1,I3))/(FLAM(J)-FLAM(L))	36601
402 SSUM=SSUM+DATA1(L+1,KI)	36701
403 DATA1(J+1,KI)=DATA2(1,KI)-SSUM	36801
2900 CONTINUE	36901
ISAV=IO	37001
IO=IN	37101
IN=ISAV	37201
290 CONTINUE	37301
ARG=42.4647*THETA	37401
EMFT=EXP(-ARG)	37501

DATA2(1,KI)

51

BNWL-236

EMNPT=EXP(-.29489*THETA)	37601
A=3.169*CON*P	37701
B=.02216*CON*P-1.007*U9I	37801
C=A+B	37901
U9I=U9I*EMFT+.022006*CON*P*(1.0-EMFT)	38001
PNI=PNI*EMNPT+A+B*EMFT-C*EMNPT	38101
DO 2901 IX=1,NCD	38201
2901 DATA1(1,IX)=DATA2(1,IX)	38301
P25=P25/8.436E+5	38302
DO 2902 I=1,6	38303
EMFT=EXP(-THETA*FLM(I))	38304
2902 PDN(I)=PDN(I)*EMFT+(DG1(I)-DG2(I))*P25*(XBAR-EMFT)+DG2(I)*P0*	38305
X(1.-EMFT)	38306
599 IF(JS1.GT.1) GO TO 700	38401
600 NSTEP=NSTEP+1	38501
READ (2,1070)P0,TIME,NSIG	38601
WRITE (3,1080)P0,TIME,NSIG	38701
WRITE (3,1050)NSTEP	38801
TET=TET+TIME	38901
IF(P0)650,650,610	39001
610 FLUX=RATIO*P0	39101
FMWD=FMWD+P0*TIME	39201
X=FLUX*SIGA25	39301
T=X*TIME	39401
P=P0*8.436E+5	39501
TFISS=TFISS+P*TIME	39601
P25=PXBAR*P/(1.0+DEL)	39701
XBAR=EXP(-T)	39801
PXBAR=PXBAR*XBAR	39901
THETA=TIME	40001
IF(NSIG)33,33,620	40101
620 JS1=2	40201
GO TO 33	40301
650 DO 670 K=1,NMA	40401
JM=NRM(K)	40501
DO 670 J=1,JM	40601
KI=LISTM(J,K)	40701

```

40801 FLAM(J)=FEED3(KI)
40901 ARG=TIME*FEED3(KI)
41001 IF(79.0-ARG)651,651,652
41101 651 SEMLT(J)=0.0
41201 GO TO 655
41301 652 IF(ARG)653,653,654
41401 653 SEMLT(J)=1.0
41501 GO TO 655
41601 654 SEMLT(J)=EXP(-ARG)
41701 655 SSUM=0.0
41801 LIM=J-1
41901 SS2=0.0
42001 DO 660 I=1,LIM
42101 TEST=(FLAM(J)-FLAM(I))*TIME
42201 IF(ABS(TEST)-.0001)660,1660,1660
42301 1660 TEST=1.0
42401 SS2=SS2+DATA1(I+1,KI)
42501 660 SSUM=SSUM+SEMLT(I)*DATA1(I+1,KI)*TEST
42601 SSUM=SSUM+SEMLT(J)*DATA1(1,KI)-SS2)
42701 670 DATA1(1,KI)=SSUM
42801 EMFT=EXP(-42.4647*TIME)
42901 EMNPT=EXP(-.29489*TIME)
43001 PNI=(PNI+1.007*U9I)*EMNPT-1.007*U9I*EMFT
43101 U9I=U9I*EMFT
43102 DO 6700 I=1,6
43103 6700 PUN(I)=PDN(I)*EXP(-TIME*FLM(I))
43201 GO TO 600
43301 700 READ (2,1090)DT
43401 WRITE (3,1091)DT
43401 NDT = 1
43401 DO 701 L=1,4
43401 IF(DT(L).GT.0.) NDT = L+1
43401 701 DT(L) = DT(L)/86400.
43401 DO 410 K=1,NMA
43401 JM=NRM(K)
43401 DO 410 J=1,JM
43401 KI=LISTM(J,K)

```

```

46401
46501
46601
46701

```

```

46801 FLAM(J)=FEED3(KI)
46901 DO 406 L=1,4
47001 ARG=DT(L)*FEED3(KI)
47101 IF(79.0-ARG)404,404,405
47201 404 EMLT(J,L)=0.0
47301 GO TO 406
47401 405 IF(ARG)409,409,411
47501 409 EMLT(J,L)=1.0
47601 GO TO 406
47701 411 EMLT(J,L)=EXP(-ARG)
47801 406 CONTINUE
47901 DO 408 L=1,4
48001 SSUM=0.0
48101 LIM=J-1
48201 SS2=0.0
48301 DO 407 I=1,LIM
48401 TEST=(FLAM(J)-FLAM(I))*DT(L)
48501 IF(ABS(TEST)-.0001)407,1407,1407
48601 1407 TEST=1.0
48701 SS2=SS2+DATA1(I+1,KI)
48801 407 SSUM=SSUM+EMLT(I,L)*DATA1(I+1,KI)*TEST
48901 SSUM=SSUM+EMLT(J,L)*(DATA1(1,KI)-SS2)
      408 DATA2(L+1,KI) = SSUM * FEED3(KI)
      410 DATA2(1,KI) = DATA1(1,KI) * FEED3(KI)
      DO 421 J=1,NCD
      WRITE(3,425) REC(J),ML(J),(DATA2(K,J),K=1,5)
      421 CONTINUE
      425 FORMAT (2H A3,I3,2X,1P10E11.3)
      430 CONTINUE
      DO 440 I=1,4
      J = 5-I
      440 DT(J+1) = DT(J)*86400.
      DT(1) = 0.
      DO 22 L=1,5
      TRY=DT(L)/100.0
      IF(TRY-1.0)14,14,15
      14 TLN(L)=DT(L)

```

```
DATA Q000HL/6H SEC. /  
  TLH(L)=Q000HL  
  GO TO 22  
15 TRY=DT(L)/3600.0  
  IF(TRY-1.0)16,16,17  
16 TLN(L)=TRY*60.0  
  DATA Q001HL/6H MIN. /  
  TLH(L)=Q001HL  
  GO TO 22  
17 TRY=TRY/24.0  
  IF(TRY-1.0)18,19,19  
18 TLN(L)=TRY*24.0  
  DATA Q002HL/6H HR. /  
  TLH(L)=Q002HL  
  GO TO 22  
19 TRY=TRY/365.0  
  IF(TRY-1.0)20,21,21  
20 TLN(L)=TRY*365.0  
  DATA Q003HL/6H DAYS /  
  TLH(L)=Q003HL  
  GO TO 22  
21 TLN(L)=TRY  
  DATA Q004HL/6H YRS. /  
  TLH(L)=Q004HL  
22 DT(L)=DT(L)/86400.0  
  RETURN  
  END
```

43901
44001
44101
44201
44301
44401
44501
44601
44701
44801
44901
45001
45101
45201
45301
45401
45501
45601
45701
45801
45901
46001
46101
46201
46301

```

C      SUBROUTINE CONTRL(MODE)
C      MAIN PROGRAM TO CALCULATE GAMMA ATTENUATION FOR VARIOUS
C      SOURCE AND SHIELD CONFIGURATIONS
C
C      IN THE FOLLOWING GLOSSARY
C      C INDICATES THE VARIABLE IS CALCULATED INTERNALLY
C      I INDICATES THE VARIABLE IS INPUT IN NAMELIST INPUT
C      L INDICATES THE VARIABLE IS INPUT FROM THE LIBRARIES
C      O INDICATES OTHER INPUT
C
C      I   ANG1 = CONE ANGLE FOR TR. CONE SOURCE, SHIELD NORMAL ANGLE FOR
C           LINE SOURCE
C      I   ANG2 = DETECTOR ANGLE FOR LINE SOURCE
C      L   BAN(8) = EFFECTIVE ATOMIC NUMBER FOR BUILD UP LIBE
C      L   BLIB (I,J,K) = BUILDUP FACTOR LIBRARY
C           I= ENERGY GROUP, J= 1 FOR A1, 2 FOR ALFA1, 3 FOR ALFA2
C           K= MATERIAL
C      L   COEF (I,J,K) = ENERGY DEPENDANT SHIELD MATERIAL COEF
C           I DETERMINES ENERGY
C           J = 1 SPECIFIES MASS ABSORBTION COEF - MU
C           J = 2 SPECIFIES ENERGY ABSORBTION COEF - MUE
C           K DETERMINES MATERIAL
C      C   DATA2 - CURIES CALCULATED IN RIBD
C      I   DELR = LENGTH OF RADIAL INTERVALS FOR NUMERICAL INTEGRATION
C      C   DSRATE - GAMMA DOSE RATE DUE TO ENERGY FLUX RATE OF 1 MEV/SCM
C      L   EAN(20) = EFFECTIVE ATOMIC NUMBER FOR SHIELD LIBE
C      L   EAW(20) = EFFECTIVE ATOMIC WEIGHT FOR SHIELD LIBE
C      C   ENERGY(16) - PHOTON ENERGY IN MEV FOR 16 GROUPS
C      I   GROUP - 5 ISOTOPE SELECTION GROUPS. INPUT VALUE SPECIFIES A
C           WEIGHTING FACTOR IF MODE = 1, AND CURIES IF MODE = 2.
C           (1) NOBLE GASES (XE,KR), (2) HALOGENS (I,BR),
C           (3) VOLATILE SOLIDS (SE,TE,CS), (4) ALL ISOTOPES

```

```

C      EXCEPT FIRST 3 GROUPS, (5) ALL ISOTOPES IN LIBRARY
C      I  IGEOM = VARIABLE TO SPECIFY SOURCE AND SHIELD GEOMETRIES
C          1= POINT SOURCE - SLAB SHIELDS
C          2= LINE SOURCE - SLAB SHIELDS
C          3= SPHERICAL SOURCE AND SHIELDS
C          4= SPHERICAL SOURCE - SLAB SHIELDS
C          5= TRUNCATED CONE SOURCE AND SHIELDS- DETECTOR AT APEX
C          6= DISC SOURCE - SLAB SHIELDS
C          7= CYLINDRICAL SOURCE AND SHIELDS
C          8= CYLINDRICAL SOURCE - SLAB SHIELDS
C          9= CYLINDER WITH DETECTOR AT END
C          10= RECTANGULAR SOLID
C      C  IPHSUB(501) - SPECIFIES STARTING SUBSCRIPT IN PHOTON ARRAY
C      I  JBUF = SHIELD REGION TO BE USED FOR CALCULATING BUILD UP
C          WILL BE SET TO LAST SHIELD IF NOT SPECIFIED
C      L  LA(500) - ATOMIC NUMBER
C      L  ML(500) - MASS NUMBER
C      O  MODE SPECIFIES TYPE OF SOURCE STRENGTH INPUT
C          1, CURIES OF EACH ISOTOPE CALCULATED BY RIBD
C          2, CURIES OF EACH ISOTOPE INPUT IN WEIGHT OR GROUP ARRAYS
C          3, PHOTONS INPUT IN SOURCE (1,I) FOR EACH ENERGY GROUP
C          GROUP SOURCE STRENGTH IN MEV INPUT IN SOURCE (2,I)
C      C  MU (I,J) = MASS ABSORPTION COEFF. I=SHIELD NO. J=ENERGY GRP
C      C  NDT NUMBER OF COOLING TIMES FOR RIBD
C      C  NPHEN = NUMBER OF PHOTON ENERGY GROUPS
C      I  NPSI = NO. OF VERTICAL INTERVALS FOR NUMERICAL INTEGRATION
C      I  NSHLD = NUMBER OF SHIELD REGIONS, MAXIMUM = 5
C      I  NTHETA = NO. OF LATERAL INTERVALS FOR NUMERICAL INTEGRATION
C      L  PHOTON (2,1006) = PHOTON PROBABILITY LIBRARY
C          PHOTON(1, ) = PROBABILITY AT
C          PHOTON(2, ) = MEV
C      C  RANGE(17) - RANGE OF PHOTON ENERGY IN MEV FOR 16 GROUPS
C      L  REC(500) - ISOTOPE NAME
C      CI SOURCE (I,J) SOURCE(1,J) = PHOTONS / SEC OF ENERGY
C          SOURCE(2,J) MEV. SOURCE(3,J)= ATTENUATED ENERGY FLUX
C      I  SLTH = LENGTH OF LINE OR CYL SOURCE, RADIUS OF DISC OR END CYL
C          SOURCE, LENGTH OF RECT SOURCE

```

```

C I SSV1 = EXPONENTIAL SS DIST. SS=SSV2*EXP(SSV1*VARIABLE)
C I T = THICKNESS OF SHIELD REGIONS - SOLID SOURCES ARE CONSIDERED
C AS FIRST SHIELD REGION
C I WEIGHT(500) - ARRAY FOR SELECTING INDIVIDUAL ISOTOPES. SUBSCRIPT
C CORRESPONDS TO THE ISOTOPES LOCATION IN THE RIBD
C AND PHOTON LIBRARY
C = WEIGHTING FACTOR WHEN MODE = 1
C = CURIES WHEN MODE = 2
C I X = DISTANCE TO DETECTOR, FROM CENTER OF CYL AND SPH SOURCES,
C THROUGH SOURCE OF CONE, ENDCYL, AND RECT SOURCES
C I Y = OFFSET OF DETECTOR FROM SHIELD NORMAL OF POINT SOURCE AND
C AND BASE OF CYL. Y= HEIGHT OF RECT SOURCE
C DIMENSION PHOTON(2,1006), JGROUP(5,3), WEIGHT(500),GROUP(5)
C 1,CASE(12),DUMMY(17),COEF (16,2,20),IPHSUB(501),BETEN(500)
C DIMENSION SHNAM(2,20),USED(10),IUSED(10), DSRATE(16),DOSE(16)
C 1,EAN(20),EAW(20),BAN(8),DUM(16)
C DIMENSION WT(10)
C COMMON ML(500),LA(500),REC(500),NCD,ENERGY(16),RANGE(17),
C 1,SOURCE(3,16),MU(6,16),MUE(6,16),NDT,DATA2(5,450)
C COMMON SSV1,SSV2,SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
C 1,JBUF,IGEOM,JPH,BUF(4,2),BLIB(16,3,8),PI,NSHLDA,TTMFS,B1MFS,
C 2,SECANT,BUIF,B1
C COMMON CASER(6),FMWD,TET,TLN(5),TLH(5)
C COMMON NTHETA,NPSI,DELR,VOLUME
C REAL MU,MUE
C NAMELIST /INPUT/ NEXT,T,GROUP,WEIGHT,NSHLD,SLTH,X,Y,ANG1,ANG2,ANG3
C 1,JBUF,IGEOM,SSV1,SSV2,SOURCE,NTHETA,NPSI,DELR
C DATA BLANK/ 0606060606060/
C DATA DSRATE / 1.77E-6,1.96E-6,2.06E-6,2.04E-6,2.08E-6,2.0E-6,
C 1 1.93E-6,1.84E-6,1.76E-6,1.71E-6,1.66E-6,1.60E-6,1.54E-6,1.52E-6,
C 2 1.48E-6,1.43E-6/
C DATA JGROUP / 54,36,3*0,53,35,3*0,34,52,55,2*0/
C DATA(DUMMY(1),I=1,17) / .1,.2,.3,.4,.55,.75,.9,1.1,1.35,1.6,1.8,
C 1 2.,2.2,2.4,2.6,2.8,3.2/
C DO 1 I=1,17
C 1 RANGE(I) = DUMMY(I)
C DATA(DUM (I),I=1,16) /.15,.25,.35,.475,.65,.825,1.,1.225,1.475,

```



```

1 1,7,1,9,2,1,2,3,2,5,2,7,3,0/
DO 2 I=1,16
2 ENERGY(I) = DUM (I)
PI = 3.1415927
15 READ (5,20) NPHCD
IF (MODE .EQ. 3) GO TO 100
READ + STORE PHOTON LIBRARY
C 20 FORMAT (I3)
NPHTN = 1
IPHSUB(1) = 1
DO 80 I=1,NPHCD
IEND = NPHTN + 5
READ(5,30) MASS,LATNO,ANA,NPC,((PHOTON(J,K),J=1,2),K=NPHTN,IEND)
1,BETEN(I)
30 FORMAT ( I3,I2,A4,I1,I3F5.0)
NPHTN = NPHTN + NPC
IPHSUB(I+1) = NPHTN
IF (I.GT.NCD .OR. MODE.EQ.2) GO TO 46
40 IF ( MASS .EQ. ML(I) .AND. LATNO .EQ. LA(I)) GO TO 50
WRITE (3,45) I
45 FORMAT (18H0 PHOTON LIBE CARD , I4,19H IS OUT OF SEQUENCE)
STOP
46 ML(I) = MASS
LA(I) = LATNO
REC(I) = ANA
50 IF (NPHTN-1000) 80, 60, 60
60 WRITE (3,70) I
70 FORMAT ( 34H0 PHOTON LIBE EXCEEDS LIMIT, ONLY ,I3,11H CARDS USED)
NISO = I
GO TO 90
80 CONTINUE
NISO = NPHCD
90 GO TO 200
C READ PAST PHOTON LIBE
100 DO 105 I=1,NPHCD
READ(5,20) J
105 CONTINUE

```

```

C      READ SHIELD MATERIAL LIBRARY
200 READ (5,201) (DUMMY(I),I=1,2),J,K,(DUMMY(I),I=3,10),AN,AW,KEY
201 FORMAT (A6,A1, I2,I1,8F7.0,2F3.0,I1)
      IF (J.GT.20.OR,J.LT.1) GO TO 215
      IF ( K .GT. 1) GO TO 210
      SHNAM( 1,J) = DUMMY(1)
      SHNAM( 2,J) = DUMMY(2)
      EAN(J) = AN
      EAW(J) = AW
      DO 205 I=3,10
205 COEF (I-2,1,J) = DUMMY (I)
      GO TO 220
210 DO 212 I=3,10
212 COEF (I+6,1, J) = DUMMY(I)
      GO TO 220
215 WRITE (3,216) (DUMMY(I),I=1,2),J,K,(DUMMY(I),I=3,10)
216 FORMAT (30H0INVALID MU LIBE CARD REJECTED/ 1XA6,A1,I2,I1,8E10.3)
220 IF (KEY.EQ.0) GO TO 200

C      READ BUILDUP COEFFICIENT LIBRARY
225 READ (5,226) J,K, (DUMMY(I),I=1,8), AN, KEY
226 FORMAT (8X 2I1,8F7.0,F3.0,2XI1)
      IF (J.GT.0 .AND.J.LE.8 .AND. K.GT.0.AND. K.LE.6) GO TO 230
      WRITE (3,228) J,K,(DUMMY(I),I=1,8), AN,KEY
228 FORMAT ( 47H0FOLLOWING INVALID BUILDUP FACTOR DATA REJECTED /
1 1X 2I1,8E10.3,-3PF3.3,I3)
      GO TO 235
230 KS =(K+1)/ 2
      KM2= MOD(K+1,2)
      DO 232 L=1,8
      LS = L + KM2*8
232 BLIB(LS,KS ,J) = DUMMY(L)
      IF (K.EQ.1) BAN(J) = AN
235 IF (KEY.EQ.0) GO TO 225
      DO 238 I=1,8
      IF(BAN(I).GT.0.) GO TO 238
      NBUD = I-1
      GO TO 240

```

```

238 CONTINUE
NBUD = 8
240 CONTINUE
      INITIALIZE
250 DO 255 I=1,5
    GROUP(I) = 0.
    T(I) = 0.
255 CONTINUE
DO 260 I=1,500
  WEIGHT(I) = 0.
260 CONTINUE
DO 265 I=1,6
  CASE(I) = BLANK
265 CASE(I) = BLANK
DO 270 I=1,3
  DO 270 J=1,16
270 SOURCE(I,J) = 0.
    NSHLD = 0
    NEXT = 0
    SLTH = 0.
    X = 0.
    Y = 0.
    ANG1 = 0.
    ANG2 = 0.
    ANG3 = 0.
    JBUF = 0
    IGEOM = 0
    SSV1 = 0.
    SSV2 = 0.
      READ NEXT CASE OF DATA
300 READ (2,301) CASE
301 FORMAT (12A6)
      READ (2,INPUT)
      CONVERT DEG TO RADIANS
      ANG1 = ANG1 * PI / 180.
      ANG2 = ANG2 * PI / 180.
      ANG3 = ANG3 * PI / 180.
      COUNT NUMBER OF PHOTON ENERGY GROUPS

```

```

IF (MODE.NE.3) GO TO 310
DO 309 I=1,16
IF(SOURCE(1,I)) 309,308,309
308 NPHEN = I-1
GO TO 311
309 CONTINUE
310 NPHEN = 16
      NEXT IDENTIFIES WHAT MUST BE DONE WITH THIS CASE
C      1-NEW ISOTOPE SELECTION AND SHIELD MAT. 2-NEW ISOT SEL
C      3-NEW SHIELD MATL 4-CHANGE IN GEOMETRY ONLY 5-REINITIALIZE
C      6-END OF RUN
311 NEXT = MAX0(1,NEXT)
      NEXT = MIN0(6,NEXT)
GO TO ( 400,400,500,600,250,320), NEXT
320 CALL EXIT
      RETURN
C      BUILD ISOTOPE SELECTION TABLE
400 IF (MODE.LE. 2) GO TO 405
      WRITE (3,401) MODE, CASE
401 FORMAT ( 6H0 MODE, I3,40H DOES NOT ALLOW ISOTOPE SELECTION. CASE
1, 6A6, 10H REJECTED.)
      GO TO 300
C      CHECK ISOTOPE GROUP SWITCHES
405 DO 420 I=1,NCD
      IF (GROUP(5)) 410,410,407
407 J = 5
      GO TO 416
410 DO 412 J=1,3
      DO 412 K=1,5
412 IF (JGROUP(K,J) .EQ. LA(I)) GO TO 416
415 J= 4
416 IF (GROUP(J).GT.0.) WEIGHT(I) = GROUP(J)
420 CONTINUE
      WRITE (3,422)
422 FORMAT ( 1H1, 40X22HISOTOPE SELECTION DATA //// 25H0 ISOTOPES CONS
1IDERED ARE)
      IF (MODE.EQ.1) GO TO 4225

```

```

4221 WRITE (3,4221)
      FORMAT (1H+, 60X, 22H VALUES SPECIFY CURIES)
      GO TO 423
4225 WRITE (3,4226)
4226 FORMAT (1H+,60X,36H VALUES REPRESENT A WEIGHTING FACTOR)
423  IF (GROUP(5)) 425,425,4231
4231 WRITE(3,424) GROUP(5)
424  FORMAT ( 1H+,26X,4H ALL,1PE14.3)
      GO TO 490
425  IF (GROUP(1)) 427,427,4251
4251 WRITE(3,426) GROUP(1)
426  FORMAT (26X11HNOBLE GASES,1PE14.3)
427  IF (GROUP(2)) 429,429,4271
4271 WRITE (3,428) GROUP(2)
428  FORMAT (26X8HHALOGENS,1PE14.3)
429  IF (GROUP(3)) 431,431,4291
4291 WRITE (3,430) GROUP(3)
430  FORMAT (26X15HVOLATILE SOLIDS,1PE14.3)
431  IF (GROUP(4)) 435,435,4311
4311 WRITE (3,432) GROUP(4)
432  FORMAT (26X57HALL EXCEPT THE NOBLE GASES, HALOGENS, AND VOLATILE S
      1OLIDS,1PE14.3)
435  NI = 0
      DO 470 I=1,NPHCD
      IF (WEIGHT(I) ) 470,470,437
437  DO 440 J=1,3
      DO 440 K=1,5
440  IF (LA(I) .EQ. JGROUP(K,J)) GO TO 442
      J = 4
442  IF (GROUP(J)) 443,443,470
443  NI = NI + 1
      USED(NI) = REC(I)
      IUSED(NI) = ML(I)
      WT(NI) = WEIGHT(I)
      IF (NI .LT. 10) GO TO 470
      WRITE (3,445) (USED(L),L=1,10),(WT(L),L=1,10)
445  FORMAT (1H0,9X10(A3,I3,4X) / 10X10E10.3)

```

```

      NI = 0
470  CONTINUE
      IF (NI.EQ.0 ) GOTO 490
      WRITE (3,445) (USED(L),IUSED(L),L=1,NI)
      WRITE (3,480) (WT(L),L=1,NI)
480  FORMAT (10X10E10.3)
490  IF (NEXT .EQ.2) GO TO 600
C    READ SHIELD MATERIAL SPECS
500  DO 501 I=1,16
      DO 501 J=1,6
501  MU(J,I) = 0.
      IF (JBUF.EQ.0) JBUF = NSHLD
      SUM1 = 0.
      SUM2 = 0.
      WRITE(3,502) (I,I=1,5)
502  FORMAT (1H1,9X,25HSHIELD COMPOSITION  GR/CC,5I12)
503  READ (2,504) MAT,(DUMMY(J),J=1,5),KEY
504  FORMAT ( 8X,I2, 5E10.4, 11X,I1)
      WRITE (3,523) (SHNAM(I,MAT),I=1,2),(DUMMY(J),J=1,5)
523  FORMAT (1H0,10X,2A6,16X,1P5E12.3)
      IF (MAT.GT. 0 .AND. MAT.LE.20) GO TO 510
      WRITE (3,507)
507  FORMAT (38H0 FOLLOWING SHIELD SPECS DATA REJECTED)
      WRITE (3,504) MAT,(DUMMY(I),I=1,5),KEY
      GO TO 525
C    CALCULATE MASS ABSORPTION COEFFICIENTS
510  DO 520 I=1,NPHEN
      IF (MODE .GE.3) VALUE = TERP(ENERGY,COEF(1,1,MAT),SOURCE(2,I))
      DO 520 J=1,NSHLD
      IF (MODE .LT.3) GO TO 519
      MU(J,I) = MU(J,I) + DUMMY(J)*VALUE
      GO TO 520
519  MU (J,I) = MU(J,I) + DUMMY(J) * COEF(I,1,MAT)
520  CONTINUE
      SUM1 = DUMMY(JBUF)/ EAW(MAT) + SUM1
      SUM2 = DUMMY(JBUF) * EAN(MAT) / EAW(MAT) + SUM2
525  IF (KEY .EQ. 0) GO TO 503

```

```

      ABAN = SUM2 / SUM1
C      BUILD MU FOR DUMMY SHIELD OF AIR
      DO 540 I=1,NPHEN
      IF (MODE .GE.3) GO TO 535
      MU(NSHLD+1,I) = COEF(I,1,3) * 1.2929E-3
      GO TO 540
535 MU(NSHLD+1,I) = TERP(ENERGY,COEF(1,1,3),SOURCE(2,I))* 1.2929E-3
540 CONTINUE
      WRITE(3,541) MU
541 FORMAT ( 1H0,9X50HMASS ABSORPTION COEFFICIENTS (LAST REGION IS AI
1R) / (/39X1P6E12.3))
C      BUILD SOURCE STRENGTH TABLE AND CALCULATE ATTENUATION
600 IEND = 1
      IF (MODE.LT.2) IEND = NDT
      DO 960 I=1,IEND
      IF (MODE.GT.2) GO TO 630
      DO 602 J=1,16
      DUM(J) = SOURCE(1,J)
      DUMMY(J) = SOURCE(3,J)
      DO 601 K=1,3,2
601 SOURCE (K,J) = 0.
602 SOURCE (2,J) = ENERGY(J)
      DO 620 J=1,NPHCD
      IF (WEIGHT(J)) 620,620,603
603 IF (MODE .EQ.1.AND.J .LE. NCD .AND. DATA2(I,J).LT.1.E-35)GOTO620
      KBEG = IPHSUB(J)
      KEND = IPHSUB(J+1) -1
      IF (KBEG.GT.KEND) GO TO 620
      TERM = WEIGHT(J)
      IF (MODE.EQ.1.AND.J.LE.NCD) TERM = DATA2(I,J) * WEIGHT(J)
      DO 610 K=KBEG,KEND
C      GROUP PHOTON ENERGIES
      IF (PHOTON(2,K) ) 610,610,604
604 DO 605 L=1,17
605 IF (PHOTON(2,K) ).LT. RANGE(L)) GO TO 607
      L = 16
      GO TO 608

```

```

607 L = MAX0(L-1,1)
608 SOURCE(1,L) = TERM * PHOTON(1,K ) * 3.7E10 + SOURCE(1,L)
610 CONTINUE
620 CONTINUE
630 IGEOM = MAX0(1,IGEOM)
    IGEOM = MIN0(10,IGEOM)
C      BUILD TWO SETS OF BUILD UP COEFFECIENTS FOR LATER INTERPOLATION
C      ON EFFECTIVE ATOMIC NO.(ABAN)
C      BUF (1, ) = A1, BUF(2, ) = A2 = 1.-A1, BUF(3, )=ALPHA 1,
C      BUF (4, ) = ALPHA 2, BUIF = BUILDUP INTERPOLATION FACTOR
C      THE CALCULATED BUILD UP FACTOR WILL BE INTERPOLATED RATHER
C      THAN THE COEF
    IF (BAN(1).LT.ABAN ) GO TO 631
    JBS1  = 1
    JBS2  = 2
    GO TO 635
631 DO 634 J=2,NBUD
    IF (ABAN - BAN(J)) 632,633,634
632 JBS1  = J-1
    JBS2  = J
    GO TO 635
633 JBS1  = J
    JBS2  = J+1
    GO TO 635
634 CONTINUE
    JBS1  = NBUD
    JBS2  = NBUD-1
635 BUIF = (ABAN- BAN(JBS1)) / (BAN(JBS2) -BAN(JBS1))
    DO 650 J=1,NPHEN
    IF (I.EQ.1) GO TO 636
C      NOT FIRST COOLING TIME - FLUX IS PROPORTIONAL TO SOURCE STRGTH
    SOURCE(3,J) = SOURCE(1,J)/DUM(J)*DUMMY(J)
    GO TO 650
636 IF (SOURCE(1,J)) 6361,650,6361
6361 BUF (1,1)= TERP (ENERGY,BLIB(1,1,JBS1),SOURCE(2,J))
    BUF (1,2)= TERP (ENERGY,BLIB(1,1,JBS2),SOURCE(2,J))
    BUF (2,1)= 1. - BUF(1,1)

```



```

        BUF(2,2)=1.-BUF(1,2)
        DO 637 L=3,4
        BUF(L,1)=TERP(ENERGY,BLIB(1,L-1,JBS1),SOURCE(2,J))
637  BUF(L,2)=TERP(ENERGY,BLIB(1,L-1,JBS2),SOURCE(2,J))
C      ATTENUATION CALCULATION
      JPH=J
      GO TO (641,642,643,643,645,646,647,647,648,649),IGEOM
641  CALL POINT
      GO TO 650
642  CALL LINE
      GO TO 650
643  CALL SPHERE
      GO TO 650
645  CALL TCONE
      GO TO 650
646  CALL DISC
      GO TO 650
647  CALL CYL
      GO TO 650
648  CALL ENDCYL
      GO TO 650
649  CALL RECT
      GO TO 650
650  DOSE(J)=SOURCE(3,J)*TERP(ENERGY,DSRATE,SOURCE(2,J))
C      PRINT OUT
      900 WRITE(3,901) CASE,X
      901 FORMAT(1H1,5X,29HGAMMA ATTENUATION CALCULATION,5X12A6/
      1 1H0,12X6HSOURCE,15X,7HSHIELDS,3X16HDIST TO DETECTOR,1PE10.3,
      2 4H CM.)
      GO TO (910,912,914,916,918,920,922,924,9251,9253),IGEOM
      910 WRITE(3,911)
      911 FORMAT(1H+,6X5HPOINT,10X4HSLAB)
      GO TO 940
      912 DEG1=ANG1*180./PI
      DEG2=ANG2*180./PI
      WRITE(3,913) SLTH,DEG2,DEG1
      913 FORMAT(1H+,7X4HLINE,17X4HSLAB,46X 13HSOURCE LENGTH,1PE10.3 /

```

```

1 1H0,7X14HDETECTOR ANGLE,0PF7.1,8H DEGREES, 12X,19HSHIELD NORMAL A
2NGLE, F7.1, 8H DEGREES)
GO TO 940
914 WRITE (3,915) VOLUME
915 FORMAT (12H+ SPHERICAL,12X, 9HSPHERICAL,66X5HVOL.=,1PE9.3,3H CC)
GO TO 940
916 WRITE (3,917) VOLUME
917 FORMAT (12H+ SPHERICAL,17X, 4HSLAB,66X5HVOL.=,1PE9.3,3H CC)
GO TO 940
918 IF (ANG1 + 0,1 .GT. PI / 2.) GO TO 9191
DEG1 = ANG1 * 180. / PI
WRITE (3,919) DEG1,VOLUME
919 FORMAT ( 12H+ TR. CONE, 17X4HSLAB, 43X10HCONE ANGLE,F7.1,3HDEG,
1 3X5HVOL.=,1PE9.3,3H CC)
GO TO 940
9191 IF (T(1).GT.0.) GO TO 9194
WRITE (3,9192)
9192 FORMAT (12H+ INF. PLANE , 17X, 4HSLAB)
GO TO 940
9194 WRITE (3,9195)
9195 FORMAT (12H+ INF. SLAB , 17X, 4HSLAB)
GO TO 940
920 WRITE (3,921) SLTH
921 FORMAT (1H+,7X4HDISC,17X4HSLAB,46X6HRADIUS,F10.3,4H CM.)
GO TO 940
922 WRITE (3,923) SLTH,VOLUME
923 FORMAT (12H+CYLINDRICAL,10X11HCYLINDRICAL,43X6HLENGTH,1PE10.3
1 , 4H CM.,3X5HVOL.=1PE9.3,3HCC )
GO TO 935
924 WRITE (3,925) SLTH,VOLUME
925 FORMAT (12H+CYLINRICAL,17X 4HSLAB,43X 6HLENGTH,1PE10.3,4H CM.,
1 3X5HVOL.=,1PE9.3,3H CC)
GO TO 935
9251 WRITE (3,9252) VOLUME, T(1),SLTH
9252 FORMAT (12H+END OF CYL.,17X4HSLAB,66X5HVOL.= ,1PE9.3,3H CC/ 1H0,
1 7X 8HLENGTH =, E10.3, 3H CM, 20X 8HRADIUS =,E10.3,3H CM)
GO TO 935

```

```

9253 WRITE (3,9254) VOLUME, T(1),Y,SLTH
9254 FORMAT (12H+      SLAB,17X4HSLAB,66X5HVOL.=,1PE9.3,3H CC / 1H0,
1 7X11HTHICKNESS =,1PE10.3,3HCM,8X 8HHEIGHT =,E10.3,3H CM,8X7HWIDTH
2 =,E9.3, 3H CM)
935 WRITE (3,936) NTHETA, NPSI, DELR
936 FORMAT ( 29H0 INTEGRATION SPECS  NTHETA = ,I5,5X 6HNPSI =, I5,
1 5X 6HDELR =, E10.4)
940 IF(MODE.GT.1) GO TO 930
WRITE (3,928) CASER, FMWD, TET ,TLN(I),TLH(I)
928 FORMAT ( 15H0 REACTOR DATA , 6A6, F7.1, 7H MWD IN, F7.1,5H DAYS,
1 F10.1,A5, 15H AFTER SHUTDOWN)
930 WRITE (3,931) JBUF,ABAN
931 FORMAT ( 32H0 TAYLOR BUILDUP DATA FOR SHIELD, I2, 32H WITH EFFECTI
1VE ATOMIC NUMBER OF, F5.1, 5H USED)
WRITE (3,941) (T(J),J=1,NSHLD)
941 FORMAT (1H0,10X,16HSHIELD THICKNESS, 1P6E13.3, 4H CM.)
WRITE(3,945)(K,(SOURCE(J,K),J=1,3),DOSE(K),K=1,NPHEN)
945 FORMAT (1H0,5X,5HGROUP,12X5HGROUP,15X5HGROUP,12X11HENERGY FLUX,
1 10X9HDOSE RATE / 18X15HPRODUCTION RATE,6X14HAVERAGE ENERGY,6X13HA
2T DOSE POINT, 7X13HAT DOSE POINT / 22X7HPHOTONS,15X3HMEV,13X11HMEV
3/CMS/SEC,8X14HROENTGENS/HOUR (/I10,1P4E20,3))
C      CALCULATE TOTALS
SUM1 = 0.
SUM2 = 0.
SUM3 = 0.
DO 946 J=1,NPHEN
SUM1 = SUM1 + SOURCE(1,J)
SUM2 = SUM2 + SOURCE(3,J)
946 SUM3 = SUM3 + DOSE(J)
WRITE (3,950) SUM1,SUM2,SUM3
950 FORMAT ( 10H0 TOTAL ,1PE20.3,E40.3,E20.3)
960 CONTINUE
C      CONVERT RADIANS TO DEG
ANG1=ANG1*57.2958
ANG2=ANG2*57.2958
ANG3=ANG3*57.2958
GO TO 300

END

```

```

SUBROUTINE ADJUST (ARG)
C      ADJUST THICKNESS OF LAST SHIELD OR ADD A DUMMY SHIELD SO THE
C      TOTAL SHIELD DISTANCE = DISTANCE TO DETECTOR
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1  SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
COMMON SSV1,SSV2, SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1  JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2  SECANT, BUIF,B1
COMMON CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR, VOLUME
REAL MU,MUE
TOTT = 0.
DO 10 I=1,NSHLD
TOTT = TOTT + T(I)
10 IF (ARG.LT.TOTT ) GO TO 20
NSHLDA= NSHLD + 1
T(NSHLDA) = ARG - TOTT
GO TO 30
20 NSHLDA= I
T(I) = T(I) - TOTT + ARG
30 CONTINUE
RETURN
END

```

```

      FUNCTION BFUNC (C,D)
C      FUNCTION TO INTERPOLATE CALCULATED BUILD UP FACTORS
C      C= INTERPOLATION FACTOR      D= MEAN FREE PATHS OF TOTAL SHIELD
      COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1     SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
      COMMON SSV1,SSV2,          SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1     JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2     SECANT, BUIF,B1
      COMMON          CASER(6),FMWD,TET,TLN(5),TLH(5)
      COMMON NTHETA, NPSI, DELR, VOLUME
      B = 0.
      B2 = 0.
      DO 400 J=1,2
      IF (C) 100,350,100
100  ARG = -BUF(J+2,2)* D
      IF (ARG.LT.88.027) GO TO 340
      ARG = 88.027
      WRITE (3,200) J,BUF(J+2,2), D
200  FORMAT ( 70H0 EXP(B) WHERE B GT, 88.027, B SET TO 88.027 IN CALC.
1BUILD UP, ALPHA, I1, 1H=E10.4, 5H B1=, E10.4)
340  B2 = B2 + BUF(J,2) * EXP(ARG)
350  ARG = -BUF(J+2,1) * D
      IF (ARG.LT.88.027) GO TO 400
      ARG = 88.027
      WRITE (3,200) J,BUF(J+2,1),D
400  B = B + BUF(J,1) * EXP(ARG)
      BFUNC = B + C      * (B2-B)
      RETURN
      END

```

```

SUBROUTINE CYL
C      CALCULATE GAMMA ATTENUATION FOR CYLINDRICAL SOURCE
C      USING SIMPSONS RULE FOR INTEGRATION OF POINT KERNEL
      DIMENSION TM(6)
      COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1 SOURCE(3,16), MU(6,16),MUE(6,16), NDT,DATA2(5,450)
      COMMON SSV1,SSV2,      SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1 JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2 SECANT, BUIF,B1
      COMMON      CASER(6),FMWD,TET,TLN(5),TLH(5)
      COMMON NTHETA, NPSI, DELR, VOLUME
      REAL MU,MUE
      REAL L2
      CALL ADJUST (X)
      IF (MOD(NTHETA,2).EQ.0) NTHETA = NTHETA + 1
      XS = X*X
      VOLUME = PI*SLTH*T**2
      IF (SSV1) 60,50,60
C      EXPONENTIAL SOURCE STRENGTH DISTRIBUTION
50 SSV2 = SOURCE(1,JPH) * SOURCE(2,JPH) * SSV1**2 / 2. / PI /
1  SLTH / (1. + EXP(SSV1*T) * (SSV1*T - 1.) )
      GO TO 65
C      CONSTANT SOURCE STRENGTH
60 SSV2 = SOURCE(1,JPH) * SOURCE(2,JPH) / VOLUME
65 TH2 = ATAN2 ( T, SQRT(ABS(XS-T*T)))
      DELTH = TH2 / FLOAT(NTHETA - 1)
      IF (Y.GT.SLTH) Y=0.
      HMAX = AMAX1(Y,SLTH-Y)
      AMID = AMIN1 ( Y, SLTH-Y)
      THETA = 0.
      SUMI = 0.
      FLIPI = 2.

```

```

DO 400 I=1,NTHETA
SINT = SIN(THETA)
COST = COS(THETA)
XCOS = X * COST
XSINS=(X * SINT)**2
SUM = 0.
IF (IGEOM.GE.8) GO TO 120
C      CYLINDRICAL SHIELD
DO 100 J=1,NSHLDA
SUM = SUM + T(J)
100 TM(J) = XCOS - SQRT(ABS(SUM*SUM - XSINS))
B1MFS = TM(1) * MU(1,JPH)
DO 110 J=2,NSHLDA
110 B1MFS = B1MFS + (TM(J)-TM(J-1))*MU( J,JPH)
B1MFS = - B1MFS
GO TO 150
C      SLAB SHIELDS
120 TTMFS = 0.
B1MFS = 0.
TM(1) = XCOS - SQRT(ABS(T*T - XSINS))
IF (NSHLDA.LT.3)GOTO 140
DO 130 J=3,NSHLDA
TTMFS = TTMFS + T(J)
130 B1MFS = B1MFS + MU(J,JPH)* T(J)
140 B1MFS = (B1MFS-MU(2,JPH)*TTMFS) / COST      + TM(1)*(MU(2,JPH) -
1      MU(1,JPH))
150 L2 = 2.*XCOS-TM
PSI2 = ATAN2(HMAX,TM(1))
SUMJ = 0.
IF (MOD(NPSI ,2),EQ.0)NPSI=NPSI+1
DELPSI = PSI2 / FLOAT(NPSI - 1)
PSI = 0.
FLIPJ = 2.
DO 300 J=1, NPSI
COSPSI = COS(PSI)
SECPSI = 1. / COSPSI
SINPSI = SIN(PSI)

```

```

      COSPSS = COSPSI * COSPSI
      TANPSI = SINPSI / COSPSI
      RHO = TM(1) * SECPSI
      IF (PSI.GT.0.) GO TO 160
      RHO2 = SECPSI * L2
      GO TO 170
160  RHO2 = AMIN1(SECPSI*L2, HMAX/SINPSI)
170  NRHO = INT ((RHO2-RHO) / DELR)
      IF (MOD (NRHO,2).EQ. 0) NRHO = NRHO+1
      DELRHO = (RHO2 - RHO) / FLOAT(NRHO-1)
      FLIPK = 2.
      SUMK = 0.
      DO 260 K=1,NRHO
      IF (SSV1) 190,180,190
180  SS = SSV2
      GO TO 200
190  SS = SSV2 * EXP(SQRT(ABS(XS - 2.*RHO*XCOS*COSPSI + RHO*RHO*COSPSS
1  ) ) * SSV1)
200  B1 = RHO * MU(1,JPH) + B1MFS*SECPSI
      FACT = 1.
      B = BFUNC(BUIF,B1)
      IF (K.EQ.1 .OR. K.EQ.NRHO) GO TO 250
      FLIPK = 6.-FLIPK
      FACT = FLIPK
250  IF(RHO.LT.AMID/SINPSI+DELRHO/2.) FACT = FACT*2.
      VAL = FACT * B * SS * EXP(-B1)
      SUMK = SUMK + VAL
      IF (K.EQ.1) FRST = VAL
      IF (ABS(VAL/FRST).LT.1.E-4) GO TO 265
260  RHO = RHO + DELRHO
265  SUMK = SUMK * DELRHO
      FACT = 1.
      IF (J.EQ.1.OR. J.EQ. NPSI) GO TO 270
      FLIPJ = 6.-FLIPJ
      FACT = FLIPJ
270  SUMJ = SUMJ + FACT * SUMK
300  PSI = PSI + DELPSI

```



```
SUMJ = SUMJ * DELPSI
FACT = 1.
IF (I.EQ.1.OR. I.EQ.NTHETA) GO TO 340
FLIPI=6,-FLIPI
FACT = FLIPI
SUMI = SUMI + FACT * SUMJ
340 THETA = THETA + DELTH
400 SUMI = SUMI/ 54./ PI * DELTH
SOURCE (3,JPH) = SUMI
RETURN
END
```

```

SUBROUTINE DISC
C      SUBROUTINE TO CALCULATE ATTENUATION FOR DISC SOURCE USING
C      SIMPS INTEGRATION FUNCTION. DSCSRC IS THE FUNCTION WHICH
C      IS INTEGRATED OVER THE SOURCE
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1  SOURCE(3,16), MU(6,16),MUE(6,16), NDT,DATA2(5,450)
COMMON SSV1,SSV2,      SLTH,TOTAL(4),T(6),NSHLDA,X,Y,ANG1,ANG2,ANG3,
1  JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2  SECANT, BUIF,B1
COMMON      CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR, VOLUME
REAL MU,MUE
EXTERNAL DSCSRC
CALL ADJUST(X)
B1 = 0.
DO 10 J=1,NSHLDA
10 B1 = B1 + T(J)*MU(J,JPH)
IF (SSV1) 25,20,25
C      CONSTANT SOURCE DIST.
20 SSV2 = SOURCE(1,JPH)* SOURCE(2,JPH)/PI/SLTH**2
GO TO 30
C      EXPONENTIAL SOURCE DIST.
25 SSV2 = SOURCE(1,JPH) * SSV1**2 / 2. / PI / (1.+(SSV1*SLTH-1.) *
1  EXP(SSV1*SLTH)) * SOURCE(2,JPH)
30 SOURCE (3,JPH) = .5 * SIMPS(0,SLTH,.001,DSCSRC)
RETURN
END

```

```

C      FUNCTION DSCSRC (ARG)
          FUNCTION INTEGRATED OVER DISC SOURCE
          COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1      SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
          COMMON SSV1,SSV2,      SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1      JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2      SECANT, BUIF,B1
          COMMON      CASER(6),FMWD,TET,TLN(5),TLH(5)
          COMMON NTHETA, NPSI, DELR, VOLUME
          RHOSQ = X * X + ARG * ARG
          RHO = SQRT (RHOSQ)
          B = BFUNC (BUIF,B1*RHO/X)
          DSCSRC = B * SSV2 * EXP(SSV1*ARG - B1*RHO/X) * ARG / RHOSQ
          RETURN
          END

```

```

SUBROUTINE ENDCYL
C      CALCULATE ATTENUATION OF CYL. SOURCE WITH DETECTOR AT END
C      USING SIMPSONS RULE FOR INTEGRATION OF POINT KERNEL
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1  SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
COMMON SSV1,SSV2,      SLTH,TOTAL(4),T(6),NSHLDA,X,Y,ANG1,ANG2,ANG3,
1  JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2  SECANT, BUIF,B1
COMMON      CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR, VOLUME
REAL MU,MUE
CALL ADJUST(X)
FLIPI = 2.
B1MFS = 0.
TTMFS = 0.
DO 5 I=2,NSHLDA
TTMFS = TTMFS + T(I)
5 B1MFS = B1MFS + MU(I,JPH) * T(I)
IF (MOD(NTHETA,2).EQ.0) NTHETA=NTHETA+1
THETA= 0.
TH2 = ATAN2(SLTH,X-T)
DELTH = TH2/FLOAT(NTHETA)
VOLUME = PI * SLTH**2* T
IF (SSV1) 15,10,15
10 SSV2 = SOURCE(1,JPH)* SOURCE(2,JPH)/ VOLUME
GO TO 20
15 SSV2 = SOURCE(1,JPH)* SOURCE(2,JPH) * SSV1**2 / 2. / PI / T /
1  (1. + EXP(SSV1*SLTH) * (SSV1* SLTH - 1.))
20 SUMI = 0.
DO 200 I=1,NTHETA
SINT = SIN(THETA)
SECANT = 1. / COS(THETA)

```

```

RHO = (X-T) * SECANT
RHO2 = AMIN1 (X * SECANT, SLTH / SINT )
NRHO = INT ( (RHO2- RHO) / DELR )
IF (MOD(NRHO,2).EQ.0) NRHO = NRHO + 1
DELRHO = (RHO2-RHO) / FLOAT(NRHO)
SUMJ = 0.
FLIPJ = 2.
TT = TTMS * SECANT
B1 = B1MS * SECANT
DO 100 J=1,NRHO
  IF (SSV1) 35,30,35
30 SS= SSV2
  GO TO 40
35 SS = SSV2 * EXP (RHO*SINT*SSV1)
40 B2 = (RHO - TT)* MU(1,JPH) + B1
  B = BFUNC (BUIF,B2)
  FACT = 1.
  IF (J.EQ.1 .OR. J.EQ.NRHO) GO TO 50
  FLIPJ = 6. - FLIPJ
  FACT = FLIPJ
50 VAL = FACT * B * SS * EXP(-B2)
  IF (J.EQ.1) FRST = VAL
  IF ( ABS(VAL / FRST) .LT. 1.E-4) GO TO 110
  SUMJ = SUMJ + VAL
100 RHO = RHO + DELRHO
110 SUMJ = SUMJ * DELRHO
  FACT = 1.
  IF ( I.EQ.1 .OR. I.EQ.NTHETA) GO TO 150
  FLIPI = 6. - FLIPI
  FACT = FLIPI
150 SUMI = SUMI + FACT * SUMJ * SINT
200 THETA = THETA + DELTH
  SOURCE (3,JPH) = SUMI * DELTH / 18.
  RETURN
END

```

```

      FUNCTION E1(ARG)
C      APPROXIMATES INTEGRAL (ARG,INF) OF EXP(-T)/ T DT FOR
C      POSITIVE ARG
      VALUE = 0.
      IF (ARG .GT. 0.0) GO TO 10
4     WRITE (3,5) ARG
5     FORMAT (19H0 INVALID ARGUMENT ,E10.3,36H FOR FUNCTION E1, RESULT
1     SET TO 0.)
      GO TO 100
10    IF (1.0 .LT. ARG) GO TO 20
      VALUE = -0.57721566 - ALOG(ARG)
      FACT = 1.
      DIV = -1.
      DO 15 I=1,10
      FI = FLOAT(I)
      FACT = FACT * FI
      DIV = -DIV* ARG
15    VALUE = VALUE + DIV/FI/FACT
      GO TO 100
20    IF (ARG .GT. 88.)GO TO 100
      VALUE = EXP(-ARG)/ARG* (0.2372905+ ARG*(4.5307924 + ARG*(5.1266902
1    + ARG))) / (2.476631+ARG*(8.6660126+ARG*(6.1265272+ARG)))
100   E1 = VALUE
      RETURN
      END

```

```

C      FUNCTION E2(ARG)
C      APPROXIMATES ARG* INTEGRAL(ARG,INF) OF EXP(-T)/T**2 DT
C      VALUE = 1.
C      IF (ARG ) 5,10,5
C      5 VALUE = EXP(-ARG) - ARG* E1(ARG)
C      10 E2 = VALUE
C      RETURN
C      END
```

```

C      FUNCTION F1(T,A)
          APPROXIMATION FOR INTEGRAL FROM 0 TO T  OF EXP(A*X)*E1(X) DX
      VALUE = 0.
      IF (T ) 5,100,5
5      IF (A,GT,0. .OR. A,LT,0. .OR. ABS(T),GT,88.) GO TO 9
      VALUE = 1. - E2(T)
      GO TO 100
9      IF (A) 10,20,10
10     IF (1.0 .LT. A .OR. ABS(T*(1.-A)).GT.88.) GO TO 20
11     VALUE = (EXP(A*T)* E1(T) - E1(T*(1.-A)) -ALOG(ABS(1.-A))) / A
      GO TO 100
20     IF (ABS(A-1.).GT.1.E-10 .OR. T,LT,1.E-38 .OR. T,GT,88.) GO TO 30
      VALUE = EXP(T)* E1(T) +ALOG(T) + 0.57721566
      GO TO 100
30     IF ( A,GT,1.0 .AND,ABS(A*T),LT, 88.) GO TO 11
      WRITE (3,40) T,A
40     FORMAT (40H0 F1 INTEGRATION FUNCTION FAILED.  TAU =, E11.3,
1      5H, A= ,E11.3)
100    F1 = VALUE
      RETURN
      END

```



```

SUBROUTINE LINE
C      CALCULATES GAMMA ATTENUATION FOR A LINE SOURCE. LINE SOURCE
C      IS ORIENTED SUCH THAT ONE END IS CONSIDERED ORIGIN, ANG1 =
C      ANGLE SHIELD NORMAL MAKES WITH THE LINE SOURCE, ANG2 = ANGLE
C      TO DETECTOR, X = DIST TO DETECTOR FROM ORIGIN, SLTH =SOURCE
C      LENGTH.  USES SIMPS INTEGRATION FUNCTION, INTEGRATING
C      FUNCTION LINSRC
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1  SOURCE(3,16), MU(6,16),MUE(6,16), NDT,DATA2(5,450)
COMMON SSV1,SSV2,      SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1  JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2  SECANT, BUIF,B1
COMMON      CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR ,VOLUME
REAL MU,MUE
EXTERNAL LINSRC
XNORM = X * COS (ABS(ANG2-ANG1 ))
IF (ANG1.LT,PI/2.) T = AMAX1(T,SLTH*COS(ANG1))
CALL ADJUST (XNORM)
B1MFS = 0.
TTMFS = 0.
DO 105 K=2,NSHLDA
TTMFS = TTMFS + T(K)
105 B1MFS = B1MFS + T(K)* MU(K,JPH)
IF (SSV1) 106, 107,106
C      EXPONENTIAL SOURCE DIST.
106 SSV2 = SOURCE(1,JPH)* SOURCE(2,JPH)* SSV1/(EXP(SSV1*SLTH)-1.)
GO TO 108
C      CONSTANT SOURCE DIST.
107 SSV2 = SOURCE(1,JPH)* SOURCE(2,JPH) / SLTH
108 SOURCE (3,JPH) = SIMPS (0,SLTH,.001, LINSRC)
CALL SLITET (1,LT1)

```

```
GO TO ( 110, 120),LT1
110 WRITE (3,115) JPH,(SOURCE (J,JPH),J=1,3)
115 FORMAT (25H0 INTEGRATION FAILED FOR , I2,14H ENERGY LEVEL ,
11PE11.4, 11H PHOTONS AT ,E12.4,15HMEV.  RESULT =,E12.4)
120 RETURN
END
```

```

C
C
REAL FUNCTION LINSRC (ARG)
  THIS FUNCTION IS INTEGRATED BY FUNCTION SIMPS TO CALCULATE
  ATTENUATION FOR A LINE SOURCE
  COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1 SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
  COMMON SSV1,SSV2, SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1 JBUF,IGEOM,JPH,BUF(4,2),BLIB(16,3,8),PI,NSHDA,TTMFS,B1MFS,
2 SECANT,BUIF,B1
  COMMON CASER(6),FMWD,TET,TLN(5),TLH(5)
  COMMON NTHETA,NPSI,DELR,VOLUME
  REAL MU,MUE
  RHOSQ = ARG**2 + X**2 - 2. *ARG*X*COS(ANG2)
  RHO = SQRT(RHOSQ)
  SINOM = ARG * SIN(ANG2) / RHO
  COSOM = (X**2 + RHOSQ - ARG**2) / 2. / X / RHO
  OMEG= ATAN2 (SINOM,COSOM)
  THETA = ABS (ANG1 - ANG2- OMEG)
  SECANT = 1. / COS (THETA)
  B1 = (RHO- TTMFS* SECANT) * MU(1,JPH) + B1MFS * SECANT
  IF (SSV1) 200,150,200
150 SS=SSV2
  GO TO 300
200 SS = SSV2 * EXP(SSV1*ARG)
300 B = BFUNC(BUIF,B1)
  LINSRC = B * SS * EXP(-B1) / 4. / PI / RHOSQ
  RETURN
END

```

```

SUBROUTINE POINT
C   SUBROUTINE POINT CALCULATES GAMMA ATTENUATION OF A POINT
C   SOURCE THROUGH MULTIPLE SLAB SHIELDS
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1  SOURCE(3,16), MU(6,16),MUE(6,16), NDT,DATA2(5,450)
COMMON SSV1,SSV2,      SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1  JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2  SECANT, BUIF,B1
COMMON      CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR, VOLUME
REAL MU,MUE
CALL ADJUST (X)
SECANT = 1. / COS(ATAN2(Y,X))
C   CALCULATE B1 = SUM MU * THICKNESS OF SHIELDS, MU = ATTEN. COEF
B1 = 0.
DO 20 J=1,NSHLDA
20 B1 = B1 + MU(J,JPH) * T(J)
B1 = B1 * SECANT
B = BFUNC(BUIF,B1)
SOURCE(3,JPH) = B * SOURCE(1,JPH) * SOURCE(2,JPH) * EXP(-B1)
1  / 4. / PI / (X * SECANT) **2
RETURN
END

```

```

SUBROUTINE RECT
C      SUBROUTINE TO CALCULATE ATTENUATION FOR A RECTANGULAR SOURCE
C      USES SIMPSONS RULE FOR NUMERICAL INTEGRATION OF A POIN KERNEL
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1  SOURCE(3,16), MU(6,16),MUE(6,16), NDT,DATA2(5,450)
COMMON SSV1,SSV2,      SLTH,TOTAL(4),T(6),NSHLDA,X,Y,ANG1,ANG2,ANG3,
1  JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2  SECANT, BUIF,B1
COMMON      CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR, VOLUME
REAL MU,MUE
VOLUME = SLTH * Y * T
C      CONSTANT SOURCE STRENGTH ONLY FOR RECT. SOURCE
SSV2 = SOURCE(1,JPH) * SOURCE(2,JPH) / VOLUME
IF (MOD(NPSI,2).EQ.0) NPSI = NPSI+1
DELPsi = Y/ FLOAT(NPSI) /2.
FLIPI = 2.
SUMI = 0.
CALL ADJUST(X)
B1MFS = 0.
TTMFS = 0.
DO 10 I=2,NSHLDA
TTMFS = TTMFS + T(I)
10 B1MFS = B1MFS + T(I)* MU(I,JPH)
IF (MOD(NTHETA,2).EQ.0) NTHETA = NTHETA +1
THETA = 0.
DELTH = SLTH/ 2./ FLOAT(NTHETA)
NZ = INT(T/DELR)
IF (MOD(NZ,2).EQ.0) NZ= NZ + 1
DZ = T / FLOAT (NZ)
DO 300      I=1,NTHETA
FLIPJ = 2.

```

```

SUMJ = 0.
PSI = 0.
THSQ = THETA**2
DO 200 J=1,NPSI
  TSPS = THSQ + PSI**2
  SUMK = 0.
  FLIPK = 2.
  Z = 0.
  DO 100 K=1,NZ
    RHOSQ = TSPS + (TTMFS+Z)**2
    RHO = SQRT (RHOSQ)
    SECANT = RHO / (TTMFS + Z )
    B1 = (RHO-TTMFS*SECANT)* MU(1,JPH) + B1MFS * SECANT
    B = BFUNC (BUIF,B1)
    FACT = 1.
    IF (K.EQ.1.OR. K.EQ.NZ) GOTO 50
    FLIPK = 6.-FLIPK
    FACT = FLIPK
50 VAL = FACT * B * SSV2 * EXP(-B1) / RHOSQ
    IF (K.EQ.1) FRST=VAL
    IF (ABS(VAL/FRST).LT.1.E-4) GO TO 110
    SUMK = SUMK + VAL
100 Z = Z + DZ
110 FACT = 1.
    IF (J.EQ.1.OR.J.EQ.NPSI) GO TO 150
    FLIPJ = 6. - FLIPJ
    FACT = FLIPJ
150 SUMJ = SUMJ + FACT * SUMK
200 PSI = PSI + DELPSI
    FACT = 1.
    IF (I.EQ.1.OR.I.EQ.NTHETA) GO TO 250
    FLIPI = 6.-FLIPI
    FACT = FLIPI
250 SUMI = SUMI + FACT * SUMJ
300 THETA = THETA + DELTH
    SOURCE (3,JPH) = SUMI * DZ * DELTH * DELPSI / PI / 27.
    RETURN

```

END

```

SUBROUTINE SPHERE
C      CALCULATES GAMMA ATTENUATION OF A SPHERICAL SOURCE WITH EITHER
C      SPHERICAL OR SLAB SHIELDS - USES FUNCTION SIMPS TO INTEGRATE
C      FUNCTION SPHSRC
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1  SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
COMMON SSV1,SSV2, SLTH,TOTAL(4),T(6),NSHLDA,X,Y,ANG1,ANG2,ANG3,
1  JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8 ), PI, NSHLDA, TTMFS,B1MFS,
2  SECANT, BUIF,B1
COMMON CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR,VOLUME
REAL MU,MUE
EXTERNAL SPHSRC
CALL ADJUST (X)
THETA2 = ATAN2(T,SQRT(ABS(X**2 - T**2)))
VOLUME = 4.189*T**3
IF (IGEOM=4) 10,8,8
C      SLAB SHIELDS
8  TTMFS = 0,
   B1MFS = 0,
   IF(NSHLDA,LT,3)GO TO 10
   DO 9 K=3,NSHLDA
   TTMFS = TTMFS + T(K)
9  B1MFS = B1MFS + T(K)*MU(K,JPH)
C      CONSTANT SOURCE STRENGTH ONLY FOR SPHERICAL SOURCE
10 SSV2 = SOURCE(2,JPH) * SOURCE(1,JPH) / VOLUME
   SOURCE (3,JPH) = .5 * SIMPS(0,THETA2,.001,SPHSRC) * SSV2
   CALL SLITET (1,LT1)
   GO TO ( 110, 120),LT1
110 WRITE (3,115) JPH,(SOURCE (J,JPH),J=1,3)
115 FORMAT (25H0 INTEGRATION FAILED FOR , I2,14H ENERGY LEVEL ,
11PE11.4, 11H PHOTONS AT ,E12.4,15HMEV. RESULT =,E12.4)

120 RETURN
END

```

```

C
C
FUNCTION SPHSRC (ARG)
  THIS FUNCTION IS INTEGRATED BY FUNCTION SIMPS TO CALCULATE
  ATTENUATION OF A SPHERICAL SOURCE
  COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1 SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
  COMMON SSV1,SSV2, SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1 JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8),PI, NSHLDA, TTMFS,B1MFS,
2 SECANT, BUIF,B1
  COMMON CASER(6),FMWD,TET,TLN(5),TLH(5)
  COMMON NTHETA, NPSI, DELR
  REAL MU,MUE
  DIMENSION VAL(2)
  XCOS = X * COS(ARG)
  REAL L1, L2
  DIMENSION TM(6)
  SINA = SIN(ARG)
  XSINS = (X*SINA)**2
  XX = SQRT (ABS( T(1) **2 - XSINS))
  L1 = XCOS - XX
  L2 = XCOS + XX
  IF (IGEOM=3) 5,9,5
    SLAB SHIELDS
  5 TT = TTMFS * X/XCOS
    B1 = L1*MU(1,JPH) - (L1-TT)*MU(2,JPH) - B1MFS*X/XCOS
    GO TO 21
  C
  SPHERICAL SHIELDS
  9 XX = T(1)
    DO 10 I=2,NSHLDA
      XX=XX + T(I)
    10 TM(I) = XCOS - SQRT (ABS( XX**2 - XSINS) )
      B1 = L1 * MU(1,JPH)
      TM(1) = L1

```



```

DO 20 I=2,NSHLDA
20 B1 = B1 - (TM(I-1)-TM(I)) * MU(I,JPH)
21 SPHSRC = 0.
DO 30 K=1,2
VAL(K) = 0.
DO 30 I=1,2
A = 1. + BUF(I+2,K)
30 VAL(K) = VAL(K) - BUF(I,K)/A/ MU(1,JPH) * (EXP(A*(B1
1 MU(1,JPH))) - EXP(A*(B1 - L1*MU(1,JPH))))
SPHSRC =(VAL(1) + BUF*(VAL(2) - VAL(1)))* SINA
RETURN
END
-L2*

```

```

C
SUBROUTINE TCONE
  CALCULATES ATTENUATION FOR TRUNCATED CONE SOURCE
  COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1 SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
  COMMON SSV1,SSV2, SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1 JBUF,IGEOM, JPH,BUF(4,2),BLIB(16,3,8),PI, NSHLDA, TTMFS,B1MFS,
2 SECANT, BUIF,B1
  COMMON CASER(6),FMWD,TET,TLN(5),TLH(5)
  COMMON NTHETA, NPSI, DELR,VOLUME
  REAL MU,MUE
  DIMENSION VAL(2)
  SECANT = 1. / COS(ANG1)
  CALL ADJUST (X)
  B1MFS = 0.
  DO 15 J=2,NSHLDA
15 B1MFS = B1MFS + MU(J,JPH)* T(J)
  B1 = B1MFS + MU(1,JPH) * T(1)
  TANS = (SIN(ANG1)/COS(ANG1))** 2
  VOLUME = 1.047*TANS*(X**3-(X-T)**3)
  IF (SSV1) 38,16,38
  IF (ANG1 - PI/2. +0.1) 18,20,20
18 SSV2 = SOURCE(1,JPH) * SOURCE(2,JPH) / VOLUME
  GO TO 25
C
  INFINITE SLAB SOURCE
20 SSV2 = SOURCE(1,JPH) * SOURCE(2,JPH)
  VOLUME=9.999E30
  IF (T(1).GT. 0.) GO TO 25
C
  INFINITE PLANE SOURCE
  DO 23 K=1,2
  VAL(K) = 0.
  DO 23 J=1,2

```

```

A = 1.0 + BUF(J+2,K)
23 VAL(K) = VAL(K) + BUF(J,K) * E1(A*B1)
SOURCE(3,JPH) = .5 * SSV2 * (VAL(1) + BUIF*(VAL(2)-VAL(1)))
RETURN
25 DO 35 K=1,2
VAL(K) = 0.
DO 35 J = 1,2
A=1.0 + BUF(J+2,K)
IF (ANG1 .LT. PI/2. - 0.1) GO TO 30
VAL(K) = VAL(K) + BUF(J,K)/A * (E2(A*B1MFS) - E2(A*B1) )
GO TO 35
30 VAL(K) = VAL(K) + BUF(J,K)/A * (E2(A*B1MFS)-E2(A*B1) - E2(A*B1MFS*
1 SECANT)/ SECANT + E2(A*B1*SECANT)/SECANT)
35 CONTINUE
GO TO 100
C EXPONENTIAL SOURCE STRENGTH DISTRIBUTION
38 IF (ANG1 .LT. PI/2. - 0.1) GO TO 40
VOLUME=9.999E30
SSV2 = SOURCE(1,JPH) * SOURCE(2,JPH)
GO TO 42
40 SSV2 = SOURCE(1,JPH)* SOURCE(2,JPH) * SSV1/( EXP(SSV1*T) *(X*X
1 - (SSV1* T - 1.) *(-2./SSV1*( X + 1./SSV1)) + T*T) - X*X - 2./SSV
2 1* (X + 1./ SSV1))
42 DO 60 K=1,2
VAL(K) = 0.
DO 60 J=1,2
A =1.0 + BUF(J+2,K)
IF (PI/2.-0.1 .LT. ANG1) GO TO 55
45 VAL(K) = VAL(K) + BUF(J,K)/A * (F1(A*B1,BUF(J+2,K)) -
1 F1(A*B1MFS,BUF(J+2,K)) - F1(A*B1*SECANT,BUF(J+2,K))/SECANT
2 + F1(A*B1MFS*SECANT,BUF(J+2,K)))
GO TO 60
55 VAL(K) = VAL(K) + BUF(J,K)/A * (F1(A*B1,BUF(J+2,K)) -
1 F1(A*B1MFS,BUF(J+2,K)))
60 CONTINUE
100 SOURCE (3,JPH) = .5 * SSV2 * EXP(SSV1/MU(1,JPH)*B1)/MU(1,JPH) *
1 (VAL(1) +BUIF*(VAL(2)-VAL(1)))
RETURN
END

```

	FUNCTION SIMPS(A,B,DELTA,F00000)	039-1	1
C	A AND B ARE MIN AND MAX OF THE DEFINITE INTEGRAL	039-1	2
C	DELTA IS THE PERMISSIBLE DIFFERENCE BETWEEN TWO SUCCESSIVE SUMS,	039-1	3
	N=1	039-1	4
	H=(B-A)/2.	039-1	5
	FJAY=H*(F00000(A)+F00000(B))	039-1	6
C	A MAXIMUM OF 2049 POINTS WILL BE USED WHEN L=11	039-1	7
	DO 35 L=1,11	039-1	8
10	S=0.0	039-1	9
	DO 20 K=1,N	039-1	10
20	S=S+F00000(A+(2.0*FLOAT (K)-1.0)*H)	039-1	11
	FI=FJAY+4.0*H*S	039-1	12
	IF(L-3)26,26,23	039-1	13
23	CONTINUE	039-1	14
	IF(DELTA-ABS ((FI-BAR)/FI))30,40,40	039-1	15
26	CONTINUE	039-1	16
30	BAR=FI	039-1	17
	FJAY=(FI+FJAY)/4.0	039-1	18
	N=2*N	039-1	19
	H=H/2.0	039-1	20
35	CONTINUE	039-1	21
	CALL SLITE (1)		
40	SIMPS =FI/3.0	039-1	23
	RETURN	039-1	24
	END		

```

FUNCTION TERP (X,Y,A)
COMMON ML(500), LA(500), REC(500), NCD, ENERGY(16), RANGE(17),
1 SOURCE(3,16), MU(6,16), MUE(6,16), NDT, DATA2(5,450)
COMMON SSV1,SSV2, SLTH,TOTAL(4),T(6),NSHLD,X,Y,ANG1,ANG2,ANG3,
1 JBUF,IGEOM,JPH,BUF(4,2),BLIB(16,3,8),PI, NSHLDA, TTMFS,B1MFS,
2 SECANT, BUIF,B1
COMMON CASER(6),FMWD,TET,TLN(5),TLH(5)
COMMON NTHETA, NPSI, DELR, VOLUME
DIMENSION X(16), Y(16)
      PERFORMS LINEAR INTERPOLATION
      IF (A-AP) 5,30,5
5 DO 10 I=1,16
10 IF (X(I) .GT.A ) GO TO 20
      J = 10
      K = 10
      GO TO 30
20 K = MAX0 (I,2)
      J = MAX0(I-1,1)
30 TERP = Y(J) + (A-X(J)) / (X(K)-X(K-1)) * (Y(K)-Y(K-1))
      AP=A
      RETURN
      END

```

C

APPENDIX D

ISOSHLD LIBRARIES

/

APPENDIX D

ISOSHL D LIBRARIES

RIBD ISOTOPE LIBRARY

This library is used by RIBD to calculate fission product inventory. The first card contains the number of isotopes in the library (Columns 1-3). There is one card for each isotope in the library and they are in an ascending atomic number order within an ascending atomic mass sequence. The current RIBD library (as listed) contains 450 fission products and daughters. The data format is:

<u>Column</u>	<u>Format</u>	<u>Variable</u>
1-3	I3	Atomic Mass Number
4-5	I2	Atomic Number
6-14	E9.3	Half life, days
15-23		Fission yield from U^{235} , %
24-32		Fission yield from U^{239} , %
33-41	F5.3	Absorption cross section, barns
42-46		Fraction of (n, γ) captures that go to isometric state
47-51		If in isomeric state, fraction of decays by beta emission; if in ground state, fraction that decays to an isomer
52-56		Average beta energy release per disintegration, MeV
69-71	A3	Isotope name
72	I1	Isotope Type: 1 - Isomer 2 - Common

The fission product library listed in this appendix has been scanned and updated five times during the past two years, the latest revisions having been made in May 1965 by R. O. Gumprecht.⁽⁴⁾ The fission yield data were obtained from the work of Yu. A. Zysin, A. A. Lbov, and L. I. Sel'chenkof.⁽¹⁴⁾ These data were compiled from over two hundred literature sources and appear to favor data presented by Catcoff.⁽¹⁵⁾ Beta and gamma energies released during isotope or isomeric decay along with their branching ratios were developed from the decay schemes presented by Landolt-Bornstein.⁽⁹⁾ Neutron capture cross sections and their branching ratios were taken from Goldman.⁽¹⁶⁾ Half lives were obtained by cross checking all of the above sources.

PHOTON PROBABILITY LIBRARY

These data are used to calculate the number of photons of various energies produced by an array of radioactive isotopes. The first card contains the number of photon probability cards in this library (Column 1-3). Following this there is one card for each isotope of the RIBD library in the same order as in the RIBD library. Other isotopes may be added in any order following the RIBD isotopes. The listed library contains 48 activation products following the 450 RIBD fission products. The photon library format is:

<u>Column</u>	<u>Format</u>	<u>Variable</u>
1-3	I3	Atomic Mass number
4-5	I2	Atomic number
6-9	A4	Isotope name
10	I1	Number of decay energies on card
11-15	F5.0	Probability
16-20		Photon decay energy, MeV
61-65		Probability
66-70		Photon decay energy, MeV
71-75		Beta decay energy (average total), MeV

The data in the photon libraries were compiled from References 9 through 12.

MASS ATTENUATION COEFFICIENT LIBRARY

Two cards contain mass attenuation coefficients (in 16 group energy levels) for each shielding material in the library.

The current materials and their material numbers are:

1. Water	10. Nickel
2. Tissue	11. Zirconium
3. Air	12. Tin
4. Hydrogen	13. Tungsten
5. Lithium	14. Lead
6. Carbon	15. Uranium
7. Aluminum	16. Ordinary concrete
8. Titanium	17. Magnetite concrete
9. Iron	18. Ferrophosphorus concrete

A total of 20 materials may be contained in this library.

The card formats are:

<u>Column</u>	<u>Format</u>	<u>Variable</u>
1-7	A7	Material name (card one only)
8-9	I2	Material number (card one only)
10	I1	Card number - 1 or 2
11-66	8F7.0	Mass attenuation coefficient for 8 energy levels
67-69	F3.0	Atomic number (card one only)
70-72	F3.0	Atomic weight (card one only)
73	I1	1 for last card in library - all others 0 or blank

The data in this library were taken from Rockwell. Equation 4 was used to calculate unit density mixed mass attenuation coefficients for the mixtures. Concretes are the standard Hanford mixes referenced by Walker and Grotenhuis.⁽¹³⁾

BUILDUP FACTOR LIBRARY

This set of data contains buildup factor coefficients (A_1 , α_1 and α_2) for a maximum of eight materials. The buildup factor is equal to $A_1 e^{-\alpha_1 b_1} + A_2 e^{-\alpha_2 b_1}$ where $A_2 = (1 - A_1)$.

There are 6 materials currently in this library:

1. water	4. tin
2. aluminum	5. tungsten
3. iron	6. lead

There are 6 cards for each material. Cards 1 and 2 contain A_1 in six energy groups; cards 3 and 4 contain α_1 , and cards 5 and 6 contain α_2 . The card format is:

<u>Column</u>	<u>Format</u>	<u>Variable</u>
9	I1	Material number
10	I1	Card number
11-66	8F7.0	Coefficients
67-69	F3.0	Atomic number
72	I1	1 for last card, all other 0 or blank

These data were obtained from Goldstein.⁽⁵⁾ This data was extrapolated from 0.5 down to 0.15 MeV to obtain buildup data for groups 1 to 4.

RIBD FISSON PRODUCT LIBRARY

450

72301.938E 001,600E-051,200E-040,	0,	0,	.12	1.235	ZN 2	001
72315.875E-010,	0,	0,	.43	2.869	GA 2	002
7232	0,	0,	1.		GE 2	003
73301.390E-039,800E-050,			2.25		ZN 2	004
73312.000E-012,000E-06			.42	.409	GA 2	005
73320,	0,	0,	14.		GE 2	006
74315.555E-033,500E-040,			1.01	3.149	GA 2	007
7432	0,	0,	.5	.4	GE 2	008
75311.389E-034,000E-04			1.43	.58	GA 2	009
75325.671E-044,000E-04				.139	GE*1	010
75325.694E-02			.42	.038	GE 2	011
7533	0,	0,	4.5		AS 2	012
76313.704E-04 .001			2.74	1.	GA 2	013
7632	.001		.2	.5	GE 2	014
76331.104E 000,	0.		1.09	0.404	AS 2	015
7634	0,	0,	85.	.259	SE 2	016
77326.250E-045,400E-030,			0.640	.77	GE*1	017
77324.583E-013,700E-030,			.64	1.134	GE 2	018
77331.625E 000,	0.		.22	0.022	AS 2	019
77342.083E-04				.16	SE*1	020
7734	0,	0,	42.		SE 2	021
78328.750E-021,800E-020,			.32	0.300	GE 2	022
78336.319E-032,000E-030,			1.47	0.888	AS 2	023
7834	0,	0,	.41	.875	SE 2	024
79336.250E-034,000E-020,			1.	.90	AS 2	025
79342.708E-030,	0.			0.096	SE*1	026
79342.555E 070,	0.		.04		SE 2	027
79350,	0,	0,	1.140E	010.2540.	BR 2	028
80331.736E-04 .08			2.73	.5	AS 2	029

100

BNWL-236

8034			.6	.2			SE 2	030
80351.875E-010.	0.				0.085		BR*1	031
80351.250E-020.	0.				.72 .116		BR 2	032
8036	0.	0.	15.				KR 2	033
81333.819E-041.250E-010.					1.66		AS 2	034
81343.958E-028.400E-030.					0.103		SE*1	035
81341.250E-020.	0.				.53		SE 2	036
8135	0.	0.	3.				BR 2	037
8136	0.	0.					KR 2	038
8234	3.800E-050.		5.400E-020.9200.				SE 2	039
82351.471E 00					.14 2.648		BR 2	040
8236	0.	0.	45.	1.			KR 2	041
83347.986E-043.000E-011.200E-01					1.0001.55 0.200		SE*1	042
83341.736E-021.800E-018.600E-02					.69 1.000		SE 2	043
83351.000E-010.	8.400E-020.			0.	1.000.34 0.010		BR 2	044
83367.750E-020.	0.	0.		0.	0.041		KR*1	045
8336	0.	0.	180.				KR 2	046
84342.083E-036.100E-023.000E-02					.49		SE 2	047
84354.167E-031.900E-021.000E-02				1.	.71 3.396		BR*1	048
84352.222E-029.200E-014.300E-01					1.23 1.863		BR 2	049
8436	0.	0.	.14	.714			KR 2	050
85334.977E-065.500E-011.260E-01					1.28 5.0		AS 2	051
85344.514E-045.500E-011.260E-01					2.24		SE 2	052
85352.083E-034.000E-011.600E-01				1.	1.04		BR 2	053
85361.833E-010.	0.			0.810.29 .179			KR*1	054
85363.927E 030.	1.270E-0115.			.25 0.004			KR 2	055
8537	0.	0.	1.000E 000.1				RB 2	056
86341.852E-041.010E 003.800E-01					1.76		SE 2	057
86356.250E-041.010E 003.800E-01					3.23 .9		BR 2	058
8636			.06				KR 2	059
86377.222E-040.	0.				0.56		RB*1	060
86371.870E 012.800E-052.300E-05					.66 0.097		RB 2	061
8638	0.	0.	.006	1.			SR 2	062
87341.852E-042.700E 009.200E-01					3.73		SE 2	063
87356.366E-040.	0.				1.87 3.780		BR 2	064
87365.278E-020.	0.	600.			1.34 1.089		KR 2	065
8737	0.	0.	.12				RB 2	066

9341	0.	0.	1.1
94361,620E-056,000E-016,000E-01			
94373,472E-052,300E 001.500E 00			
94388,333E-042,900E 001.640E 00			
94391,389E-027,000E-017,400E-01			
9440	0.	0.	.08
94414,583E-030,	0.		
94417,300E 060,	0.		15.
9442	0.	0.	
95361,157E-053,200E 002.900E 00			
95372,314E-053,200E 002.900E 00			
95385,556E-04			
95397,292E-03			
95406,500E 010,	0.		
95413,750E 000,	0.		
95413,500E 010,	0.		7.
9542	0.	0.	14.
96391,597E-033,200E 002,585E 00			
9640	3,200E 002,585E 00,05		
96419,583E-015,700E-043,600E-03			
9642	0,	0,	1.
97361,157E-052,400E 002,210E 00			
97372,315E-052,400E 002,210E 00			
97383,472E-05			
97394,630E-05			
97407,083E-011,400E 001,230E 00			
97416,944E-040,	0.		
97415,000E-020,	0.		
9742	0.	0.	2.
98406,944E-04 ,2	1,000E-01		
98413,576E-02 ,064	1,000E-01		
98411,806E-02 3,	2,845E 00		
9842	2,516	2,845E 00,15	
99401,852E-053,050E 003,050E 00			
99411,736E-033,050E 003,050E 00			
99422,750E 00			
99432,500E-010,	0,		

,909

	2,70	
	4,57	
	1,46	
	2.23	1.
.001	.00050,042	
	.16	1,570
	4,57	
	3,58	
	2,72	
	2,09	
.02	.12	0,728
		0,235
	.043	0,760
	1,55	1,7
	.22	2,456
	4,20	
	4,39	
	3,57	
	2,31	
.9	.70	0,221
		0,75
	.47	.673
	1,99	
1.	1,31	2.
	1,26	1,2
	1,55	
	1,36	.26
.92	.41	0,124
		.1423

NB 2	104
KR 2	105
RB 2	106
SR 2	107
Y 2	108
ZR 2	109
NB*1	110
NB 2	111
MO 2	112
KR 2	113
RB 2	114
SR 2	115
Y 2	116
ZR 2	117
NB*1	118
NB 2	119
MO 2	120
Y 2	121
ZR 2	122
NB 2	123
MO 2	124
KR 2	125
RB 2	126
SR 2	127
Y 2	128
ZR 2	129
NB*1	130
NB 2	131
MO 2	132
ZR 2	133
NB*1	134
NB 2	135
MO 2	136
ZR 2	137
NB 2	138
MO 2	139
TC*1	140

99437.665E 070.	0.	22.	.084	TC 2	141
9944	0.			RU 2	142
100412.083E-036.300E 007.100E 00			3.39 1.05	NB 2	143
10042	0.	.2		MO 2	144
100431.968E-040.	0.		1.44 .114	TC 2	145
10044	0.			RU 2	146
101416.944E-042.500E 002.950E 00			1.03	NB 2	147
101421.014E-022.500E 002.950E 00			.42 1.649	MO 2	148
101439.722E-030.	0.		.47 0.362	TC 2	149
10144	0.			RU 2	150
102427.981E-034.200E 005.990E 00			.44 1.3	MO 2	151
102435.787E-050.	0.		1.79	TC 2	152
10244	0.	1.4		RU 2	153
103435.787E-041.550E 002.835E 00			1.03	TC 2	154
103444.000E+011.450E 002.835E 00			.995 .063 0.488	RU 2	155
103453.958E-020.	0.		0.040	RH*1	156
10345	0.	155.	.071	RH 2	157
104421.111E-031.800E 005.930E 00			1.08 1.	MO 2	158
104431.250E-020.	0.		.98 3.1	TC 2	159
10444	0.	.7		RU 2	160
104453.056E-030.	0.	800.	.0013.0002.131	RH*1	161
104454.861E-040.	0.	40.	.98 0.013	RH 2	162
10446	0.			PD 2	163
105424.630E-046.000E-012.600E 00			2.54	MO 2	164
105435.556E-033.000E-011.300E 00			2.09	TC 2	165
105441.846E-010.	0.	.2	.2690.42 .7680	RU 2	166
105453.472E-040.	0.		0.129	RH*1	167
105451.500E 000.	0.	2.100E+04.715 0.	.17 0.032	RH 2	168
10546	0.			PD 2	169
106443.650E 023.800E-014.570E 00.1			.01	RU 2	170
106459.167E-02			1. .35 2.627	RH*1	171
106453.472E-040.	0.		1.40 .222	RH 2	172
10646	0.			PD 2	173
107431.042E-031.600E-013.600E 00			2.71	TC 2	174
107442.917E-034.000E-020.			1.67 .144	RU 2	175
107451.507E-020.	0.		.42 0.328	RH 2	176
107462.555E 090.	0.		.014	PD 2	177

10747	0.	0.	35.	0.0100.			AG 2	178
108443.125E-038	.000E-022	.100E 00			.54	0.059	RU 2	179
108451.968E-040.	0.				1.74	0.553	RH 2	180
10846	0.	0.	12.2	.016			PD 2	181
108471.825E 030.	0.			.9		1.605	AG*1	182
108471.667E-030.	0.				.62	.017	AG 2	183
10848	0.	0.	10.				CD 2	184
109453.472E-042	.800E-021	.400E 00		1.	1.16	.31	RH 2	185
109463.333E-030.	0.					0.18	PD*1	186
109465.625E-010.	0.			1.	.36	.0002	PD 2	187
109474.630E-040.	0.					0.088	AG*1	188
10947	0.	0.	92.	.0326			AG 2	189
11046	2.000E-020.		.24	.167			PD 2	190
110472.600E 020.	0.	80.		0.98	.069	2.722	AG*1	191
110472.778E-040.	0.				1.17	0.033	AG 2	192
11048	2.000E-070.		3.1	.0322			CD 2	193
111462.292E-011	.000E-031	.000E-02		0.32	.048	.676	PD*1	194
111461.528E-021	.800E-022	.200E-01		1.	.85	.3	PD 2	195
111478.565E-04						.065	AG*1	196
111477.500E 00					.36	0.025	AG 2	197
111483.403E-020.	0.					0.397	CD*1	198
11148	0.	0.					CD 2	199
112468.750E-011	.100E-021	.200E-01			.08	0.018	PD 2	200
112471.333E-010.	0.				1.44	0.695	AG 2	201
11248	0.	0.	.03	1.			CD 2	202
113461.042E-031	.100E-021	.000E-02		1.	1.40		PD 2	203
113478.333E-040.	0.			.1	.08	0.200	AG*1	204
113472.208E-010.	0.				.79	0.030	AG 2	205
113485.110E 030.	0.			0.999	.18	.0003	CD*1	206
11348	0.	0.	2.000E 04				CD 2	207
11349			12.	.67			IN 2	208
114461.667E-031	.000E-021	.000E-02			.52		PD 2	209
114475.787E-050.	0.				2.02	0.5	AG 2	210
11448	0.	0.	1.24	0.1130.			CD 2	211
114495.000E 01						.192	IN*1	212
114498.333E-04					.779	.002	IN 2	213
115465.208E-04 .01	.0038			.28	1.91		PD 2	214

115472.315E-04			1.	1.49		AG*1	215
115471.458E-02	.0005	3.000E-04	.09	1.21	.2	AG 2	216
115484.300E 010.	0.		1.	.61	0.036	CD*1	217
115482.300E 000.	0.		1.	.32	0.192	CD 2	218
115491.833E-010.	0.		.055	.015	0.317	IN*1	219
11549 0.	0.	203.		.15		IN 2	220
11550 0.	0.					SN 2	221
116463.472E-041.	0.000E-020.			.93		PD 2	222
116471.736E-030.	0.			2.21	1.217	AG 2	223
11648 0.	0.	1.4				CD 2	224
116493.750E-020.	0.		1.	.29	2.495	IN*1	225
116491.620E-040.	0.			1.39		IN 2	226
11650 3.000E-030.	.006		1.			SN 2	227
117477.639E-041.	1.100E-021.	1.100E-02	.5	1.63		AG 2	228
117481.208E-010.	0.		1.	.35	1.6	CD*1	229
117483.472E-020.	0.		1.	.70	0.49	CD 2	230
117497.917E-020.	0.		0.8	.52	.132	IN*1	231
117493.125E-020.	0.			.24	.73	IN 2	232
117501.400E 010.	0.				0.32	SN*1	233
11750 0.	0.					SN 2	234
118483.472E-021.	0.000E-021.	0.000E-03		.27	.2	CD 2	235
118495.903E-050.	0.			1.85	0.244	IN 2	236
11850 0.	0.	.01	1.			SN 2	237
119481.875E-03 .01	4.000E-03		.99	1.56		CD*1	238
119486.597E-03			1.	1.44	.1	CD 2	239
119491.250E-02			.96	1.04	0.066	IN*1	240
119491.389E-03			.1	.61	.84	IN 2	241
119502.500E+02					.089	SN*1	242
11950 0.	0.					SN 2	243
120495.787E-040.	0.500E-020.	0.500E-03		.88	3.2	IN 2	244
12050 0.500E-020.	0.500E-03.	141	.007			SN 2	245
121482.431E-032.	0.500E-042.	0.500E-03		1.73	0.85	CD 2	246
121492.153E-032.	0.500E-042.	0.500E-03	1.	1.58		IN*1	247
121493.472E-04 .0005	.0053			1.20	.94	IN 2	248
121509.125E+030.	0.500E-030.	0.500E-02	1.	.15	.01	SN*1	249
121501.125E 001.	0.400E-023.	0.000E-02		.11		SN 2	250
12151 0.	0.	6.06	.01			SB 2	251

122498.681E-050,650E-020,500E-03		2.68 2.14	IN 2	252
12250 0,650E-020,500E-03.201	.005		SN 2	253
122512.847E-030, 0,		0,136	SB*1	254
122512.750E 000, 0,		.58 .405	SB 2	255
12252 0, 0, 3,	.333		TE 2	256
123491.157E-040,600E-030,500E-03		1.39 1.1	IN 2	257
123501.250E+020,600E-030,500E-03	1,	.52 0,022	SN*1	258
123502.778E-021,400E-020,		.46 0,160	SN 2	259
12351 0, 0, 3.345	.0135		SB 2	260
123521.040E+02		.248	TE*1	261
12352 0, 0, 400,			TE 2	262
12450 2.000E-020, .104	.962		SN 2	263
124511.458E-020, 0,	.982	.97 0,427	SB*1	264
124516.020E+010, 0, 2000.		.38 1.899	SB 2	265
12452 0, 0, 7,	.714		TE 2	266
125506.736E-031,100E-021,000E-03	1,	.79 0,361	SN*1	267
125509.400E 001,200E-027,100E-02		.92 0,094	SN 2	268
125519.855E 020, 0, 20,	.26	.096 .415	SB 2	269
125525.800E 010, 0,		0,145	TE*1	270
12552 0, 0, 1.5			TE 2	271
126503.650E+071,000E-012,000E-01	1,	.12 .09	SN 2	272
126511.319E-020, 0,	.01	.00780,117	SB*1	273
126511.250E 010, 0,		.74 1,780	SB 2	274
12652 0, 0, 1,	.1		TE 2	275
127508.750E-022,400E-013,900E-01		1,34 1,	SN 2	276
127513.900E 001,000E-021,000E-02	.2	.38 0,505	SB 2	277
127521.050E 020, 0,	.015	.00410,088	TE*1	278
127523.875E-010, 0,		.23 0,004	TE 2	279
12753 0, 0, 6.4			I 2	280
128504.306E-023,700E-014,000E-01	.03	3.85 3,27	SN 2	281
128514,000E-015,000E-020,	1,	.35 3.6	SB*1	282
128516.944E-038,000E-021,000E-01		1,20 1.7	SB 2	283
12852 0, 0, .157	.108		TE 2	284
128531.736E-023,000E-052,000E-04		.77 0,093	I 2	285
12854 0, 0, 5,			XE 2	286
129511.792E-011,000E 001,000E 00	.36	.542 .916	SB 2	287
129523.300E 010, 0,		0,106	TE*1	288

129524.653E-020,	0.			.45	.238	TE 2	289
129535.840E 090,	0.	28.		.050	.040	I 2	290
12954 0,	0.	25.				XE 2	291
130501.806E-032.000E 002.000E 00				4.23		SN 2	292
130512.292E-020,	0.			1.72	1.0	SB 2	293
13052 0,	0.	.23	.13			TE 2	294
130535.208E-01 .0005 .0052 18.				.27	2.123	I 2	295
13054 0,	0.	5.				XE 2	296
131511.597E-022.700E 003.100E 00				.15	1.33	SB 2	297
131521.200E 004.000E-021.300E-01				.783	.16 1.468	TE*1	298
131521.736E-021.600E-015.400E-01					.74 0.376	TE 2	299
131538.050E 00 .2 0.		.7		.007	.18 0.399	I 2	300
131541.200E 010,	1.000E-02				0.164	XE*1	301
13154 0,	0.	85.				XE 2	302
132511.458E-033.400E 005.100E 00				2.68		SB 2	303
132523.250E 001.000E 00 .18				.055	0.280	TE 2	304
132539.583E-020,	0.			.49	2.249	I 2	305
13254 5.2			.962			XE 2	306
133512.847E-033.800E 003.000E 00				.72	1.72	SB 2	307
133523.472E-021.100E 001.000E 00				.87	.49 1.613	TE*1	308
133521.389E-031.100E 001.000E 00					.97 0.6	TE 2	309
133538.750E-015.000E-012.000E-01				.02	.46 .53	I 2	310
133542.300E 000,	0.				0.233	XE*1	311
133545.270E 000,	1.700E 00190.			.10	.082	XE 2	312
13355 0,	0.	30.6	.085			CS 2	313
134515.556E-043.000E 003.500E 00				3.45	0.200	SB 2	314
134522.917E-023.700E 004.000E 00				.52	.1	TE 2	315
134533.681E-029.000E-010,				.78	2.5	I 2	316
13454 0,	0.	5.2	.962			XE 2	317
134551.208E-010,	0.		.01	.00170.153		CS*1	318
134557.665E 020,	0.	136.		.16	1.588	CS 2	319
13456 4.16			.033			BA 2	320
135512.778E-04 4.3 1.1				3.16		SB 2	321
135526.944E-04				2.68		TE 2	322
135532.792E-01 1.9 5.700E 00			.27	.32	1.642	I 2	323
135541.111E-020,	0.				0.530	XE*1	324
135543.833E-013.000E-01 .47 2.900E+06				.31	0.261	XE 2	325

135557,300E+080,		8.7
135561,208E 000,	0,	
13556	0,	5.
136539,606E-043,100E 002,100E 00		
13654	3,36	4,520E 00,15
136551,300E 016,800E-031,100E-01		
13656	0,	1,01
137532,778E-044,900E 005,100E 00		
137542,708E-031,300E 001,530E 00		
137551,095E+040,	0,	.11
137561,806E-030,	0,	
13756	0,	4.
138537,292E-053,400E 003,700E 00		
138549,722E-032,100E 002,210E 00		
138552,236E-023,000E-014,000E-01		
13856	0,	.4
139532,314E-051,800E 001,700E 00		
139544,745E-042,900E 002,800E 00		
139556,597E-031,200E 001,230E 00		
139565,764E-021,000E-011,400E-014,		
13957	0,	8,9
140541,852E-043,700E 003,300E 00		
140557,639E-042,300E 002,100E 00		
140561,280E 013,000E-010,		20.
140571,675E 000,	2,000E-01	
14058	0,	.6
141541,968E-051,800E 001,100E 00		
141552,778E-042,900E 003,700E 00		
141561,250E-021,200E 009,000E-01		
141571,625E-011,000E-010,		
141583,250E 010,	0,	30.
14159	0,	12.
142541,736E-053,500E-013,100E-01		
142552,662E-053,050E 002,870E 00		
142567,639E-032,200E 001,830E 00		
142575,833E-023,000E-010,		
14258	0,	1.

.01

.92

.055	
0,268	
1,68	3,237
.11	2,466
2,19	.71
1,48	1.
.20	
0,662	
3,10	1,5
.96	0,420
1,10	2,153
2,40	
2,00	.4
1,74	0,232
.91	.053
1,09	
2,66	.59
.30	.222
.48	2,468
2,36	
1,72	
1,14	.46
.96	.0272
.15	0,101
1,70	
2,98	
.78	.112
1,42	1,164

CS 2	326
BA*1	327
BA 2	328
I 2	329
XE 2	330
CS 2	331
BA 2	332
I 2	333
XE 2	334
CS 2	335
BA*1	336
BA 2	337
I 2	338
XE 2	339
CS 2	340
BA 2	341
I 2	342
XE 2	343
CS 2	344
BA 2	345
LA 2	346
XE 2	347
CS 2	348
BA 2	349
LA 2	350
CE 2	351
XE 2	352
CS 2	353
BA 2	354
LA 2	355
CE 2	356
PR 2	357
XE 2	358
CS 2	359
BA 2	360
LA 2	361
CE 2	362

142598.000E-010.	0.	20.	.83	.063	PR	2	363
14260	0.	17.			ND	2	364
143541.157E-053.100E 002.650E 00			2.91		XE	2	365
143552.314E-053.100E 002.650E 00			2.32		CS	2	366
143561.389E-04			1.47		BA	2	367
143579.722E-03			1.33	1.	LA	2	368
143581.375E 000.	0.	6.	.37	.377	CE	2	369
143591.370E 010.	0.	89.	.32		PR	2	370
14360	0.	330.			ND	2	371
144541.157E-052.900E 001.600E 00			2.19		XE	2	372
144552.315E-052.900E 001.600E 00			3.50		CS	2	373
144563.472E-05			1.00		BA	2	374
144574.630E-05			2.23		LA	2	375
144582.850E 023.000E-015.900E-011.			.080	0.030	CE	2	376
144591.201E-020.	1.400E-01		1.22	.031	PR	2	377
14460	0.	5.			ND	2	378
145582.083E-034.200E 003.130E 00			.77		CE	2	379
145592.458E-010.	0.		.68	.056	PR	2	380
14560	0.	50.			ND	2	381
146589.722E-033.200E 002.600E 00			.22	0.320	CE	2	382
146591.667E-021.000E-010.			1.27	1.107	PR	2	383
14660	0.	2.			ND	2	384
147588.333E-040.650E 000.550E 00			1.55		CE	2	385
147598.333E-030.650E 000.550E 00			1.12	1.	PR	2	386
147601.110E+011.300E 001.100E 00			.23	0.196	ND	2	387
147619.855E 020.	0.	230.	.059		PM	2	388
14762	0.	90.		.522	SM	2	389
148584.861E-041.710E 001.730E 00			.95		CE	2	390
148591.354E-030.	0.		2.17	0.300	PR	2	391
14860	0.				ND	2	392
148615.400E 000.	0.	4.	.39	1.343	PM#1	1	393
148614.100E 010.	0.	2000.	.41	1.227	PM	2	394
14862	0.	3.000E+04			SM	2	395
149607.500E-021.300E 001.320E 00			.55	.5	ND	2	396
149612.208E 000.	0.		.36	.035	PM	2	397
14962	0.	4.150E 04			SM	2	398
15060	7.400E-011.010E 001.5				ND	2	399

162643.650E+02	1.800E-03		.34	1.	GD 2	437
162658.333E-02			1.68		TB 2	438
16266	140.				DY 2	439
163652.917E-01	4.000E-04		1.22	.2	TB 2	440
16366	4.000E-04				DY 2	441
16466	3.000E-04				DY 2	442
165668.727E-040.	1.200E-04	.714	.00840	.120	DY*1	443
165669.583E-020.	0.		.44	.0269	DY 2	444
16567	0.				HO 2	445
166663.333E 000.	6.800E-05		.12	0.088	DY 2	446
166671.133E 000.	0.		.67	.0558	HO 2	447
16668	0.				ER 2	448
167682.892E-050.	0.	.01		0.208	ER*1	449
16768	0.				ER 2	450

PHOTON LIBRARY

499

7230ZN2	1	.95	1.3											.12	001
7231GA2	6	.41	3.343	.35	3.05	.07	2.515	.07	2.06	.05	1.465	.05	.835	.43	002
7232GE2	0	.	.												003
7330ZN2	0	.	.											2.25	004
7331GA2	2	.07	1.04	.91	.295									.42	005
7332GE2	0	.	.												006
7431GA2	6	.11	4.53	.04	3.76	.03	3.55	.10	3.33	.69	2.93	.03	1.47	1.01	007
7432GE2	0														008
7531GA2	11.00	.5												1.43	009
7532GE1	11.00	.139													010
7532GE2	4	.41	.628	.29	.477	.114	.265	.014	.199					.42	011
7533AS2	0														012
7631GA2	0													2.74	013
7632GE2	0														014
7633AS2	5	.0192	.670	.09	2.42	.066	1.86	.036	1.216	.306	.559			1.09	015
7634SE2	0														016
7732GE1	2	.08	.215	.14	.159									.77	017
7732GE2	6	.03	2.37	.15	1.99	.14	1.55	.24	1.19	.29	.632	.14	.475	.64	018
7733AS2	2	.028	.52	.028	.246									.22	019
7734SE1	11.00	.161													020
7734SE2	0														021
7832GE2	11.00	.3												.32	022
7833AS2	6	.0222	.85	.0212	.78	.14	2.67	.0622	.41	.0971	1.307	.19	.6151	.47	023
7834SE2	0														024
7933AS2	11.00	.096												.90	025
7934SE1	11.00	.096													026
7934SE2	0													.04	027
7935BR2	0														028
8033AS2	11.00	.50												2.73	029

113

BNWL-236

[illegible]

[illegible]

[illegible]

[illegible]

12952TE2	4	.10	1.15	.04	.713	.15	.502	.71	.027		.45	289		
12953I	2	11.00	.040									290		
12954XE2	21.00	.196	1.00	.040								291		
13050SN2	0										.78	292		
13051SB2	11.0	1.0									1.72	293		
13052TE2	0											294		
13053I	2	5	.30	1.15	.70	.74	1.0	.66	1.0	.53	.24	.41	.27	295
13054XE2	0													296
13151SB2	0												1.33	297
13152TE1	3	.52	.204	.17	1.76	.046	1.50						.16	298
13152TE2	5	.08	1.12	.04	.95	.06	.60	.23	.45	.94	.147		.74	299
13153I	2	3	.028	.724	.093	.638	.876	.365					.18	300
13154XE1	11.00	.164												301
13154XE2	0													302
13251SB2	0												2.68	303
13252TE2	21.00	.23	1.00	.053									.055	304
13253I	2	5	.15	2.84	.20	2.69	.23	2.40	.24	1.96	.18	1.45	.49	305
13254XE2	0													306
13351SB2	0												1.72	307
13352TE1	2	.70	2.0	.17	1.0								.49	308
13352TE2	11.0	.6											.97	309
13353I	2	3	.01	1.4	.05	.85	.94	.53					.46	310
13354XE1	11.00	.233												311
13354XE2	3.000	.2	.382	.01	.160	.99	.081						.10	312
13355CS2	0													313
13451SB2	11.0	.2											3.45	314
13452TE2	0												.52	315
13453I	2	12.4	1.1										.78	316
13454XE2	0													317
13455CS1	11.0	.153											.0017	318
13455CS2	3	.94	.80	.97	.60	.13	.57						.16	319
13456BA2	0													320
13551SB2	0												3.16	321
13552TE2	0												2.68	322
13553I	2	3	.11	1.80	.34	1.28	.37	1.14					.32	323
13554XE1	11.0	.53												324
13554XE2	3	.03	.61	.001	.36	.97	.25						.31	325

[illegible]

[illegible]

[illegible]

[illegible]

MASS ABSORPTION COEFFICIENTS

H2O	11	0.1500	0.1275	0.1130	0.1015	0.0832	0.0775	0.0705	0.0635	4	6	1
	12	0.0580	0.0537	0.0505	0.0480	0.0457	0.0436	0.0418	0.0395			2
TISSUE	21	0.1455	0.1225	0.1080	0.0995	0.0835	0.0750	0.0685	0.0615	4	6	3
	22	0.0555	0.0520	0.0493	0.0465	0.0443	0.0425	0.0418	0.0395			4
AIR	31	0.1334	0.1140	0.1015	0.0915	0.0865	0.0695	0.0635	0.0573	7	14	5
	32	0.0515	0.0478	0.0450	0.0425	0.0407	0.0387	0.0370	0.0339			6
H	41	0.2650	0.2440	0.1975	0.1750	0.1570	0.1385	0.1260	0.1125	1	1	7
	42	0.1025	0.0950	0.0892	0.0835	0.0800	0.0765	0.0730	0.0688			8
LI	51	0.115	0.0990	0.0880	0.0775	0.0685	0.0605	0.0550	0.0505	3	7	9
	52	0.0447	0.0420	0.0390	0.0375	0.0360	0.0350	0.0335	0.0304			10
C	61	0.135	0.115	0.1015	0.0915	0.0865	0.0695	0.0635	0.0573	6	12	11
	62	0.0515	0.0478	0.0450	0.0425	0.0407	0.0387	0.0370	0.0339			12
AL	71	0.1780	0.1280	0.0990	0.0868	0.0755	0.0676	0.0615	0.0553	13	27	13
	72	0.0498	0.0467	0.0438	0.0414	0.0390	0.0375	0.0365	0.0357			14
TI	81	0.163	0.120	0.0970	0.0840	0.0730	0.0640	0.0585	0.0530	22	48	15
	82	0.0478	0.0455	0.0435	0.0410	0.0400	0.0390	0.0375	0.0350			16
FE	91	0.2040	0.1370	0.0998	0.0875	0.0720	0.0637	0.0588	0.0513	26	56	17
	92	0.0470	0.0446	0.0415	0.0402	0.0381	0.0378	0.0366	0.0355			18
NI	101	0.221	0.140	0.110	0.0880	0.0780	0.0680	0.0614	0.0610	28	59	19
	102	0.0500	0.0485	0.0445	0.0430	0.0420	0.0410	0.0380	0.0372			20
ZR	111	0.378	0.195	0.120	0.0905	0.0750	0.0640	0.0579	0.0540	40	91	21
	112	0.0468	0.0440	0.0425	0.0405	0.0400	0.0395	0.0380	0.0363			22
SN	121	0.640	0.220	0.130	0.0935	0.0720	0.0620	0.0550	0.0490	50	119	23
	122	0.0445	0.0415	0.0405	0.0390	0.0380	0.0365	0.0365	0.0360			24
W	131	1.52	0.600	0.275	0.145	0.095	0.0775	0.0655	0.0600	74	184	25
	132	0.0498	0.0480	0.0450	0.0440	0.0435	0.0430	0.0420	0.0408			26
PB	141	1.92	0.5950	0.3065	0.1775	0.1280	0.0875	0.0726	0.0618	82	207	27
	142	0.0534	0.0488	0.0463	0.0443	0.0428	0.0419	0.0413	0.0411			28
U	151	2.49	0.7680	0.3880	0.2275	0.1370	0.0995	0.0815	0.0670	92	238	29
	152	0.0560	0.0515	0.0483	0.0462	0.0450	0.0441	0.0436	0.0432			30

ORDINAR161	0.1780	0.1280	0.0990	0.0890	0.0860	0.0750	0.0637	0.0610	12	31
CONCRET162	0.0550	0.0520	0.0460	0.0440	0.0430	0.0410	0.0395	0.0366	17	32
MAGNETI171	0.1800	0.1220	0.0945	0.0870	0.0830	0.0750	0.0618	0.0600	21	33
CONCRET172	0.0550	0.0520	0.0470	0.0430	0.0420	0.0410	0.0395	0.0364	1	34
FEROPHO181	0.1820	0.1220	0.0935	0.0860	0.0830	0.0670	0.0609	0.0590	1	35
CONCRET182	0.0540	0.0500	0.0450	0.0420	0.0410	0.0400	0.0390	0.0363	1	36

BUILD UP FACTOR COEFFICIENTS

DOSE	11	24.	24.	24.	19.	14.9	11.0	8.9	4
BUILD-UP	12	7.8	7.8	7.4	7.0	6.7	6.5	6.2	
FACTOR	13	-0.14	-0.14	-0.14	-0.122	-0.114	-0.104	-0.095	
DATA,	14	-0.088	-0.082	-0.078	-0.074	-0.068	-0.065	-0.062	
WATER	15	0.0	0.0	0.0	0.0	0.0	0.03	0.06	
	16	0.074	0.083	0.088	0.094	0.102	0.104	0.108	13
DOSE	21	9.0	9.0	9.0	9.0	8.2	8.0	7.3	
BUILD-UP	22	6.4	5.95	5.65	5.3	4.95	4.75	4.5	
FACTOR	23	-0.15	-0.15	-0.15	-0.15	-0.12	-0.11	-0.10	
DATA,	24	-0.091	-0.087	-0.084	-0.081	-0.079	-0.076	-0.074	
ALUMINUM	25	0.00	0.00	0.00	0.00	0.025	0.044	0.055	
	26	0.075	0.084	0.09	0.096	0.101	0.11	0.115	26
DOSE	31	11.2	10.8	10.7	10.2	9.1	8.6	8.0	
BUILD-UP	32	7.5	7.1	6.7	6.5	5.8	5.5	5.0	
FACTOR	33	-0.099	-0.097	-0.097	-0.095	-0.092	-0.088	-0.081	
DATA,	34	-0.080	-0.077	-0.075	-0.073	-0.072	-0.072	-0.072	
IRON	35	0.0	0.001	0.004	0.009	0.016	0.028	0.034	
	36	0.039	0.044	0.048	0.05	0.054	0.059	0.062	50
DOSE	41	4.8	4.7	4.7	4.65	4.55	4.5	4.4	
BUILD-UP	42	4.3	4.1	4.05	3.95	3.65	3.5	3.3	
FACTOR	43	-0.088	-0.086	-0.085	-0.084	-0.082	-0.08	-0.079	
DATA,	44	-0.078	-0.078	-0.079	-0.08	-0.082	-0.086	-0.09	
TIN	45	0.1	0.105	0.11	0.114	0.125	0.13	0.134	
	46	0.139	0.141	0.142	0.141	0.137	0.135	0.13	74
DOSE	51	3.6	3.6	3.5	3.5	3.4	3.3	3.18	
BUILD-UP	52	3.05	2.95	2.93	2.88	2.8	2.78	2.70	
FACTOR	53	-0.00	-0.008	-0.01	-0.02	-0.028	-0.042	-0.05	
DATA,	54	-0.058	-0.063	-0.068	-0.07	-0.074	-0.08	-0.086	
TUNGSTEN	55	0.06	0.07	0.08	0.10	0.12	0.13	0.146	
	56	0.18	0.184	0.187	0.187	0.184	0.166	0.135	

DOSE	61	1.0	1.2	1.3	1.5	1.7	2.5	2.9	2.6	82
BUILD-UP	62	2.65	2.65	2.6	2.55	2.5	2.35	2.3	2.1	
FACTOR	63	-0.01	-0.015	-0.02	-0.03	-0.03	-0.04	-0.04	-0.05	
DATA,	64	-0.055	-0.06	-0.07	-0.075	-0.08	-0.08	-0.085	-0.095	
LEAD	65	0.37	0.37	0.35	0.29	0.25	0.20	0.17	0.15	
	66	0.13	0.12	0.11	0.10	0.09	0.08	0.075	0.07	1

APPENDIX E

SAMPLE PROBLEMS

APPENDIX E
SAMPLE PROBLEMS

ACTIVITY OF Co^{60} BNL STANDARD STRIP*

In support of the Co^{60} production at the Hanford Atomic Products Operation it was necessary to design a device for routine determination of the specific activity of irradiated BNL standard strip.⁽¹⁷⁾ The device (Figure E-1) consists of a calibrated ion chamber mounted about 11 inches from a Co^{60} strip holder. The assembly is immersed in a water-filled storage basin. ISOSHL D was used to calculate the expected dose rates at the ion chamber so that a chamber of the correct dose rate operating range could be obtained. ISOSHL D calculated (input listing following Figure E-1) dose rates and the subsequent measured dose rates (using the accurately calibrated ion chamber and Co^{60} strips of known activity) are summarized in Table E-I.

TABLE E-I. Comparison of Calculated and Measured Dose Rates.

Co^{60} Specific Activity Ci/g	Calculated dose rates R/hr	Measured dose rates R/hr
10	3,141	2,984
12	3,770	3,582
14	4,398	4,178
16	5,026	4,774

*Courtesy of: M. H. Montgomery
Douglas-United Nuclear
Richland, Washington

FIGURE E-1. BNL Standard Co^{60} Source

SAMPLE PROBLEM - ACTIVITY OF CO60 BNL STANDARD STRIP

COBALT - 60 SOURCE DOSE VS ACTIVITY 10 CI/GM
 \$INPUT IGEOM=2,NSHLD=5,JBUF=5,NEXT=1,T(1)=.7163,T(2)=31.30,T(3)=3.3274,
 T(4)=.39116,T(5)=.31496,WEIGHT(472)=651.7,ANG1=90.0,ANG2=64.0,
 SLTH=30.48,X=34.9,SSV1=0.0 \$
 97.94 1.0 7.94
 1 2.70 2.70 1
 COBALT - 60 SOURCE DOSE VS ACTIVITY 12 CI/GM
 \$INPUT NEXT=2,WEIGHT(472)=782.04 \$
 COBALT - 60 SOURCE DOSE VS ACTIVITY 14 CI/GM
 \$INPUT NEXT=2,WEIGHT(472)=912.38 \$
 COBALT - 60 SOURCE DOSE VS ACTIVITY 16 CI/GM
 \$INPUT NEXT=2,WEIGHT(472)=1042.72 \$
 COBALT - 60 SOURCE DOSE VS ACTIVITY 16 CI/GM NEXT=6
 \$INPUT NEXT=6,WEIGHT(472)=1042.72 \$

DOSE RATES FROM AQUEOUS-FILLED CYLINDERS*

A family of curves showing dose rate versus distance from various sized cylinders, containing aqueous solutions of radioactive isotopes, was desired by the Personnel Protection Section of the Hanford Chemical Processing facilities.

Since there are several variables involved in each calculation of a given dose rate (hand calculations are extremely tedious), the speed and accuracy gained by the use of a computer was thought to be ideal for such a problem. ISOSHLDD (input on next page) was used to compute dose rates from a cylinder of specified dimensions containing Cs^{137} . (This work has since been extended to many cylinder sizes and isotopes.)

The dose rates obtained were plotted against the distance from the cylinder giving a smooth continuous curve (Figure E-2). Dose rates, which were determined by hand with the formulas and data of Rockwell,⁽¹⁾ are plotted on this same graph. It can be seen from Figure E-2 that the points are similar except when the dose rate is determined at a short distance from the cylinder.

*Courtesy of D. T. Vladimiroff and J. Dirlam
ISOCHEM Inc.
Richland, Washington

AMPLE PROBLEM - DOSE RATES FROM AQUEOUS FILLED CYLINDERS

CYLINDER ATTENUATION CALCULATION AT EDGE CS137
 \$INPUT NEXT=1,T=10.,.635,4*0.,WEIGHT(335)=2.0,NSHLD=2,SLTH=200.,
 X=10.635,Y=100.,JBUF=2,IGEOM=7,NTHETA=6,NPSI=6,DELR=3.\$
 WATER 1 1.1
 IRON 9 7.86
 CYLINDER ATTENUATION CALCULATION 30 CM FROM EDGE
 \$INPUT NEXT=4, X=40.635\$
 CYLINDER ATTENUATION CALCULATION 50 CM FROM EDGE
 \$INPUT X=60.635 \$
 CYLINDER ATTENUATION CALCULATION 70 CM FROM EDGE
 \$INPUT X=80.635 \$
 CYLINDER ATTENUATION CALCULATION 90 CM FROM EDGE
 \$INPUT X=100.635 \$
 CYLINDER ATTENUATION CALCULATION 110 CM FROM EDGE
 \$INPUT X=120.635 \$
 CYLINDER ATTENUATION CALCULATION 130 CM FROM EDGE
 \$INPUT X=140.635 \$
 CYLINDER ATTENUATION CALCULATION 150 CM FROM EDGE
 \$INPUT X=160.635 \$
 CYLINDER ATTENUATION CALCULATION 170 CM FROM EDGE
 \$INPUT X=180.635 \$
 CYLINDER ATTENUATION CALCULATION 190 CM FROM EDGE
 \$INPUT X=200.635 \$
 CYLINDER ATTENUATION CALCULATION 210 CM FROM EDGE
 \$INPUT X=220.635 \$
 CYLINDER ATTENUATION CALCULATION 250 CM FROM EDGE
 \$INPUT X=260.635 \$
 CYLINDER ATTENUATION CALCULATION 300 CM FROM EDGE
 \$INPUT X=310.635 \$
 END OF RUN
 \$INPUT NEXT=6 \$

FIGURE E-2. Dose Rate Versus Distance

REFERENCES

1. Reactor Shielding Design Manual, edited by T. Rockwell, III, D. Van Nostrand Company, Inc., New York, 1956.
2. Nuclear Engineering Handbook, 1st ed., edited by H. Etherington, McGraw-Hill Book Company, New York, 1958.
3. "Shielding," Reactor Handbook, Vol. III, Part B, edited by E. P. Blizard, Interscience Publishers, New York, 1962.
4. R. O. Gumprecht. Unpublished Data, Douglas-United Nuclear, Richland, Washington
5. H. Goldstein. Fundamental Aspects of Reactor Shielding, Addison-Wesley Publishing Co., Inc., Reading, Mass., 1959.
6. R. C. Murty. "Effective Atomic Numbers of Heterogeneous Materials," Nature, Vol. 207, July 24, 1965.
7. M. Grotenhuis. Lecture Notes on Reactor Shielding, ANL-600, Argonne National Laboratory, Lemont, Ill., March 1959.
8. D. S. Duncan and A. B. Speir. GRACE 1, An IBM 704-709 Program Designed for Computing Gamma Ray Attenuation and Heating in Reactor Shields, NAA-SR-3719, North American Aviation, Inc., Downey, California, June 1959.
9. "Energy Levels of Nuclei: $A = 5$ to $A = 257$," Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series, Vol. 1, edited by K. H. Hellwege, Springer-Verlag, Berlin, Germany, 1961.
10. Nuclear Data Sheets, published by The National Academy of Sciences - National Research Council, 2101 Constitution Ave., Washington, D.C. 20418
11. John F. Stehn. "Table of Radioactive Nuclides," Nucleonics, Vol. 18, no. 11, p. 186, November 1960.
12. B. S. Dzhelepov and L. K. Peker. Decay Schemes of Radioactive Nuclei, translated by D. L. Allen, Pergamon Press, New York, 1961.
13. R. L. Walker and M. Grotenhuis. A Summary of Shielding Constants for Concrete, ANL-6443, Argonne National Laboratory, Lemont, Ill. November 1961.

14. Yu. A. Zysin, A. A. Lbov, and L. I. Sel'chenkov. Fission Product Yields and Their Mass Distributions, Consultants Bureau, New York, 1964.
15. S. Katcoff. "Fission-Product Yields from Neutron-Induced Fission." Nucleonics, vol. 18, no. 11; p. 201, 1960.
16. D. T. Goldman. "Chart of Nuclides," Seventh Edition, revised to June 1964. Knolls Atomic Power Laboratory, Schenectady, New York.
17. A. Oltmann and O. A. Kuhl, Fabrication of BNL Standard Cobalt-60 Source, BNL-848, Brookhaven National Laboratory, Upton, New York, February 1964.

DISTRIBUTIONNumber of Copies

1	<u>Air Force Weapons Laboratory</u> Kirtland Air Force Base Albuquerque, New Mexico Lt. Nelson S. Demuth
2	<u>Argonne National Laboratory</u> Lamont, Illinois M. Grothenhuis D. H. Shaftman
4	<u>Atomic International</u> R. L. Ashley J. Belcher J. Susnir W. A. Rhoades
1	<u>Bechtel Corporation</u> San Francisco, Calif. R. P. Schmitz
2	<u>Brookhaven National Laboratory</u> Upton, New York B. Manowitz L. Galanter
8	<u>Computer Sciences Corporation, Richland</u> E. Z. Block R. L. Causey R. L. Engel (5) G. L. Otterbein
1	<u>Canadian General Electric Company, Limited</u> Peterborough, Ontario, Canada A. C. Wittier
385	<u>Division of Technical Information Extension</u>
1	<u>Donald W. Douglas Laboratory</u> Richland, Washington R. S. Cooper
8	<u>Douglas United Nuclear</u> G. F. Bailey C. E. Bowers P. D. Gross R. O. Gumprecht M. H. Montgomery F. E. Owen M. L. Smith J. R. Spink

- 1 General Electric Company, Cincinnati
 J. Moteff
- 28 General Electric Co., Richland
 R. A. Chitwood
 D. L. Condotta
 H. S. Davis
 R. L. Dickeman
 W. J. Ferguson
 E. A. Grimm
 L. L. Gumme
 R. E. Hall
 M. M. Hendrickson (10)
 E. E. Lietz
 M. C. Leverett
 D. S. Lewis
 C. A. Mansius
 J. S. McMahan
 N. R. Miller
 W. S. Nechodom
 J. W. Nickolaus
 E. G. Pierick
 D. D. Stephewski
 R. E. Trumble
- 1 General Electric Co. (APED)
 San Jose, California
 F. C. Skopec
- 6 ISOCHEM, Inc.
 G. E. Backman
 J. S. Cochran
 R. W. Harvey
 E. T. O'Sullivan
 H. A. Moulthrop
 D. T. Vladimiroff
- 1 A. Kania
 Boite Pastale No. 1
 Saint-Paul-Lez-Durance, France
- 1 Knolls Atomic Power Laboratory
 Schenectady, New York
 R. J. Feinberg
- 1 Martin Company
 Baltimore, Maryland
 E. B. Rosenthal
- 3 NASA Lewis Research Center
 J. F. Mondt
 L. Soffer
 C. Witmarsh

- 1 National Aeronautics and Space Administration
Office of Advanced Research and Technology
R. F. Trapp
- 2 Naval Radiological Defense Laboratory
W. E. Kreger
J. G. Dardis
- 1 North American Aviation, Inc.
Space and Information Systems Division
Downey, California
F. A. Aschenbrenner
- 1 Oak Ridge National Laboratory
P. C. Maienschein
- 2 Oak Ridge National Laboratory
Radiation Shielding Information Center
B. F. Maskewitz
S. K. Penney
- 10 Richland Operations Office
M. H. Arndt
A. Brunstad (2)
J. T. Christy
P. G. Holsted
L. R. Lucuas
R. L. Plum
R. K. Sharp
Technical Information Library
C. N. Zangar
- 1 U. K. Atomic Energy Research Establishment
Harwell, Didcot, Berks, England
J. Butler
- 1 University of Illinois
Urbana, Illinois
A. B. Chilton
- 1 University of Washington
A. L. Babb
- 1 U. S. Atomic Energy Commission
Division of Reactor Development
P. G. Hemmig, Physics Branch
- 2 Vitro Engineering Company
New York, N. Y.
J. H. Frankfort
S. Hillman

- 4 Vitro Engineering Co., Richland
 J. M. Frome
 G. Kligfield
 L. D. Lash
 M. Z. Marshall
- 1 Westinghouse Electric Corporation, Bettis
 Atomic Power Laboratory, West Mufflin,
 Pennsylvania
 K. Shure
- 67 Battelle-Northwest
 D. T. Aase
 F. W. Albaugh
 E. R. Astley
 J. M. Batch
 C. L. Bennett
 R. A. Bennett
 W. L. Bunch
 S. H. Bush
 J. L. Carter, Jr.
 P. D. Cohn
 G. M. Dahlen
 R. E. Dahl
 F. G. Dawson
 E. A. Eschbach
 G. W. R. Endres
 L. G. Faust
 J. F. Fletcher
 J. C. Fox
 J. Greenborg (10)
 S. Goldsmith
 H. Harty
 R. E. Heineman
 R. J. Hennig
 P. L. Hofmann
 E. R. Irish
 R. L. Junkins
 A. R. Keene
 E. L. Kelley, Jr.
 L. W. Lang
 D. D. Lanning
 C. E. Leach
 C. W. Lindenmeir
 W. W. Little
 L. L. Maas
 D. McConnon
 W. I. Neef
 R. E. Nightingale
 R. E. Peterson
 J. J. Regimbal
 C. A. Rohrmann
 D. N. Samsky

Battelle-Northwest (contd)

R. E. Schenter
D. P. Schively
L. C. Schmid
L. C. Schwendiman
J. R. Sheff
R. I. Smith
W. G. Spear
W. H. Swift
J. A. Ulseth
H. H. VanTuy1
P. C. Walkup
N. G. Wittenbrock
H. H. Yoskikawa
H. S. Zwibel
Technical Files (5)
Technical Publications (2)