1 of 3

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RADMODL MODELING MANUAL (U)

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EXECUTIVE SUMMARY

RADMODL is a set of computer codes that model the transport of material through a network of interconnected compartments. This version of RADMODL is designed to model the transport of radioactive material from either a loss of coolant accident (LOCA) or a fuel handling accident (FHA) into a set of interconnected compartments and determine the equivalent dose each compartment will see for the duration of the accident. The code is flexible enough to allow modeling of other types of materials and their dilution/dispersion during transport by designing a new set of input files corresponding to the facility layout and the dilution/dispersion factors.

This report documents the issuance of the Modeling Manual, originally developed by EGS Corporation and ISSI as volume 1 of the Programmer's Manual, with the incorporation of minor editorial comments. Though a Modeling Manual in itself is not required for the RADMODL code certification, this manual does contain information that is required for the User's Manual and hence fulfills one of the requirements for code certification.

INTRODUCTION

This report documents the issuance of the RADMODL Programmer's Manual, volume 1, for Version 1.0. The original version of the Programmer's Manual was developed by the EGS Corporation and ISSI as part of the software development task. The Programmer's Manual is a supplement to the already issued User's Manual (ref. 3). This manual provides more detail on how to modify the input files to the RADMODL code and hence will be renamed and issued as the Modeling Manual. Volume 2 of the Programmer's Manual contains mainly the source code for RADMODL and will be issued as the Maintenance Manual at a future date. This report presents the Modeling Manual with editorial corrections incorporated into the original manual.

DISCUSSION

RADMODL is a set of computer codes that model the transport of material through a network of interconnected compartments. This version of RADMODL is designed to model the transport of radioactive material from either a loss of coolant accident (LOCA) or a fuel handling accident (FHA) into a set of interconnected compartments and determine the equivalent dose each compartment will see for the duration of the accident. The code is flexible enough to allow modeling of other types of materials and their dilution/dispersion during transport by designing a new set of input files corresponding to the facility layout and the dilution/dispersion factors.

There are six specific modules within the code, all tied seamlessly into an integrated menu driven system. Five of the modules perform most of the transport modeling and dose calculations. The sixth module is a graphics display program that displays the total gamma dose in a mimic of the interconnected compartments. For a more detailed description of the modules, refer to the Appendix, pages 1 and 2.

RADMODL was co-developed by the EGS Corporation and Infinite Software Solutions, Inc. (ISSI) for the Westinghouse Savannah River Company in support of the K Reactor Environmental Qualification Program. As part of this program, RADMODL must be certified for critical applications.

This Modeling Manual is provided as a guide for RADMODL Version 1.0. It is supplementary to the User's Manual in that it gives more detailed guidance in modifying the input files for the RADMODL code.

CONCLUSIONS

Modification of the input files for the RADMODL Code is documented in this report. Though a Modeling Manual in itself is not required for the RADMODL code certification, this manual does contain information that is required for the User's Manual and hence fulfills one of the requirements for code certification.

It is noted that some of the terminology used in the Modeling Manual is outmoded; for instance, the reference to the use of cards for inputting information. Due to the lack of time and manpower, these references were not updated. When time and manpower permit, the manual will be revised to reflect current nomenclature.

REFERENCES

1. 1Q35 Procedure 1.13, Revision 0, Software Development and Control, September 18, 1990.
2. Task SRT-SAE-92-8008, Software Development Plan, Revision 0, December 1992.
3. WSRC-RP-93-436, RADMODL User's Manual, Revision 0, April 1993.
4. RADMODL Programmer's Manual, Volume 1 and 2, Revision 0, EGS Corporation International and Infinite Software Solutions, Inc., December 1992.

APPENDIX

Attached in this section is the RADMODL Modeling Manual for the RADMODL Code Version 1.0. This manual was originally produced by the EGS Corporation and Infinite Software Solutions, Inc. as volume 1 of the RADMODL Programmer's Manual. Minor editorial changes were the only modifications made by WSRC.

RADMODL
MODELING MANUAL

Co-developed by
EGS Corporation International
and
Infinite Software Solutions, Inc.

December 1992

Revision 0

RADMODL MODELING MANUAL

RADMODL was developed specifically for the K-Reactor at the Savannah River Site. EGS Corporation and Infinite Software Solutions, Inc. provide no warranty either expressed or implied with respect to this document and the software described herein. All risk resulting from the use of this product is assumed by the user unless otherwise directed by state limitations.

Any modifications to the source codes void any warranty either expressed or implied. Any errors encountered should be reported to EGS Corporation or Infinite Software Solutions, Inc. at the address or phone number as listed on page 3 of this manual.

RADMODL MODELING MANUAL

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RADMODL MODELING MANUAL

INTRODUCTION AND EXECUTIVE SUMMARY

RADMODL is a system of linked computer codes specifically designed to calculate the radiation environment in the Savannah River K reactor following an accident in which significant fuel damage occurs.

The system consists of five modules: STPISOTP, STP, QADSR, PARABINT and DOSE. Four of these modules (STPISOTP, STP, QADSR and DOSE) require user input. For two specific accidents (DEGB of a 16" plenum inlet line LOCA and FHA) this input is provided. Information in the Modeling Manual is intended to provide the user with sufficient information to understand the structure of the code and provide more detailed instructions on the user input for the RADMODL code.

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HARDWARE AND SOFTWARE

The following are the general requirements for running RADMODL.

HARDWARE

To run RADMODL the following hardware configuration is required, with additional recommendations listed for improved efficiency.

MACHINE

Required	Recommended
IBM or 100% Compatible System	
386 Processor, with a math co-processor	486 Processor
6 Mb of RAM on Board	33 MHz clock speed
3 1/2" Floppy Drive	

HARD DRIVE STORAGE

Each model requires a separate directory. The programs required to support RADMODL in each directory require 2.5 Mb of hard drive storage. The input files for a model may require up to 1.5 Mb. The output files for a model may require up to 55 Mb of storage. The estimated storage requirements for the models provided by EGS is 120 Mb.

PRINTER INFORMATION

RADMODL requires wide carriage printouts when the printing option is selected. Therefore a 132 column printer or an 80 column printer that can switch to a condensed mode is required. Note, many of the reports used in RADMODL are very large. A fast printer with an extremely fast rate is highly recommended.

SOFTWARE

The following are the software requirements for running RADMODL.

RADMODL MODELING MANUAL

DOS 5.0

DOS 5.0 is required to run RADMODL. Its enhanced memory management features are required by the model.

WINDOWS 3.1 - 386 Enhanced Mode.

WINDOWS 3.1 running in enhanced mode is required by RADMODL. RADMODL is initiated under DOS, but a call is made to WINDOWS 3.1 to execute STP which requires an enormous amount of memory to execute. WINDOWS 3.1 is required since the memory handling routines allow STP to break the 640K application barrier found in the DOS environments.

SOFTWARE SETUP AND CONFIGURATION

INSTALLATION OF RADMODL

To install RADMODL, insert the first diskette labelled RADMODL into the floppy drive. Type A: or B: for the floppy drive from the DOS prompt. Then type "INSTALL" <floppy drive> <hard drive> <directory name> .

An example for installing into the RADMODL directory on drive c: would be:

INSTALL A: C:\RADMODL

The install utility will automatically copy all the files necessary for running the RADMODL. Any errors encountered while installing will be displayed on the screen.

REQUIRED DATA FILES AND DIRECTORY PATHS

RADMODL may be installed into any directory and on any drive letter you choose, however, WINDOWS 3.1 must be installed in the \WINDOWS directory.

WINDOWS SETUP

There is no special setup required for WINDOWS, except for the directory name of \WINDOWS.

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CONFIG.SYS SETUP

The config.sys file needs to be modified to have at least the following parameters:

FILES=30

BUFFERS=30

Additionally, the following memory manager command needs to be added to the config.sys file:

DEVICE=\WINDOWS\HIMEM.SYS

DEVICE=\WINDOWS\EMM386.EXE

DOS=HIGH

AUTOEXEC.BAT SETUP

The autoexec.bat file only needs the PATH updates for Windows. These are installed automatically when utilizing the standard install procedures provided with WINDOWS.

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1. INTRODUCTION TO RADMODL

RADMODL is a system of linked computer codes specifically designed to calculate the radiation environment in the Savannah River K reactor following an accident in which significant fuel damage occurs.

The system consists of five modules: STPISOTP, STP, QADSR, PARABINT and DOSE. Four of these modules (STPISOTP, STP, QADSR and DOSE) require user input. For two specific accidents (DEGB of a 16" plenum inlet line LOCA and FHA) this input is provided. A post-processor is also available which displays the results in a graphic form.

1.1 Purpose

The dose rate in any location after an accident depends on the activity in that area, i.e. the amount of each isotope present, and any existing shielding of sensitive components. RADMODL, as provided, assumes that there is no shielding in the area other than the self-shielding by the water in which the activity is uniformly distributed. The total dose to a sensitive component depends on the dose rate and the time for which the component is exposed to that dose rate. RADMODL assumes that the total exposure time is 30 days; however, while not usually displayed, the dose for shorter exposure times is also calculated. The models generated for the K-reactor assume the length of the accident is 30 days. If it is desired that these accidents last longer than 30 days, time steps can be added as required. A description of each module follows.

1.2 Define RADMODL

The RADMODL program connects the five modules (STPISOTP, STP, QADSR, PARABINT and DOSE) together into one seamless integrated system. Additionally, RADMODL provides a user-friendly menu interface for navigating through the system.

1.2.1 Define STPISOTP

This module provides information required by the subsequent module STP about the radioisotopes to be considered in the analysis. The input is a list of isotopes specified by the user and a list of energy groups specified by the user; the output is the information required by STP in a format suitable for direct input to that module.

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1.2.2 Define STP

This module calculates the radioactivity in a given area, and the photon spectrum resulting from that activity. Information on water levels in the various areas of the building as a function of time, and flow rates into through and out of the building is obtained from a companion system (FLOODNET). Note that there is no direct coupling between FLOODNET and RADMODL; information supplied by using FLOODNET is user supplied input to RADMODL. STP input also requires the output from STPISOTP; this input is directly transferred by RADMODL between the two modules. While other information is available from STP output, the output relevant to the dose calculation is the photon spectra in the affected areas as a function of time after the accident.

1.2.3 Define QADSR

This module calculates the dose rates in the affected areas as a function of time and location, using the photon spectra developed by STP and room dimensions compatible with those used in FLOODNET. RADMODL directly transfers the STP-generated photon spectra to QADSR; remaining required input is user supplied. The pertinent output from QADSR is the time after the accident and the dose rate at that time and location.

1.2.4 Define PARABINT

This module integrates the dose rates obtained with QADSR over time, resulting in the total gamma dose at the location in question. No user input to this module is required.

1.2.5 Define DOSE

This module allows the user to examine the results of variations in such input parameters as reactor power level, failed fuel fraction, or isotopic release splits. The post-processor uses the output of this module for its displays.

1.2.6 Define Post-Processor

The post-processor loads the total gamma dose output from PARABINT and displays it in a graphic display form. A mimic screen is available for the -20

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and the -40 elevations. Names of the volumes and the maximum dose rates are available on the display.

1.2.7 Define Pre-Processor

The pre-processor for RADMODL is the interface between the user and the modules with RADMODL. The pre-processor code is contained in the RAD.EXE program code. The pre-processor receives input from the user and prepares the necessary files for the module runs. Additionally, it links the modules together providing a smooth transition between the modules.

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2. GENERAL CODE INTRODUCTION

RADMODL was developed with three programming languages: Microsoft Fortran (R) for the Modeling Code, Clipper (R) for the menu and pre-processor portion of the program, and Microsoft C Language for the graphics post-processor.

2.1 Languages

2.1.1 Fortran (R)

Fortran (R) was the ideal language for developing the model codes. Microsoft Version 5.1 of Fortran (R) was used to compile the following modules:

STPISOTP	STPISOTP.EXE
STP	STP.EXE
QADSR	QADSR.EXE
PARABINT	PARABINT.EXE

2.1.2 Clipper Version 5.0 (R)

Clipper Version 5.0 (R) is a database environment, like Dbase, which allows the applications to be compiled into .EXE files. The source code for the menu and pre-processor code was compiled into RAD.EXE. The DOSE module code is also contained in the RAD.EXE file.

2.1.3 Microsoft C Language Version 6.1 (R)

Microsoft C Language Version 6.1 (R) was used to compile the source code for the graphics post-processor. Microsoft C Language Version 6.1 (R) provides the speed and enormous graphics libraries which created the ideal environment for development of the Post-Processor in RADMODL. RADSIM.EXE is the compiled C program for the post-processor.

2.2 RADMODL Flowcharts

FIGURE 2.2.1 is a flowchart of the modules linked to form RADMODL. FIGURE 2.2.2 shows the interaction of the user generated and RADMODL generated input and output files which are used by the various modules.

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FIGURE 2.2.1
RADMODL FLOWCHART

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Figure 2.2.2.
RADMODL INPUT/OUTPUT FLOWCHART

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3. STPISOTP MODULE

3.1 Description of STPISOTP code

STPISOTP was written in Fortran (R) and compiled with Microsoft 5.1 version of FORTRAN Compiler. The following is a listing of the filenames used to build the executable file STPISOTP.EXE:

STPISOTP.FOR
HANDLR.FOR
RETRV.FOR
ISOHDR.FOR
TIMEU.FOR
LETTER.FOR
FUNRD.FOR
MOV.FOR

3.2 Compiler Options Used to Make STPISOTP.EXE

FL /FPi87 /G2 /AH /c *.FOR /FeSTPISOTP *.OBJ /link

3.3 Source Code Listing

The source code listing is contained in Volume 2, Source Code Listing, Volume STPISOTP.

3.4 Documentation for STPISOTP

See Annex 3.

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STPISOTP

I. INTRODUCTION

STPISOTP is a supplementary program to the program STP. STPISOTP provides basic isotope information for user-selected isotopes that will be used by STP. This isotope information includes the isotope decay constant, precursors (present isotopes) and their "effective" decay constants, the "class" of the isotope, average beta energy per decay and gamma energy per decay sorted into groups with energy boundaries determined by the user. The program obtains basic information on the isotopes' decay from DRALIST (ref. 1). The output of STPISOTP consists of a printed listing of the input and the desired information for the requested isotopes as well as a file suitable for direct use by STP.

II. GENERAL DESCRIPTION

STPISOTP reads the required input information and immediately prints it unchanged to provide a QA record. The input consists of the names of the isotopes requested and the boundaries of the energy groups to be used. The isotopes are separated into "classes". Classes are groups of isotopes which, for purposes of the subsequent analysis, behave in the same way. STPISOTP allocates space for certain arrays based on the number of isotopes requested, calls two subroutines which perform the actual calculations and provide the output, closes all open files and exits. One of the subroutines, HANDLR, prepares the output containing the half life and precursor information; the other, RETRV, prepares the beta and gamma information.

III. SPECIFIC PROGRAM DESCRIPTION

A. STPISOTP

This is the main routine in the STPISOTP package. The program initially reads the names (chemical symbol, hyphen, atomic weight) of the isotopes requested from a file called ISONAME and, after printing out the date and time of the start of this run, writes out the exact image of the input records. It then reads and writes the energy group edges using a file called GAMEN. This serves to provide a convenient QA record for the input to the program. The files are then rewound and the information is read again, this time for processing.

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After reading a record giving a title for this run, which will be used to label the subsequent output, the program reads in the isotope names. This input is free form using subroutine FUNRD. Each isotope is assigned a sequential number, starting with 1, in the order in which it appears in the input. It is also assigned a class number, again starting with 1 and increasing by 1 each time the program encounters END. The isotope number, name and class are stored.

Upon encountering the end of the list of isotope names, the solo letter T, the program proceeds to read in the energy group edges. Again, the terminator is the solo letter T.

Since the number of isotopes and the number of energy groups to be used is not known prior to the run, it is more efficient to allocate space for arrays to be used in subroutines HANDLR and RETRV by using a variable dimensioning scheme. For this purpose one large array is set up in blank common, and the starting addresses of the arrays to be used in the subroutines are calculated from the number of isotopes requested (equal to the highest isotope number) and the number of energy groups (one less than the number of energies read in). The large array in blank common is dimensioned 25001. The program checks to see that the total storage allocation in this array does not exceed the array length, and prints out the calculated total and ends the program if the array is exceeded.

B. HANDLR

Subroutine HANDLR prepares the STP input containing the half life and precursor information. It utilizes the file FILE06.SRL from ref. 2 to get the information on the isotopes requested. FILE06.SRL contains, in order, the isotope name (chemical symbol, hyphen, atomic weight), first daughter isotope and fraction of decay to that daughter, second daughter isotope and fraction of decay to that daughter, third daughter isotope and fraction of decay to that daughter, half life of parent isotope and the units in which the half life is given. HANDLR compares the name of each parent isotope with the name of the isotopes in the user-provided list. If no match is found, a message to that effect is printed. If a match is found, subroutine TIMEU is used to convert the half life of that isotope to hours. STP expects the input to be a decay constant, with units of s^{-1} , rather than half life, so HANDLR converts the half life to a decay constant in these units.

HANDLR next rewinds FILE06.SRL and searches each isotope's daughters for a match with an isotope on the user's list. Again, if no match is found a message to

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that effect is printed. If a match is found, the **parent's** name and the **daughter's** decay fraction are stored. Note that here the daughter is the isotope on the user's list, so that the parent is the precursor. For each isotope on the user's list the program then finds its precursor(s) and computes for each an "effective decay constant" which is the product of the precursor's decay constant and the decay fraction to the daughter isotope.

HANDLR finally writes the isotope number, isotope name, isotope class number, first precursor number, first precursor effective decay constant, second precursor number, second precursor effective decay constant, third precursor number, third precursor effective decay constant to the print file and an output file for use by STP. Note that, if there is not a precursor, the precursor number listed will be one and its effective decay constant will be zero.

C. RETRV

Subroutine RETRV prepares the STP input containing the beta and gamma energy information. It utilizes the file DRALIST.SRL from ref. 2 to get the data for the isotopes requested by the user. DRALIST.SRL contains, in order,

1. a record giving the isotope name, half life and atomic number;
2. a record giving the number of alpha groups, followed by as many records as required to give the pairs of alpha energy in MeV and the intensity of that group;
3. a record giving the number of beta groups, the number of first forbidden transitions and the index for each first forbidden transition, followed by the number of records required to give the triplets of the beta end point energy in MeV, the average beta energy in MeV and the intensity of that group;
4. the same information as in 3. for positron transitions;
5. a record giving the number of Auger and conversion electrons, followed by that many records giving the energy in MeV and intensity for each such transition;
6. the number of photons, followed by as many records as required to give the pairs of energy in MeV and intensity for each.

RETRV compares the name of each isotope in the user's list with the isotope names in DRALIST.DAT. When a match is found, RETRV reads in the beta, Auger/conversion electron and gamma information. The total electron energy is obtained by summing the product of the average beta energy and intensity for all beta groups of that isotope, and adding thereto the product of beta energy and intensity for

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the Auger and/or conversion electrons. The gamma energy in each user-specified energy group is obtained by comparing the energy of each gamma-ray with the boundaries of each energy group, and summing into the group for which the gamma energy is equal to or greater than the lower limit, and less than the upper limit, the product of the photon energy and intensity.

Like HANDLR, RETRV writes out the results to the print file and to an output file for use by STP. The latter file contains, for each user-requested isotope, the isotope number, isotope name, total electron energy, photon energy in each energy group and the maximum gamma energy for that isotope. The printer file contains the same information but in somewhat different format.

IV. INPUT REQUIREMENTS

The input for an STPISOTP run is rather simple, and is in free form so that the user is not required to remember particular formats. The input consists of a list of isotope names (chemical symbol, hyphen, atomic weight) followed by a list of numbers representing the limits of the energy groups. Metastable states are denoted by M following the atomic weight. The available isotopes are listed in Table 1.2.7 of the RADMODL User's Manual.

The isotope names must be contiguous, i.e. there cannot be spaces between the chemical symbol, hyphen and atomic weight. Names may, but need not, be enclosed in single quotes. The order of the isotopes is not important to the code (however, see below for classes), but the user must remember that this is also the order in which they will appear in STP. It is recommended that the isotopes be listed within each class in order of increasing Z, and within each element in order of increasing A.

The isotopes are divided into classes by placing an END after the last isotope of that class. It is not necessary to pad the END to five characters, although that is not prohibited.

The boundaries ("edges") of the energy groups ("energy bins") are listed in order of increasing energy. The energy units are MeV. For all but the lowest energy, the upper edge of one bin constitutes the lower edge of the next higher bin; hence, only one entry for an energy is allowed. The maximum number of energy groups is 30, because of limitations in module QADSR.

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V. REFERENCES

- 1) Kocher, D. "DRALIST. Radioactive Decay Data for Application to Radiation Dosimetry and Rdiological Assessments." DLC-80. RSIC. Oak Ridge, TN. June 1988.
- 2) "DRALIST Modification for Savannah River Radiation Model." EGS-TR-910600-13 Janet Davidson. September 1992.

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Appendix A

Table A1: Routines in Program STPISOTP

Routine	Function
MAIN	Main program sets dynamic dimensions, reads input, sets classes
HANDLR	Calculates isotope decay constant, selects precursors, calculates precursor(s) effective decay constant
RETRV	Calculates total electron energy, bins photon energies
ISOHDR	Writes headings to start program, headings for top of each page and headings for end of job
TIMEU	Converts to hours from any normal time units
LETTER	Takes a four-letter word and returns the first N letters
FUNRD	Free form input routine
MOV	Moves or clears an array

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Table A2: Common Blocks and Their Distribution
in Program STPISOTP

<u>Routine</u>	<u>Common</u>	<u>Variables</u>
MAIN	Blank	A (26501)
	FUN	SBUFF1(20), IPAR(40), IT
	DIM	LNAME, LA, LYLD, LHALF, LEB, LEG, LGAM, LPREC, LAST
HANDLR	Blank	A (26501)
	FUN	SBUFF1(20), IPAR(40), IT
	DIM	LNAME, LA, LYLD, LHALF, LEB, LEG, LGAM, LPREC, LAST
RETRV	DIM	LNAME, LA, LYLD, LHALF, LEB, LEG, LGAM, LPREC, LAST
TIMEU	--	
LETTER	--	
FUNRD	INTRNL	REXP, FRACT, XNUMB, PART2, XIEC, PART1, IE, IP, IS, IPF, IWF, IXF, IEF, ISL1F, IDF, ISLF, IER, ITF, IIF, IEND, ISFLAG, IAPF
	FUN	SBUFF1(20), IPAR(40), IT
MOV	--	

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4. STP MODULE

4.1 Description of STP Code

STP was written in Fortran (R) and compiled with Microsoft 5.1 version of Fortran Compiler. The following is a listing of the filenames used to build the executable file STP.EXE:

TIMEU.FOR
MOV .FOR
FUNRD.FOR
WRITSO.FOR
READER.FOR
LAMINT.FOR
SETTER.FOR
LETTER.FOR
HEADER.FOR
STP.FOR
STPPC.FOR

4.2 Compiler Options Used to Make STP.EXE

FL /FPi87 /MW0 /G2 /AH /c *.FOR /FeSTP
LINK /NOD /SEG:256 TIMEU MOV FUNRD WRITSO READER LAMINT
SETTER LETTER HEADER STP STPPC STPISOTP HANDLR RETRV

4.3 Source Code Listing

The source code listing is contained in Volume 2, Source Code Listing, Volume STP.

4.4 Documentation for STP

See Annex 4

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ABSTRACT

The STP code, developed by the Tennessee Valley Authority, is a highly flexible isotope transport code. A major feature of this code is the ability to model complex flow systems while taking into account radioactive decay with the attendant production of daughter isotopes as well as other production and removal modes as the material moves through the system.

The input to STP has been made free form and position independent wherever possible to facilitate use of the program by those not familiar with the details of formatted input. The input describing the system follows a "key letter" concept. Under this concept, the quantity to be entered, volumes, flows, etc., is signalled by a "key" letter followed by numerical information as required.

The output of STP consists of two parts. The first part is the activities for each isotope in each component of the model. The second part is the photon spectrum by energy group for each component of the model based on the isotopic source in the component. Either or both of these may be punched for use in other offsite dose or shielding codes.

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PROGRAM DESCRIPTION

Purpose and Application

In the design of nuclear power plants one is frequently faced with the necessity of determining the transport of radioactive material through a system to arrive at an isotopic inventory in a system component. It may be desired to evaluate the shielding required for the component, or to determine the concentration in a room to set ventilation requirements, or to calculate effluent concentrations for offsite dose calculations. In all of these and similar cases, one deals with a source of radioisotopes in one component of the system which is transported at known rates to the other components. Radioactive decay with attendant production of daughter isotopes, plate-out, adsorption on filters, etc. occurring while the material is moving through the system must be taken into account. The computer code STP (Source Transport Program) was developed to perform these calculations.

STP is designed in such a manner that the model of the system under study very closely resembles the actual system. In general, a system will consist of a number of connected volumes through which the material of interest is transported. There may be branches and loops in the paths through the system, as well as sources and sinks for the material. The model then consists of components, corresponding to the physical spaces, connected by the same flow paths as the system. In the model the volumes of the connecting links between the components, e.g., pipes or passageways, are considered zero. If delay time in transit from one component to the other must be considered, components can be added to the model to describe these connectors.

Basic Engineering Theory

STP is based on the assumption that the distribution of material in the system to be analyzed can be described by dividing the system into components within which the material is uniformly distributed, that is, the activity in a component is completely mixed in the volume of the component. This assumption is equivalent to the condition that the removal or loss of material from a component is proportional to the inventory in the component. Note that when using dummy components to describe a connector, it may be necessary to use several components to model the connector in order to maintain the homogeneity requirement.

The quantity of any isotope at some time can then be determined using a simple mass balance on the component desired. That is, the rate of change of a particular isotope in a component with time will be equal to the amount of that isotope added minus the amount of that isotope removed. The addition term includes that material flowing into the component from other

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components, the amount added to the component from outside the system, and the amount produced by the radioactive decay of other materials in the component to the isotope in question. The removal term includes that material flowing out of the component into other components, the amount removed from the system at that component, and the amount of the isotope which undergoes radioactive decay.

ASSUMPTIONS AND LIMITATIONS

Applicable Equations and Derivations

The equation which describes the time dependent activity or quantity of material in a component is:

$$\frac{dA_{ij}(t)}{dt} = -\Lambda_{ij}A_{ij}(t) + P_{ij}(t) \quad (1)$$

where A_{ij} is the activity or quantity of material i in component j , P_{ij} is the rate at which activity or material i is added to component j , and Λ_{ij} is the rate at which activity or material i is removed or lost from component j . If both Λ and P are independent of time, then for one material and one component one obtains the solution

$$A = A_0 e^{-\Lambda t} + \frac{P}{\Lambda} (1 - e^{-\Lambda t}) \quad (2)$$

where A_0 is the initial activity. However, in general, P is time dependent and in some cases Λ is also time dependent.

The addition of material to the component, $P_{ij}(t)$, may come from three sources. First, a flow from outside the system may add material directly to the component. Second, flow from another component in the system may add material to the component. Third, material may be produced within the component by radioactive decay. Thus, the addition rate for material i to component j can be expressed as:

$$P_{ij}(t) = P_{ij}^{(1)}(t) + P_{ij}^{(2)}(t) + P_{ij}^{(3)}(t) \quad (3)$$

where $P_{ij}^{(1)}(t)$ is the addition rate from outside the system,

$P_{ij}^{(2)}(t) = \sum_{jj \neq j}^n c_{ij-j}(t) A_{jj}(t)$; $c_{ij-j}(t)$ is the transfer coefficient of i from component jj to j , and

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$$P_{ij}^{(3)}(t) = \sum_{ii}^n \gamma_{ii \rightarrow i} A_{ij}(t); \quad \gamma_{ii \rightarrow i} \text{ is the rate of production of } i \text{ from } ii \text{ in component } j.$$

Note that $\gamma_{ii \rightarrow i}$ is not normally a function of time or component.

Similarly, the loss from a component can be due to: (1) loss within the component (such as radioactive decay), (2) flow out of the component to other components, and (3) flow out of the component and out of the system. Thus, the loss rate from component j for material i can be expressed as

$$\Lambda_{ij}(t) = \lambda_i + \Lambda_{ij}^{(2)}(t) + \Lambda_{ij}^{(3)}(t) \quad (4)$$

where λ_i is the removal rate inside the component due to radioactive decay (neither time nor component dependent),

$$\Lambda_{ij}^{(2)}(t) = \sum_{jj \neq j}^n f_{ij \rightarrow jj}(t);$$

$f_{ij \rightarrow jj}(t)$ is the transfer coefficient of material i from component j to jj , and $\Lambda_{ij}^{(3)}(t)$ is the removal due to flow out of the system, $R_{ij}(t)$.

Equation (1) can now be rewritten as:

$$\begin{aligned} \frac{dA_{ij}(t)}{dt} = & - (\lambda_i + \sum_{jj \neq j} f_{ij \rightarrow jj}(t) + R_{ij}(t)) A_{ij}(t) + P_{ij}^{(1)}(t) \\ & + \sum_{jj \neq j} c_{ij \rightarrow j}(t) A_{ij}(t) + \sum \gamma_{ii \rightarrow i} A_{ij}(t) \end{aligned} \quad (5)$$

Equation (5) is difficult to solve because the coefficients are time dependent. However, if the coefficients do not vary rapidly with time, it is possible to divide the original problem into a series of time steps such that the coefficients can be assumed constant over the time step without significant loss of accuracy. The requirement that the coefficients be slowly variable is not particularly restrictive in practice. The time dependence of the coefficients is fundamentally due to the time variations of flows and/or volumes within the system which are usually constant over extended periods of time and tend to change in a stepwise fashion.

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Assuming then that $f_{i \rightarrow jj}$, $P_{ij}^{(1)}$, $c_{jj \rightarrow j}$, and R_{ij} are constant over the time period of interest, one has:

$$\begin{aligned} \frac{dA_{ij}(t)}{dt} = & - (\lambda_i + \Sigma f_{ij \rightarrow jj} + R_{ij}) A_{ij}(t) + P_{ij}^{(1)} \\ & + \Sigma c_{jj \rightarrow j} A_{jj}(t) + \Sigma \gamma_{ii \rightarrow i} A_{ii}(t) \end{aligned} \quad (6)$$

This is the basic equation STP was designed to solve in subroutine LAMINT.

In LAMINT this equation is integrated by the use of a combination of analytical means, a difference scheme, and an iteration scheme. A discussion of this scheme is given in Appendix A.

Programming Considerations

Isotope Classes

The coefficients in equation (6) depend on material i . In most cases, a group of materials (e.g., all isotopes of an element, or all halogens, etc.) act in a sufficiently similar manner that they may be assumed to have the same properties excepting the radioactive decay constant λ_i . One can then divide the list of materials present into classes within which materials behave in the same manner. The coefficients f and c are then defined for the class k , which contains the material i .

In equation (4) f was defined as the transfer coefficient for a material from one component to another. From the preceding discussion one can define it in terms of class k rather than material i . One can see that this transfer is due to flow out of the component, and from equation (1) one can see that it must be a rate (i.e., its units must be inverse time). Thus, one can describe

$$f_{kj \rightarrow jj} = \frac{F_{kj \rightarrow jj}}{V_j} \quad (7)$$

where $F_{kj \rightarrow jj}$ is the flow rate for material of class k from component j to jj , and V_j is the "volume" of all material in component j . The important requirement is that F and V are expressed in consistent units to yield f in inverse time. It is therefore equally valid to specify the flow rate in ft^3/hr and the "volume" in ft^3 , or to specify the flow rate in g/hr and the "volume" in g .

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Similarly, one can see that c is the transfer coefficient for material i or, as can now be said, material in class k due to flow from component jj into component j . Again c is a rate, and its units must be inverse time. It seems obvious to conclude that $c_{kij \rightarrow j}$, the rate of gain in component j for class k material due to flow from component jj , must be related to $f_{kij \rightarrow j}$, the rate of loss from component jj for class k material due to flow to component j . It is erroneous to equate the two. One can see from equation (6) that f is determined by the total flow rate out of component jj . For a variety of reasons this is not necessarily the total flow rate into component j . The most obvious reason is a flow split after component jj ; however, the flow of material in class k can also be affected by such items as filters between components jj and j . One can define $X_{kij \rightarrow j}$ as the ratio of the material of class k added to component j to that leaving component jj . Then

$$c_{kij \rightarrow j} = f_{kij \rightarrow j} X_{kij \rightarrow j} \quad (8)$$

In general, $X_{kij \rightarrow j}$ is less than or equal to 1.0; however, $X_{kij \rightarrow j}$ may be greater than 1.0. If for example two alternate flow paths exist and an analysis of each is required, $X_{kij \rightarrow j}$ for the flow out of the last common component could be set equal to 2.0 thus allowing both flow paths to be examined simultaneously.

In the discussion of the concept of class it was noted that the decay constant λ could not be included in the class. The decay constant λ_i for material i appears explicitly in equation (6); further, the coefficients $\gamma_{ii \rightarrow i}$ also depend on λ_i . If a precursor of material i is defined as a material decaying to material i , then the coefficients $\gamma_{ii \rightarrow i}$ represent the decay constant λ_i adjusted for the branching ratio of precursor ii to material i .

Variable Volumes

In many cases it is desirable to calculate the concentration of a material in a component rather than the total inventory. The simplest way to accomplish this is to calculate the inventory and divide it by the volume of the component. This scheme may break down in the case of variable volumes if the volume becomes very small because the error in concentration may become large due to division by a small number.

In STP a switch (KCONC) is used to indicate inventory (KCONC=0) or concentration (KCONC=1) calculations. Let C_{ij} be the concentration of material i in component j , and let

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$V_j(t)$ be the volume of component j . In this case, one may assume that the volume is time dependent. Then

$$A_{ij}(t) = C_{ij}(t) V_j(t) \quad (9)$$

Substituting into equation (1), one gets

$$\frac{d}{dt} (C_{ij}(t) V_j(t)) = -\Lambda_{ij}(t) C_{ij}(t) V_j(t) + P_{ij}(t) \quad (10)$$

$$\frac{d}{dt} C_{ij}(t) = -(\Lambda_{ij}(t) + \frac{1}{V_j(t)} \frac{d}{dt} V_j(t)) C_{ij}(t) + \frac{P_{ij}(t)}{V_j(t)} \quad (11)$$

Equations (11) and (1) have the same form, only the coefficients are changed. Following the expansion of equation (4), one sees that only the second term, corresponding to $\frac{\sum F_{ij \rightarrow jj}(t)}{V_j(t)}$ must be modified by the addition of the volume change. Assuming that the volume change is linear with time, $\frac{dV_j}{dt}$ is constant, we can substitute in equation (5) for the first term which becomes:

$$-(\lambda_i + (\sum F_{ij \rightarrow jj} + \frac{dV_j}{dt}) / V_j + R_{ij}) \quad (12)$$

Note that V_j is the volume of component j ; since it is time dependent, the division is performed in subroutine LAMINT.

To indicate the type of component, STP uses a flag array called NAC. Each component is represented in this array. Normal components i.e. those which obey equation (5), have the flag set at 1; components with varying volumes have the flag set at <0. Note, only 25 variable volumes are allowed per time step.

Accumulators

There are occasions in which it is desired to suppress consideration of radioactive decay within a component. Consider, for example, a case in which material is released and it is desired to determine the total amount of this release over a period of time. One can define a component into which material flows; if there is no flow out of the component and decay is

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suppressed, the material will accumulate in the component; hence one speaks of "accumulator" components. They are denoted in the flag array NAC by a 0.

In accumulator components only the radioactive decay, and concomitant production of daughter isotopes, is turned off. In equation (5) this implies that λ_i and $\gamma_{ii \rightarrow i}$ are set to zero for that component.

Plate Out Factors

Under certain circumstances a fraction of the inventory of material i in component j may be tied up in such a manner that it is unavailable for removal from the component by the flow through it. The obvious case is that of material plating out on the walls of the component. In general, these processes are characteristic of a material class, so that one can define a plate out factor $POF(J,K)$ as the ratio of the total quantity of material of class k in component j to the quantity available for removal from the component by a flow. From the definitions one can see that, in equation (5), the variables $f_{ij \rightarrow jj}$, R_{ij} , and $c_{ij \rightarrow j}$ will be affected. They are inversely proportional to $POF(J,K)$.

Equilibrium Constants

At times there are two components in the model such that there is an interchange of material between them. In the actual system this could be a tank with a liquid and a gas phase in equilibrium.

Let there be some flow rate $F_{kj \rightarrow jj}$ from components j to component jj . Since the two components are assumed to be in equilibrium there will be some return flow from component jj to component j . These flows will be related by an equilibrium constant, α_k , such that

$$F_{jj \rightarrow j} = \alpha_k F_{kj \rightarrow jj} \quad (13)$$

If there is no flow from j to jj , i.e. $F_{kj \rightarrow jj} = 0$, the program takes for the return flow the product of α_k and the sum of all flow rates into jj from components other than jj .

The system could also contain items such as demineralizers, filters, etc. One can represent such a system element by inserting a component representing the absorbing medium between the upstream and downstream components. Let the upstream component be j , the downstream component be jjj , and the absorbing medium be jj . If the flow rate from j toward jjj is $F_{kj \rightarrow jjj}$, then a fraction $\epsilon(k)$ of $F_{kj \rightarrow jjj}$, representing the filter efficiency, will go to jj with the remainder going to jjj . When dealing with radioactive materials it is possible that

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an isotope which has a nonzero filter efficiency, and therefore would be deposited on the filter medium, will decay into an isotope for which the filter efficiency is zero. The daughter should not be retained in component jj. Therefore, one can write:

$$F_{k \rightarrow jj} = F_{j \rightarrow jj} \epsilon(k) \quad (14)$$

$$F_{k \rightarrow jj} = F_{j \rightarrow jj} (1 - \epsilon(k)) \quad (15)$$

$$F_{k \rightarrow jj} = 0; \quad \epsilon(k) \neq 0 \quad (16) \\ = 10^6; \quad \epsilon(k) = 0$$

The first two relations are obvious; the last accounts for daughter products of materials absorbed by the filter medium which may have different absorption properties. The fictitious flow rate of 10^6 immediately removes these isotopes from the filter.

Input Requirements

General

The input to STP was designed to facilitate use of the program by engineers not necessarily familiar with the details of FORTRAN formatted input. To the maximum extent practicable the input is therefore made free form and position independent, i.e. for many input variables the order of their appearance is immaterial.

Free form input is accomplished by use of subroutine FUNRD which is described in TVA Report 0-7260 "FUNRD - A Free Form Input Subroutine." FUNRD accepts both numerical and literal information and keeps them in separate arrays. Numerical and literal information must each be in the order specified for the input, but the types may be interspersed on the same card. If the input specifies only numeric information, literal comments may appear on the card and will be ignored. Any card having a \$ in column 1 is treated as a comment card, is immediately printed out, and the next card is read. This feature aids the documentation of calculations by permitting the user to include descriptive material in the input without requiring such material.

The complexity of the system modelled for STP can vary widely from one application to the next. Obviously, a complex system will require more information to describe it than will a simple system. The input must therefore be sufficiently flexible to accommodate these varying requirements without demanding unnecessary or "dummy" information. The input

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describing the system, which consists of such items as component volumes, flow between components, transmission factors, etc., follows what we term the "key letter" concept. Under this concept, the quantity to be entered is signalled by a letter (the "key" letter) followed by numerical information as required. The key letters currently recognized, and the numerical information demanded by each, are listed in Table 1. Information once entered for a quantity remains valid for all subsequent time intervals and need not be repeated unless it is to be changed.

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Table 1

Key Letter Definitions and Requirements

<u>Letter</u>	<u>Represents</u>	<u>Requires</u>
A	Accumulator Component	J
B	Variable Volume	J Θ
C	Continuous Source	M J K Θ
E	Exchange Between Two Components	J JJ K F α
F	Flow Rate	J JJ K Θ
G	Gamma Source Output Conversion Factor	J Θ Units(first card only)
I	New Parameter Values	CA CB CC CD CE CF
N	New Source	J M
P	Punch Information	NPA NPP JA ₁ ... JA _{NPA} JP ₁ ... JP _{NPP}
PF	Plate Out Factor	J K Θ
R	Removal Rate	J K 0
S	Step Source	M J K Θ
U	Shorthand Method of Handling Filters	J JJ JJJ F f ₁ ... f _{NK}
V	Component Volume (Mass)	J Θ Units
X	Transmission Factor	J JJ K Θ

Note 1. J, JJ, JJJ, JA, JP are component numbers,
M is source number,
K is material class number,
 Θ is the value of the quantity.
 α is an equilibrium constant,
f is the decimal fraction of the flow for a specific class.

Note 2. Letters E, I, U are designed for special situations and are explained in the text.

Note 3. Units are not required. Units may be included as an aid to the programmer. The program does not check for consistency of units.

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The quantities corresponding to the key letters F, V, X, R, E, U, A, B and PF are, respectively, $F_{i \rightarrow j}$ and V_j of equation (7), $X_{i \rightarrow j}$ of equation (8), R_{ij} of equation (12). E is used in situations of equation (13); U in those of equations (14-16). The concepts requiring A, denoting an accumulator; B, denoting a variable volume, and PF, the plate out factor, were discussed earlier.

The key letters S (step), C (continuous), and N (new) relate to $P^{(i)}$ of equation (3), the source of the material. At the beginning of the run a list of materials (source library) is read in. Materials from this list may be placed into any component at the beginning of any time interval using the key letter S. The value (Θ) multiplies the activities or quantities of material in class K in the appropriate source library M, and the result is placed in component J.

Material may also be added to any component continuously during the time interval. These sources correspond to $P_{ij}^{(i)}$ of equation (6), i.e. the flow of material i from outside the system into component j. This situation is handled through the key letter C; the value (Θ) again multiplies the activities or quantities of materials in class K in the source library M, and the result is placed in component J.

There arise situations in which the content of one component should be transferred to another in a time very short compared to the overall time interval, i.e., an instantaneous transfer is desired. This can be accomplished through use of the key letter N. The material inventory in component J becomes the source library M; the inventory in component J is then set to zero. Using the key letter S, one can then place the source library M into a component JJ. The key letter N can be used to only zero the inventory in a component by setting $M = 0$; it can also be used to multiply the inventory in a component by any factor. For this latter function it is only necessary when using the key letter S to specify the same component J and same source library M, which were specified with the key letter N, and to make the value (Θ) equal to the multiplier.

Note that the sequence of operations initiated by key letter N takes place at the end of a time interval, while the operations occasioned by key letter S take place at the beginning of a time interval. It follows that a transfer or multiplying function must have the key letter N specification in one time interval, and the corresponding S specification in the next.

STP has the capability of calculating gamma ray photon and energy spectra resulting from radioactive material within a component. The program assumes for these calculations that the activities in the component are expressed in units of μCi . If the activities are expressed

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in other units, the key letter G is provided to enable unit conversion. The activities in component J are divided by the value (Θ); for example, if the activities are in Ci, $\Theta = 10^6$.

In many cases the output of an STP calculation will be used as input to other programs for further calculations. It is, therefore, desirable to have STP not only print the information but also to "punch" the material inventory and/or the photon spectrum for a specified component. The key letter P is used to direct the program to punch. The number of activities and the number of photon sources are first specified, followed by the component numbers for the activities desired and the component numbers for the photon spectra desired.

The numerical integration routine LAMINT, discussed in Appendix A, uses a number of parameters to check for instabilities, etc. Normally, these parameters are preset; however, it may be desirable to use different ones for certain studies. To facilitate such changes the key letter I was introduced. Note that this is the only key letter which is not directly connected with aspects of the system under study, but rather with the numerical analysis. Key letter I should be used sparingly, and only by those thoroughly familiar with the program.

Specific Requirements

The input can be considered at three levels: first, input required for a run, where a run consists of one or more cases; second, input required for a case, where a case consists of one or more time intervals; third, input required for a time interval. As might be expected, information for a run is read first, followed by information for the first case, then the information for consecutive time intervals of that case; this is succeeded by the information for the second case and its time intervals, etc.

Certain input quantities are given default values, i.e. values which the program will use if no other values are specified in the input. These default values are indicated where applicable. Caution must be exercised when using these default values. In free form input the values are assigned to the variables in the order in which they appear on the card. It follows that, if a value were omitted to take advantage of a default value, a number intended for the next variable would be moved up and assigned instead of the default value; hence, only those values may be omitted which have no input information following on that card.

Input Deck Setup

For ease of description it will be assumed that the input is in the form of a card deck. It is, of course, possible to read the information from another medium (e.g. a disk file); in that case the records must be card images. Cards will be numbered in the order in which they

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appear in the deck, with first level categorized as 100 type, second level as 200 type, and third level as 300 type.

Where free form input is specified, numerical and/or alphanumerical quantities must be separated by delimiters (usually blanks or commas, but see description of FUNRD). Numerical quantities may be integer or real, in Fortran F, E, or D format (e.g. 12.34 may be written as 12.34 (F format), or 1.234E+1 (E format), or 1.234D+1 (D format). Alphanumerical quantities containing characters normally used as delimiters must be enclosed in single quotes. It is a good habit to enclose all alphanumerical information in such quotes.

Run Level Information

Card 100: NV, MS. Free form input.
NV denotes the maximum number of components for any case of the run; MS denotes the total number of sources for all cases of the run.
NV defaults to 5, MS defaults to 5.

Case Level Information

Card 101: NI, NK, NG, NL. Free form input.
NI denotes the number of isotopes used for the run; NK denotes the maximum number of classes used in the run; NG denotes the number of gamma ray groups used for the run; NL denotes the maximum number of precursors to be allowed. There is no default value for NI; NK defaults to 6, NG defaults to 0, NL defaults to 1. Note that photon spectra cannot be output if NG = 0.

Card(s) 102: I, HEADI(I), KK(I), W(I), LL(I,1), GAMMA(I,1), LL(1,2), GAMMA(I,2), etc.
Formatted input, FORMAT(I4,A8,I1,F11.4,4(I4,F10.3)). I is the isotope identification number, HEADI is the isotope name (usually the chemical symbol and atomic weight), KK is the material class to which this isotope belongs, W is the radioactive decay constant in units of sec^{-1} , and the pairs of values LL and XGAMMA denote the precursor isotope number and effective decay constant, respectively. There may be a maximum of four precursors.

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There must be one card 102 for each isotope; these cards need not be in order of identification number, although that is convenient. Note: STP converts the decay constants from sec^{-1} to hr^{-1} and prints out in the latter units.

Card(s) 110: XG(1) ... XG(NG). Free form input.

XG denotes the effective gamma ray energy for each energy group. These values must be in the same order as the groups. Note that these cards appear only if $\text{NG} > 0$.

Card(s) 111: I, YG(I,1) ... YG(I,NG+2). Formatted input, FORMAT(I4,6X,(13F5.4)).

I is the isotope identification number, YG(I,1) is the total electron energy per disintegration in MeV/Dis, YG(I,2) to YG(I,NG+1) are the gamma ray energies per disintegration for each energy group in MeV/Dis/group, YG(I,NG+2) is the highest photon energy in the decay of isotope I in MeV.

There must be one card 111 for each isotope; these cards need not be in order of identification number, although that is convenient. Note that these cards appear only if $\text{NG} > 0$.

Card 120: M, HSOR(M). Free form input.

M is the source identification number, HSOR a title identifying that source. The source identification number must be $\leq \text{MS}$. The identifying title will appear in the output as two strings of 16 characters each, one above the other. Remember the rules for free form alphameric input.

Card(s) 121: I, S(I,M). Free form input.

Pairs of isotope identification numbers I and activity or quantity of material [S(I,M)] of material I in source M. As many pairs [I,S(I,M)] as desired may appear on a card; however, no pair may be split between two cards. The pairs need not be in order of isotope identification numbers, although that is convenient. The last entry for a source must be an isotope identification number of 0 (zero). There must be one set of type 120 and 121 cards for each source used. These sets need not be in order of source identification numbers, although that

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is convenient. Note: STP assumes all activities are in μCi when calculating photon spectra.

- Card 122: Source read terminator, the letter T. Free form input. Note that, because of this feature, a T may not appear on any type 121 card.
- Card 200: HTITLE. Formatted input, FORMAT (10A8)
HTITLE is the title of this case. This title will be printed in the heading for each page of the output. The run is terminated by a case title of T, i.e. the letter T anywhere on an otherwise blank card.
- Card 201: NJ, KCONC, NDECAY, ITMAX, KDEBUG. Free form input.
NJ denotes the number of components used in this case; KCONC is the inventory/concentration calculation switch; NDECAY is the decay calculation switch; ITMAX sets the maximum number of iterations to be used in the integration routine LAMINT; KDEBUG specifies the debug option.
- NJ must be $\leq \text{NV}$. Inventory (activity/component) will be calculated if $\text{KCONC} = 0$; concentration (activity/unit volume or activity/unit mass) will be calculated if $\text{KCONC} > 0$, depending on the units for V. If $\text{NDECAY} = 0$, decay will be included as a source of daughter isotopes; if $\text{NDECAY} = 1$, decay will be excluded. NDECAY is always set to 1 if $\text{NL} = 0$. $\text{KDEBUG} = 0$ results in normal output; $\text{KDEBUG} = 1$ results in vastly increased output for debugging purposes. This option should be used sparingly. KCONC defaults to 0; NDECAY defaults to 0; ITMAX defaults to 10; KDEBUG defaults to 0.
- Card(s) 202: J, HOL. Free form input.
J is the component identification number; HOL is the title assigned to that component.
- J must be $\leq \text{NJ}$. HOL, the component title, will appear in the output as two strings of 16 characters each, one above the other. Remember the rules for free form alphameric input. There must be one card type 202 for each component. These cards need not be in order of component identification number, although that is convenient.

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Time Interval Information

Card 300: TN, ITU, NSTEP, NPRINT, KDEBUG. Free form input.
TN denotes the time at the end of the time interval in any common units; ITU denotes the units in which the time is specified; NSTEP denotes the number of steps into which the time interval is to be divided for the integration over time; NPRINT is a switch which controls printing of the output.

It is important to recognize that TN is not the time difference from the preceding time interval, but is the time reckoned from the starting event to the end of this time interval. As an example, assume that it is desired to calculate the activity in a component at two hours, eight hours, and twenty-four hours after an event which constitutes time $t=0$; then TN would be 2-hour, 8-hour, and 24 hour (or, if desired, 1 day) for the three time intervals. There are three special values for TN: TN = 0 (or a blank card 300) terminates the case; TN negative but not -2 signifies a null interval, and integration over this interval is omitted; TN = -2 resets the start time to zero. Note that for TN negative but not -2 other cards of the 300 series may follow, but that a card 300 carrying TN = -2 must be followed by another card 300. ITU determines the time unit from the first letter, so that any abbreviation is acceptable (e.g. second, sec, s; or hour, hr, h), except that "month" must start with the letters MO.

NSTEP defaults to 30. In the case of feedback loops or variable volumes, NSTEP is automatically increased by a factor of 3. To print the output for the time interval, NPRINT = 0; NPRINT > 3 suppresses printing of model information; $2 \leq \text{NPRINT} \leq 5$ suppresses printing of the source library; and NPRINT odd suppresses printing of the answers. NPRINT defaults to 0. KDEBUG defaults to 0. Note, once KDEBUG is set it remains set for the remainder of the run.

Card 301: HEAD. Formatted input, FORMAT(10A8).
HEAD is the title for this time interval. This title will be printed in the heading of the output for this time interval.

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Card(s) 302: Key letter cards. Free form input.
The acceptable key letters are given in Table 1. There can be a number of specification sets associated with one key letter in the record. The key letter records may be arranged in any order except that the key letter P, if present, must be the last key letter for that time interval. Information which was entered for a previous time interval and which is to remain the same for the current one need not be repeated. Again the key letter P is the exception; it must be used in every time interval for which punched card output is desired. The end of a time interval is signalled by a blank card, by a letter T, or by the first record for the next time interval (a card 300). If the letter T is used, the case is terminated, and a card 200 should follow.

Example Input

A pictorial representation of a card data deck for use on an IBM-370/165, IBM 3081, or compatible machine is shown in Figure 1. It must be stressed that this figure does not represent a sample case, but is used solely to illustrate the input; nevertheless it is sufficiently realistic that a discussion of the figure will bring out many of the features of the program.

We note first that there are changes in the input unit between cards 100 and 101, and between cards 111 and 120. This enables the user to have commonly used isotopic data on a medium other than cards, e.g. a disk, thereby not only reducing the amount of cards to be handled for any one run but also enabling access to the same data by several jobs without the necessity for many duplicate decks. This feature can be eliminated easily by removing the changes in variable NIN in subroutines SETTER and STP; see the comments in the subroutine listings.

On cards 100, 101, and 201 we have demonstrated a feature of FUNRD: Literal information which is not used by the program is disregarded. For convenience in reading an input deck we have written the variable name before the value (e.g. NV=, or KCONC=). Note that a delimiter must follow the literal string; we have found it a common error to forget this delimiter, thus making the value of the variable part of the literal string. Card 201 also illustrates the use of delimiters other than a blank, in this case a comma, and the variable spacing between entries.

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We see from card 101 that there are 66 isotopes to be used in this run. We therefore expect to have 66 cards 102, which are here shown only as a block. We also see that there are 21 gamma ray energy groups. Since $NG \neq 0$, we require cards 110 and 111; were $NG = 0$, these cards would be omitted. For this illustration we have chosen to have only one source, defined on cards 120 through 121. On cards 121 we have attempted to illustrate the various ways in which numerical information can be written; for details reference is made to the FUNRD report. There are 66 entries shown for this source, followed by a 0 to designate the end of this source. Since there are no other sources, the source read is terminated by a T (card 122).

This concludes the information common to all cases in a run.

We next show the information required for a case. For illustrative purposes we have chosen to alter ITMAX from the default value of 10 to 15. We therefore had to include the default values for KCONC and NDECAY explicitly. If this were not done, the value of 15 would be assigned to KCONC, and ITMAX would default to 10 since effectively no value would be read in for it. There was no need to enter a value for KDEBUG since the default value was used. It is only shown for completeness to indicate where it would be entered.

Cards 202 illustrate the headings for the three assumed components. The numeral 1 in the heading for the first component must be included in quotes, otherwise it would be treated as a numeral rather than a literal, and would be ignored. A maximum of 16 characters is permitted per string. The spacing within the string, if 32 characters are not required, is up to the aesthetic sense of the user. Since three components are assumed ($NJ = 3$), this completes the general information for the case.

On the type 300 cards shown we have illustrated some different ways of showing units of time. As we discussed before, M and MIN are equivalent and represent minutes; MO is required to designate month. All times refer to a common zero. The first time interval begins at time zero and ends at 15 minutes. The second time interval begins at 15 minutes and ends at 30 minutes. The third time interval extends from 30 minutes to 1 day, and the last from 1 day to 1 month.

Cards 301 represent typical titles for the different time intervals. These titles are printed out in the heading for that time interval and can, therefore, carry any information which the user desires to see in that heading subject only to the 80 character limitation.

Let us now consider the information conveyed by the 302 cards. We see first that there is a continuous source of activity into component 1, using source 1, with a multiplier of 1800 on

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all classes of the source. If the source is given in units of $\mu\text{Ci/g}$ (a common specification), then the 1800 would represent 1800 g/h. The main point to recognize here is that the product of the source and the multiplier must carry units of activity per hour. For a step source (not illustrated here) the units of the product must be activity. The information that the multiplier is to apply to all classes is conveyed by the class designator 0. This scheme of using class designator 0 to indicate "for all classes" is used for all key letters which require class information.

Next we find flow information from one component to another. We have assumed that the flow from component 1 to component 2 for all classes is 10 cfm, and from component 2 to component 3 for classes 2 and 3 is 20 cfm. Since all information must be expressed in reciprocal hours, we have flows of 600 cfh and 1200 cfh, respectively.

The flow information told us that activity was removed from component 2 by a flow to component 3 for classes 2 and 3; the next card indicates that activity for class 1 leaves the system out of component 2 at a rate of 1200 h^{-1} . The mode of removal is irrelevant. It could, for example, be a flow to a physical component which is not included in the system under study. However, note that unlike a flow, the removal rate does not have units of volume (or mass) per hour, but is expressed in reciprocal hours similar to a decay constant.

The last item of information specified for the first time interval is the volume of the various components. We have assumed volumes of 12000, 1200, and 1200 cu. ft. for volumes 1, 2, and 3, respectively. We have provided labels indicating these units for components 1 and 2. No label will appear on the output for the volume of component 3. It is important to note here that the units for volumes and flows must be such that the product of flow and volume carries units of h^{-1} . We therefore could have used a volume of 1 for component 1, and a flow from component 1 to component 2 for all classes of 0.05 volumes/h to achieve exactly the same result. The appropriate units in any particular application will usually be evident from the information available.

The next time interval, which ends at $t=30$ minutes, is characterized by a reduction in flow from component 1 to component 2 for all classes from 600 cfh to 300 cfh, and the insertion of a filter into the flow from component 2 to component 3 with a filter efficiency of 0.9 for material in class 3, and 0.0 for all other material. This is indicated by a transmission factor (X) of 0.1 and 1.0, respectively. Transmission factors of 1.0 need not be entered since that is the default value. All other specifications remain the same as in the first time interval. Note particularly that the changes take place at the beginning of the time interval, i.e., at $t=15$ minutes, and not at $t=30$ minutes.

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The next time interval, which extends from 30 minutes to 1 day, does not require any changes in the parameters, so only cards 300 and 301 are provided. However, after 1 day the filter is again removed from the system and remains out of the system for the remainder of the case which terminates at 1 month. The change in transmission factor on card 302 for class 3 for flow from component 2 to component 3 accomplishes this.

The T on the last type 300 card terminates the case. An additional T on a type 200 card terminates the run. For the convenience of the user, Tables 2 and 3 summarize the input requirements briefly.

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Figure 1
Sample Input Deck

	CARD TYPE 300
X 2 3 3 1.0	CARD TYPE 302
ACTIVITIES AFTER 1 MONTH OF OPERATION	CARD TYPE 301
1 MONTH	CARD TYPE 300
ACTIVITIES AFTER 1 DAY OF OPERATION	CARD TYPE 302
1 DAY	CARD TYPE 300
X 2 3 3 0.1	CARD TYPE 302
F 1 2 0 300	CARD TYPE 302
ACTIVITIES AFTER 30 MINUTES OF OPERATION	CARD TYPE 301
30 MINUTES	CARD TYPE 300
V 1 12000 CUFT 2 1200 CUFT 3 1200	CARD TYPE 302
R 2 1 1200	CARD TYPE 302
F 1 2 0 600 2 3 2 1200 2 3 3 1200	CARD TYPE 302
C 1 1 0 1000 C \ \ 0 1000	CARD TYPE 302
ACTIVITIES AFTER 15 MINUTES OF OPERATION	CARD TYPE 301
15 M	CARD TYPE 300
3 ' HEADING FOR ' COMPONENT 3 '	CARD TYPE 202
2 ' HEADING FOR ' COMPONENT 2 '	CARD TYPE 202
1 ' HEADING FOR ' COMPONENT 1 '	CARD TYPE 202
NJ= 3 KCONC= 0 NDECAY=0 IYMAX= 15 KDEBUG= 0	CARD TYPE 201
TITLE FOR THIS CASE	CARD TYPE 200
66 1.2E-3 0	CARD TYPE 122
CONTINUE THESE CARDS FOR N1 PAIRS	CARD TYPE 121
1 2.1E-02 2 0.11 3 1.9 4 6E-2 5 2-1 6 5.0-3	CARD TYPE 121
1 'REACTOR COOLANT'	CARD TYPE 120
//DDFT25F001 DD #	
GAMMA-RAY ENERGIES PER DISINTEGRATION PER GROUP	CARD TYPE 111
EFFECTIVE GAMMA-RAY ENERGIES (FREE FORM)	CARD TYPE 110
ISOTOPE INFORMATION	CARD TYPE 102
N1= 66 NK= 3 NG= 21 NL= 2	CARD TYPE 101
//DDFT15F001 DD #	
NV= 12 NS= 1	CARD TYPE 100
//DDFT05F001 DD #	

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Output Description

The output from STP can be divided into five categories. First, there is a reproduction of the input data deck. Second, the parameters for the run are detailed. Third, the data for the particular case within the run are detailed. Fourth, the data for the time interval within the case are given. Included are source and component descriptions and the flows associated with them. Fifth, the results are presented for the time interval. The third category is printed once for each case in a run and the last two categories are printed for each time interval in a case.

The input data deck reproduction is simply the printout of the card images used to input the STP run. An example of this is given in Figure 2. Note that the "+" at the top and bottom of the reproduction are in columns 1, 11, 21, etc. This is to aid the user in verifying that the parameters that are not in free form input are in the proper columns.

The run parameters are then printed. Basically this consists of the data input on the 100 and 101 cards. Also appearing in this part is the run date and start time for the run. Finally, the amount of storage used for the run is given.

The case data are printed in up to four parts. The first part is the nuclide data input (card 102) or isotope library for the case. This consists of the isotope number (i), name, class (k), decay constant (λ_i), precursor (ii), and production rate of i from ii ($\gamma_{ii \rightarrow i}$) for each precursor up to the maximum number of precursors. Next, if NG > 0 (card 101), the effective gamma ray energy for each energy group and the gamma ray energies per disintegration for each energy group in MeV/Dis/group is output for each isotope.

The next output page shows the run loop information for the case being run. Then the source library is output. This includes the sources input in cards 120, 121, and 122 as well as those generated by a key letter "N" card.

The next part of the output gives the input data for a time interval. The first page(s) gives the time step, the delta t, and the information input on the key letter cards for the time interval. The next page gives the source term information for the time interval.

Finally, the results for the time interval are output. The first part gives the activities for each isotope in each component of the model. Also given are the totals for each class and the grand total of all the activities. Next, if NG > 0 the STP gamma shielding information is output for each component of the model for which the total activity is non-zero. The beta source and energy source are printed with units of (MeV/s/_) where the "_" represents the

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unit input with key letter card "G". Note that STP calculates these based on the activities being in μCi unless modified. The energy source is given for each energy group input in card 110. The particle source for each energy group, obtained by dividing the energy spectrum by the corresponding group energy, is also printed, with units of (photon/s/_)

The output for the next time interval is printed until all time intervals for a case have been output. Then the next case is output with all of its time intervals until there are no more cases in the run.

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Appendix A

If there are only one or two components an analytical solution can usually be determined. However, use of an analytical solution is not practical when handling complex systems with longer decay chains, feedback loops, and/or large numbers of components. In these cases a difference scheme is required. However, most numerical solutions have a major fault: they are stable only for values of $\alpha = \Lambda \Delta t$ less than 1 or 2. While this may frequently be true, it will not apply to all materials in all components of a system. The result is either an unstable or highly inaccurate solution.

The basis of the integration scheme employed in STP is the expansion of $P_{ij}(t)$ in equation (1) in a Taylor series. Thus, one can write

$$P(t) \approx P(0) + \Delta t P' + \frac{(\Delta t)^2}{2!} P'' + \frac{(\Delta t)^3}{3!} P''' \quad (A1)$$

where Δt is the time element, the primes denote the time derivative at $t=0$, and the subscripts ij have been dropped for clarity. The equation (1) becomes:

$$\frac{dA}{dt} \approx -\Lambda A + P(0) + \Delta t P' + \frac{(\Delta t)^2}{2!} P'' + \frac{(\Delta t)^3}{3!} P''' \quad (A2)$$

This nonhomogeneous differential equation has as its general solution

$A_t = C_t e^{-\Lambda t}$. For the particular solution choose

$$A_p = C_0 + C_1 t + C_2 t^2 + C_3 t^3.$$

Differentiating A_p and substituting into equation (A2).

$$C_1 + 2C_2 t + 3C_3 t^2 = -\Lambda C_0 - \Lambda C_1 t - \Lambda C_2 t^2 - \Lambda C_3 t^3$$

$$+ P(0) + \Delta t P' + \frac{(\Delta t)^2}{2!} P'' + \frac{(\Delta t)^3}{3!} P''' \quad (A3)$$

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Since one evaluates the derivative at the end of the time increment and for each increment the initial time is zero, one can equate t and Δt . Collecting terms one obtains:

$$P(0) - \Lambda C_0 - C_1 = 0 \quad (A4a)$$

$$P' - \Lambda C_1 - 2C_2 = 0 \quad (A4b)$$

$$\frac{P''}{2} - \Lambda C_2 - 3C_3 = 0 \quad (A4c)$$

$$\frac{P'''}{6} - \Lambda C_3 = 0 \quad (A4d)$$

then

$$C_3 = \frac{P'''}{6\Lambda} \quad (A5a)$$

$$C_2 = \frac{P''}{2\Lambda} - \frac{P'''}{2\Lambda^2} = \frac{1}{2\Lambda} \left(P'' - \frac{P'''}{\Lambda} \right) \quad (A5b)$$

$$C_1 = \frac{1}{\Lambda} \left(P' - \frac{P''}{\Lambda} + \frac{P'''}{\Lambda^2} \right) \quad (A5c)$$

$$C_0 = \frac{1}{\Lambda} \left(P(0) - \frac{P'}{\Lambda} + \frac{P''}{\Lambda^2} - \frac{P'''}{\Lambda^3} \right) \quad (A5d)$$

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The full solution is the sum of the general and particular solutions:

$$\begin{aligned}
 A &= C_1 e^{-\Lambda t} + \frac{P(0)}{\Lambda} - \frac{P'}{\Lambda^2} + \frac{P''}{\Lambda^3} - \frac{P'''}{\Lambda^4} + \frac{tP'}{\Lambda} - \frac{tP''}{\Lambda^2} + \frac{tP'''}{\Lambda^3} \\
 &\quad + \frac{t^2 P''}{2\Lambda} - \frac{t^2 P'''}{2\Lambda^2} + \frac{t^3 P'''}{6\Lambda} \\
 &= C_1 e^{-\Lambda t} + \frac{P(0)}{\Lambda} + \frac{P'}{\Lambda} \left(t - \frac{1}{\Lambda} \right) + \frac{P''}{\Lambda} \left(\frac{t^2}{2} - \frac{t}{\Lambda} + \frac{1}{\Lambda^2} \right) \\
 &\quad + \frac{P'''}{\Lambda} \left(\frac{t^3}{6} - \frac{t^2}{2\Lambda} + \frac{t}{\Lambda^2} - \frac{1}{\Lambda^3} \right)
 \end{aligned} \tag{A6}$$

at $t=0$, $A = A_0$ then

$$C_1 = A_0 - \frac{P(0)}{\Lambda} + \frac{P'}{\Lambda^2} - \frac{P''}{\Lambda^3} + \frac{P'''}{\Lambda^4}$$

and

$$\begin{aligned}
 A &= A_0 e^{-\Lambda t} + \frac{P(0)}{\Lambda} (1 - e^{-\Lambda t}) + \frac{P'(0)}{\Lambda} \left(t - \frac{1}{\Lambda} (1 - e^{-\Lambda t}) \right) \\
 &\quad + \frac{P''(0)}{\Lambda} \left(\frac{t^2}{2} - \frac{t}{\Lambda} + \frac{1}{\Lambda^2} (1 - e^{-\Lambda t}) \right) \\
 &\quad + \frac{P'''(0)}{\Lambda} \left(\frac{t^3}{6} - \frac{t^2}{2\Lambda} + \frac{t}{\Lambda^2} - \frac{1}{\Lambda^3} (1 - e^{-\Lambda t}) \right)
 \end{aligned} \tag{A7}$$

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Using central difference formulation

$$P'(0) = \frac{P(0+\Delta t) - P(0-\Delta t)}{2\Delta t} = \frac{P(t) - P(-t)}{2t}$$

$$P''(0) = \frac{P(0+\Delta t) - 2P(0) + P(0-\Delta t)}{(\Delta t)^2} = \frac{P(t) - 2P(0) + P(-t)}{t^2}$$

where the same correspondence between t and Δt above was used. Substituting into equation (A7).

$$\begin{aligned} A = & A_0 e^{-\Lambda t} + \frac{P(0)}{\Lambda} \left((1 - e^{-\Lambda t}) - \frac{2}{t^2} \left(\frac{t^2}{2} - \frac{t}{\Lambda} + \frac{1}{\Lambda^2} (1 - e^{-\Lambda t}) \right) \right) \\ & + \frac{P(t)}{\Lambda} \left(\frac{1}{2} - \frac{1}{2\Lambda t} (1 - e^{-\Lambda t}) + \frac{1}{t^2} \left(\frac{t^2}{2} - \frac{t}{\Lambda} + \frac{1}{\Lambda^2} (1 - e^{-\Lambda t}) \right) \right) \\ & + \frac{P(-t)}{\Lambda} \left(\frac{1}{2\Lambda t} (1 - e^{-\Lambda t}) - \frac{1}{2} + \frac{1}{t^2} \left(\frac{t^2}{2} - \frac{t}{\Lambda} + \frac{1}{\Lambda^2} (1 - e^{-\Lambda t}) \right) \right) \\ & + \frac{P'''(0)}{\Lambda} \left(\frac{t^3}{6} - \frac{t^2}{2\Lambda} + \frac{t}{\Lambda^2} - \frac{1}{\Lambda^3} (1 - e^{-\Lambda t}) \right) \end{aligned} \quad (A8)$$

If the last term is dropped the error will only be

$$E \cong P'''(0) \left(\frac{t^4}{24} \right) .$$

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Then

$$\begin{aligned}
 A = & A_0 e^{-\Lambda t} + \frac{P(0)}{\Lambda} \left((1 - e^{-\Lambda t}) - \frac{2}{t^2} \left(\frac{t^2}{2} - \frac{t}{\Lambda} + \frac{1}{\Lambda^2} (1 - e^{-\Lambda t}) \right) \right) \\
 & + \frac{P(t)}{\Lambda} \left(\frac{1}{2} - \frac{1}{2\Lambda t} (1 - e^{-\Lambda t}) + \frac{1}{t^2} \left(\frac{t^2}{2} - \frac{t}{\Lambda} + \frac{1}{\Lambda^2} (1 - e^{-\Lambda t}) \right) \right) \quad (A9) \\
 & + \frac{P(-t)}{\Lambda} \left(\frac{1}{2\Lambda t} (1 - e^{-\Lambda t}) - \frac{1}{2} + \frac{1}{t^2} \left(\frac{t^2}{2} - \frac{t}{\Lambda} + \frac{1}{\Lambda^2} (1 - e^{-\Lambda t}) \right) \right)
 \end{aligned}$$

Note that the activity (of material i in component j) depends on the production evaluated at the current time step ($P(0)$), the preceding time step ($P(-t)$), and the next succeeding time step ($P(t)$). It is clear that $P(0)$ is known, and so is $P(-t)$ except at the initial point. It remains to be shown that $P(t)$ can also be determined.

From equation (3) one sees that P_{ij} is composed of a flow from outside the system into component j, a flow from another component into component j, and radioactive decay to material i within component j. The flow from outside the system into component j is known and is constant over the time interval, hence $P_{ij}^{(1)}(t)$ is known. In the absence of feedback loops within the system it is possible to order the components such that the flow out of the preceding component(s) is known. Equation (8) shows that the flow into component j is proportional to the flow out of the preceding component(s). Since this has already been calculated $P_{ij}^{(2)}(t)$ is known. The production in the next time step due to radioactive decay depends only on the material present in component j in the present time step. Since this quantity is already calculated $P_{ij}^{(3)}$ is known.

If feedback loops exist $P_{ij}^{(2)}$ is not necessarily known, thus requiring iteration. In order to form the initial estimate required for iteration, it is assumed that changes in the quantity of material in a component occur exponentially; decreases follow e^{-x} , and increases follow $1 - e^{-x}$. The latter is approximated by a straight line for simplicity. Thus for increasing P,

$$P(t) = 2P(0) - P(-t) \quad (A10a)$$

and, for decreasing P,

$$P(t) = P(0) * P(0) / P(-t) \quad (A10b)$$

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The activity in the component is then calculated according to equation (A9). This is used to determine a new value for $P(t)$, etc., until the newly calculated activity agrees with the immediately preceding value to within $0.03/\text{NSTEP}$ percent. For the usual case in which $\text{NSTEP}=30$, this results in a fractional error of 10^{-3} percent.

It was pointed out above that for the initial point of a time interval only $P(0)$ is known, so that $P(-t)$ as well as $P(t)$ must be estimated. An iterative scheme similar to that above is used. First $P(t)$ is estimated from the appropriate expression of equation (A10), using the initial inventory in the component for $P(-t)$; then $P(-t)$ is estimated from expressions similar to equation (A10), in which $P(t)$ replaces $P(-t)$.

It has been shown that the activity A can be calculated using equation (A9); however, as Δt becomes small, the result will become inaccurate.

Equation (A9) can be written as

$$A = G_4 A_0 + G_1 P(-t) + G_2 P(0) + G_3 P(t) \quad (\text{A11})$$

so that

$$G_1 = \frac{1}{\Lambda} \left(\frac{1}{2\Lambda t} (1 - e^{-\Lambda t}) - \frac{1}{2} + \frac{1}{2} - \frac{1}{\Lambda t} + \frac{1}{\Lambda^2 t^2} (1 - e^{-\Lambda t}) \right) \quad (\text{A12a})$$

$$G_2 = \frac{1}{\Lambda} \left((1 - e^{-\Lambda t}) - 1 + \frac{2}{\Lambda t} - \frac{2}{\Lambda^2 t^2} (1 - e^{-\Lambda t}) \right) \quad (\text{A12b})$$

$$G_3 = \frac{1}{\Lambda} \left(\frac{1}{2} - \frac{1}{2\Lambda t} (1 - e^{-\Lambda t}) + \frac{1}{2} - \frac{1}{\Lambda t} + \frac{1}{\Lambda^2 t^2} (1 - e^{-\Lambda t}) \right) \quad (\text{12c})$$

$$G_4 = e^{-\Lambda t} \quad (\text{A12d})$$

It can easily be seen that as Δt approaches zero G_1 , G_2 , and G_3 approach infinity. Therefore, an expansion of $e^{-\Lambda t}$ is substituted in these expressions

$$G_1 = t \left(-\frac{1}{12} + \frac{\Lambda t}{24} - \frac{(\Lambda t)^2}{80} + \frac{(\Lambda t)^3}{360} - \frac{(\Lambda t)^4}{2016} \right) \quad (\text{A13a})$$

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$$G_2 = t \left(\frac{2}{3} - \frac{5\Delta t}{12} + \frac{3(\Delta t)^2}{20} - \frac{7(\Delta t)^3}{180} + \frac{(\Delta t)^4}{126} \right) \quad (A13b)$$

$$G_3 = t \left(\frac{5}{12} - \frac{\Delta t}{8} + \frac{7(\Delta t)^2}{240} - \frac{(\Delta t)^3}{180} + \frac{(\Delta t)^4}{1120} \right) \quad (A13c)$$

$$G_4 = t \left(1 - \Delta t + \frac{(\Delta t)^2}{2} - \frac{(\Delta t)^3}{6} + \frac{(\Delta t)^4}{24} - \frac{(\Delta t)^5}{120} \right) \quad (A13d)$$

It can easily be shown that for $\Delta t = 0.1$, equations (A12) and (A13) are equivalent, however, for $\Delta t < 0.01$, the results differ in the third significant figure for G_1 . Therefore, a test is incorporated in the program such that equations (A12) are used unless Δt is 0.01 or less, in which case equations (A13) are used. This transfer point may be altered with variable CD of key letter I.

While the integration scheme described above is generally stable, it can generate negative answers for rapidly decreasing P. It has been assumed that P decreases exponentially; then

$$\frac{P(0)}{P(-t)} = \frac{P(t)}{P(0)} = \text{const} < 1.$$

From equations (A11) and (A13) for $\Delta t = 0$,

$$A = A_0 - \frac{t}{12} P(-t) + \frac{2t}{3} P(0) + \frac{5t}{12} P(t) \quad (A14)$$

But $P(0) = cP(-t)$, and $P(t) = c^2P(-t)$, so

$$A = A_0 + \frac{t}{12} P(-t) (-1 + 8c + 5c^2) \quad (A15)$$

For $c < 0.1165$ the term in parenthesis becomes negative, A may become negative depending on the values of A_0 , t and $P(-t)$, all of which must be positive. Note that c represents the fraction remaining at the end of each time step so that one is concerned with a production term which decreases by an order of magnitude or more in each time step.

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Having determined the behavior of the solution as the production term rapidly decreases, the behavior as the removal term rapidly increases will be considered. For $\Delta t \gg 0$, using the same scheme as above for equations (A11) and (A12)

$$A \cong \frac{P(-t)}{2\Lambda^2 t} (2\Lambda t c^2 - 3c^2 + 4c - 1) \quad (A16)$$

This expression will be positive for all values of c if Λt is large.

The preceding indicates that the desired solution may be drastically incorrect for small values of Λt if the production term decreases rapidly. To circumvent this, assume that P decreases exponentially

$$P(t) = P(0)e^{-\alpha t} \quad (A17)$$

Then, from equation (1)

$$\frac{dA}{dt} = -\Lambda A + P(0)e^{-\alpha t} \quad (A18)$$

From equation (A17), remembering that here t and Λt are equivalent,

$$\alpha = -\frac{1}{\Delta t} \ln\left(\frac{P(t)}{P(0)}\right) \quad (A19)$$

The solution to equation (A18) is

$$A = A_0 e^{-\Lambda t} + \frac{P(0)}{\Lambda - \alpha} [e^{-\alpha t} - e^{-\Lambda t}] \quad (A20)$$

In subroutine LAMINT $e^{-\Lambda t}$ is given by G_4 (equations (A12)), $P(0)$ is given by P_2 and $P(t)$ by

$$P_3. \quad \Lambda = -\frac{\ln(G_4)}{\Delta t} \quad \text{so that}$$

$$\frac{1}{\Lambda - \alpha} = -\frac{\Delta t}{\ln(G_4) - \ln\left(\frac{P_3}{P_2}\right)} = \frac{\Delta t}{\ln\left(\frac{P_3}{P_2 * G_4}\right)} = -\frac{\Delta t}{\ln\left(\frac{P_2 * G_4}{P_3}\right)}$$

from equation (A17)

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$$e^{-\alpha} = \frac{P_3}{P_2}$$

Therefore one can write equation (A20) as

$$A = G_4 * A_0 + \frac{P_2 * \Delta t}{\ln\left(\frac{G_4 * P_3}{P_2}\right)} \left[G_4 - \frac{P_3}{P_2}\right] \quad (A21)$$

The formulation of equation (A21) is invoked whenever the ratio P_3/P_2 is less than 0.9. This can be changed using the variable CA of key letter I. Note that using 0.9 implies that the production term drops by a factor of 25 over the time interval.

If the removal term is so large that over a time step $e^{-\Delta t}$ is less than $10^{-20} * P_3/P_2$, Δt is sufficiently large so that the special calculation of equation (A21) is not required. Again, this can be changed using the variable CB of key letter I.

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Appendix B

To avoid requiring unnecessarily large blocks of computer memory, STP uses variable dimensioning for most of its arrays. The total space allocated for these arrays is given in program MAIN and can be altered by changing two cards. It has been found that an allocation of 40000 8-byte words is adequate for most problems. The storage requirement can be calculated from

$$\begin{aligned} \text{NDATA} = & \text{NI} * (6 + \text{NG} + \text{MS} + 1.5 * \text{NL}) + \text{NI} * \text{NV} * \text{NDP} * 8 \\ & + \text{NV} * (14.5 + 2 * \text{NDP} + \text{NV} * \text{NK} * (\text{MS} + 4)) \\ & + \text{NV} * \text{NV} * (0.5 + 3 * \text{NK}) + \text{NG} * (1 + \text{NV}) \\ & + 2 * \text{NK} + 8 * \text{MS} + 7 \end{aligned} \quad (\text{B1})$$

where

NI = Number of isotopes
NV = Maximum number of components for the run
NK = Number of material classes
NL = Maximum allowed number of precursors
MS = Maximum number of sources for the run
NG = Number of energy groups in gamma information
NDP = 1 for single precision, 2 for double precision
(Single precision requires the user to make specific changes to the subroutines in the code)

The actual allocation of space is performed in subroutine SETTER. If the space required exceeds the space allocated (NDATA), the required number is printed and the program terminates.

The various subroutines and their functions in program STP are listed in Table B1. The common blocks in each routine and their contents are listed in Table B2.

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Table B1: Routines in Program STP

Routine	Function
MAIN	Dummy main program to establish common length
BDEFLT	Sets default values
SETTER	Sets array lengths after reading the first data card and then calls STP
HEADER	Writes headings to start program, headings for top of each page and headings for end of job
STP	Reads isotope data, initializes variables, sets up model, calculates the shielding sources and prints them
READER	Reads and sets up step data according to the key letters
WRITSO	Writes activities and initial and continuous sources
TIMEU	Converts to hours from any normal time units
LETTER	Takes a four-letter word and returns the first N letters
LAMINT	Solves the coupled differential equation set for activity transfer among coupled components and for sources due to decay of precursors
FUNRD	Free form input routine
MOV	Moves or clears an array

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**Table B2: Common Blocks and Their Distribution
in Program STP**

Routine	Common	Variables
MAIN	DATA	DUMMY (225001)
BDEFLT	BDEFLT	ITMAXD, NSTEPD, ERSTPD
	BC	CA, CB, CC, CD, CE, CF
SETTER	FUN	SBUFF1(20), IPAR(40), RPAR(40)
	BDEFLT	ITMAXD, NSTEPD, ERSTPD
	BNDATA	DEL, ER, VEND(25), NEWSJ(30), NEWSM(30), NDUM, NJ, NS, NG, KCONC, NDECAY, ITMAX, NSS, NSC, NEWS, NSTEP, ISUM, KVEND
	BSTUFF	HTITLE(10), HEAD(10) UNIT, LD(10)
	DATA	X(225001)
HEADER	TIME	ADATE, ANOW, MARK
	--	--
STP	FUN	SBUFF1(20), IPAR(40), RPAR(40)
	BDEFLT	ITMAXD, NSTEPD, ERSTPD
	BNDATA	DEL, ER, VEND(25), NEWSJ(30), NEWSM(30), NDUM, NJ, NS, NG, KCONC, NDECAY, ITMAX, NSS, NSC, NEWS, NSTEP, ISUM, KVEND
	BUG	KDEBUG
	TIME	ADATE, ANOW, MARK

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Table B2 (Continued)

Routine	Common	Variables
READER	BC	CA, CB, CC, CD, CE, CF
	DATA	X(225001)
	BUG	KDEBUG
	BNDATA	DEL, ER, VEND(25), NEWSJ(30), NEWSM(30), NDUM, NJ, NS, NG, KCONC, NDECAY, ITMAX, NSS, NSC, NEWS, NSTEP, ISUM, KVEND
WRITSO	BSTUFF	HTITLE(10), HEAD(10) UNIT, LD(10)
TIMEU	--	--
LETTER	--	--
LAMINT	DATA	X(225001)
	TIME	ADATE, ANOW, MARK
	BUG	KDEBUG
	BNDATA	DEL, ER, VEND(25), NEWSJ(30), NEWSM(30), NDUM, NJ, NS, NG, KCONC, NDECAY, ITMAX, NSS, NSC, NEWS, NSTEP, ISUM, KVEND
	BSTUFF	HTITLE(10), HEAD(10) UNIT, LD(10)
	BC	CA, CB, CC, CD, CE, CF
FUNRD	FUN	SBUFF1(20), IPAR(40), RPAR(40)

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Table B2 (Continued)

Routine	Common	Variables
	INTRNL	REXP, FRACT, XNUMB, PART2, XIEC, PART1, IE, IP, IS, IPS, IWF, IXF, IEF, ISL1FIDF, ISLF, IER, ITF, IIF, IEND, ISFLAG, IAPF

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TABLE 2
General Input Requirements

VARIABLE		COLUMNS DESCRIPTION	
CARD TYPE	NAME		
100	NV	*	Maximum number of components for any case (Default: 5)
	MS	*	Maximum number of sources for any case (Default: 5)
	NI	*	Number of isotopes
	NK	*	Maximum number of classes (Default: 6)
	NG	*	Number of gamma ray groups (Default: 0)
102	NL	*	Maximum number of precursors allowed (Default: 1)
	I	1-4	Isotope identification number
	HEAD(I)	5-12	Isotope name
	KK(I)	13	Material class
	W(I)	14-24	Decay constant (sec ⁻¹)
	LL(I,1)	25-28	First precursor identification number
	GAMMA(I,1)	29-38	First precursor effective decay constant (sec ⁻¹)
	LL(I,2)	39-42	Second precursor identification number
	GAMMA(I,2)	43-52	Second precursor effective decay constant (sec ⁻¹)

*Denotes free form input

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TABLE 2 (cont'd)
General Input Requirements

VARIABLE		COLUMNS DESCRIPTION	
CARD TYPE	NAME		
110	LL(I,3)	53-56	Third precursor identification number
	GAMMA(I,3)	57-66	Third precursor effective decay constant (sec ⁻¹)
	LL(I,4)	67-70	Fourth precursor identification number
	GAMMA(I,4)	71-80	Fourth precursor effective decay constant (sec ⁻¹)
110	XG	*	Effective gamma ray energy for each group (required only if NG > 0)
111 First Card	I	1-4	Isotope identification number
	YG(I,1)	11-15	Total electron energy per disintegration (MeV/Dis)
	YG(I,2)	15-20 etc. by 5's	Gamma ray energy per disintegration for each group (MeV/Dis) (Required only if NG > 0)
	YG(I,15)	1-5 etc. by 5's	Gamma ray energy per disintegration for each group (MeV/Dis)
111 Succeeding Cards	YG(I,NG + 2)		Last Entry: Highest photon energy (MeV)
	M	*	Source identification number
	HSOR	*	Source identifying title (Max. 32 characters)

*Denotes free form input

TABLE 2 (cont'd)
General Input Requirements

CARD TYPE	VARIABLE NAME	COLUMNS DESCRIPTION
121	I	* Isotope identification number) Pairs as required
	S(I,M)	* Activity or quantity of material) Last entry must have an I of 0
122		* Enter the letter T
200	HTITLE	1-80 Title for this case
201	NJ	* Number of components used in this case
	KCONC	* KCONC = 0: Calculate activity (Act/Comp); otherwise calculate concentration(ACT/MASS or ACT/VOL) (Default: 0)
	NDECAY	* NDECAY = 1: Do not include decay as source of daughters; otherwise include decay (Default: 0)
	ITMAX	* Maximum number of iterations used by LAMINT (Default: 10)
	KDEBUD	* KDEBUG = 0: Normal output; KDEBUG # 0: Increased output for debugging (Default: 0)
202	J	* Component identification number (Must be $\leq$ NJ)
	HOL	* Component identifying title (Max. 32 characters)

*Denotes free form input

TABLE 2 (cont'd)
General Input Requirements

VARIABLE		COLUMNS DESCRIPTION
CARD TYPE	NAME	
300	TN	* Time at end of time interval (any common units)
	ITU	* Units in which time is specified
	NSETP	* Number of increments into which time interval is divided (Default: 30)
	NPRINT	* NPRINT = 0: Print output for this time interval; NPRINT $\neq$ 0: See page 22 (Default: 0)
	KDEBUG	* KDEBUG = Debugging option for this and successive time intervals (Default: 0)
301	HEAD	1-80 Title of this time interval
302		Key letter cards. See Table 3

*Denotes free form input

TABLE 3
Key Letter Input Requirements

KEY LETTER	USED FOR	REQUIRED INPUT	COMMENTS
A	Accumulator	J	
B	Variable Volume	J Θ	Θ is volume (or mass) at end of time interval
C	Continuous Source	M J K Θ	Θ in units of mass (or volume)/hour
E	Exchange	J JJ K F α	F in units of volume (or mass)/hour
F	Flow Rate	J JJ K Θ	Θ in units of volume (or mass)/hour
G	Gamma Source Output Conversion	J Θ Units	Units alphanumeric, on first card only
I	New Parameters	CA CB CC CD CE CF	Do not use lightly
N	New Source	J M	
P	Punch	NPA NPP JA ₁ ...JA _{NPA}	Must be last key letter card for time interval
PF	Plate Out Factor	JP...JP _{NPF} J K Θ	
R	Removal Rate	J K Θ	Θ in units of hour ⁻¹
S	Step Source	M J K Θ	Θ in units of mass (or volume)
U	Shorthand Way for Filters	J JJ JJJ F f ₁ ...f _{NK}	F in units of volume (or mass)/hour
V	Component Volume (or mass)	J 0 Units	Units alphanumeric
X	Transmission Factor	J JJ K Θ	

Note for symbols in third column: First Letter J - Component Numbers; K - Class Number; M - Source Number;
 Θ - Value of Quantity; α - Equilibrium Constant

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5. QADSR MODULE

5.1 Description of QADSR Code

QADSR was written in Fortran (R) and compiled with Microsoft 5.1 version of Fortran Compiler. The following is a listing of the filenames used to build the executable file QADSR.EXE:

BLKDAT.FOR
BUILD.FOR
LENGTH.FOR
INPUTGP.FOR
GEOMIN.FOR
IHUNT.FOR
KERNELGP.FOR
LITEBF.FOR
BUFACT.FOR
READBF.FOR
READX.FOR
SETP.FOR
SHIFT.FOR
TERPU.FOR
SPHGEO.FOR
TTRACE.FOR
TAD.FOR
CYLGEO.FOR
XSECQD.FOR
QADHEADR.FOR
TITLE.FOR
SOURCE.FOR
PRINT.FOR
BOXGEO.FOR
GENGEO.FOR
MAIN.FOR

5.2 Compiler Options Used to Make QADSR.EXE

FL /FPi87 /G2 /AH /c *.FOR /FeQADSR *.OBJ /link

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5.3 Source Code Listing

The source code listing is contained in Volume 2, Source Code Listing, Volume QADSR.

5.4 Documentation for QADSR

See Annex 5

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Annex 5

QAD - P5Z

User's Manual

by

**Walter Zobel
William M. Bennett
Robert L. Sanders**

December, 1992

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Disclaimer

Program Name QAD-P5Z (PC) Version 1.0

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December, 1992

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QAD-P5Z

ABSTRACT

QAD-P5Z is a version of the QAD-P5F code with the neutron and gamma heating portion of the code removed. Also, the buildup factor was changed to make use of several different approximations instead of the polynomial fit. For ease of use with many frequently occurring configurations, the input was made similar to that used in the SDC code, CCC-60, and six "standard" configurations were included.

The QAD-P5Z program provides an estimate of uncollided gamma flux, dose rate, and other quantities which result from a point-by-point representation of a volume-distributed source of radiation, i.e., through the point kernel method. This method involves representing the source by a number of point isotropic sources and computing the distances through all regions traversed by the line-of-sight from the source points to a desired dose point (or "receiver point"). Energy-dependent attenuation factors are applied to the distances through the regions based on the characteristics of the materials within them. After application of a flux-to-dose conversion factor, desired responses to the individual source points are summed by source-energy groups and recorded.

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THE QAD-P5Z PROGRAM

I. INTRODUCTION

QAD has been subject to a series of changes, additions, and revisions since its first application in April 1961. In order to avoid excessive confusion, the designation QAD has been employed in a generic sense with individual modifications designated by postscripts added to the generic term. The original version, QAD IV, was modified by Aerojet General Corporation to accept FASTER geometry and became QAD-P5F. This version served as the starting point for QAD-P5Z.

In changing QAD-P5F to QAD-P5Z, all information concerning neutrons was removed. The calculation of gamma heating was removed as well. Six library source-shield configurations were added to the QAD-P5Z code to simplify input for frequently occurring situations.

The QAD-P5Z program provides an estimate of uncollided gamma flux, dose rate, and other quantities which result from a point-by-point representation of a volume-distributed source of radiation, i.e., through the point kernel method. This method involves representing the source by a number of point isotropic sources and computing the distances through all regions traversed by the line-of-sight from the source points to a desired dose point (also called "detector" or "receiver" point). Energy-dependent attenuation factors are applied to the distances through the regions based on the characteristics of the materials within them. After application of a flux-to-dose conversion factor, desired responses to the individual source points are summed by source-energy groups and recorded.

II. GENERAL DESCRIPTIONS

The point kernel methodology employed by QAD-P5Z evaluates the attenuation of gamma-rays in passing through various regions along a ray from a "source point" to a "detector point." The regions are defined by quadratic surfaces and may consist of the same or different materials. The gamma-rays are characterized by an energy spectrum, i.e., the number of photons at various discrete energies.

Only one region may contain the gamma-ray source. This region must be either a rectangular parallelepiped with the faces perpendicular to the coordinate axes, or a cylinder with its axis along a coordinate axis, or a sphere with its center at the origin of the coordinate system. The source region is divided into a number of small source volumes, each containing a gamma-ray source of a strength proportional to its size. A "source point" is the geometric center of a source volume; it is at this point that the total source contained in the source volume is assumed to be concentrated.

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To arrive at the dose rate at a "detector point," the code determines the distance (in "mean free paths," the geometric length times the attenuation coefficient) along the ray joining the source point and the detector point for each region traversed by the ray and for each photon energy, uses this distance to arrive at the gamma attenuation, multiplies by a buildup factor to account for scattering and by an additional factor to convert from photon flux to dose, and sums over all source volumes and all photon energies.

As presently constituted, the code can accept up to 50 surfaces, 50 regions, 5 materials, and 30 energy groups. For the convenience of the user, a library of attenuation coefficients and buildup factors for seven commonly used materials is provided. A table of flux-to-tissue dose conversion factors is also built in.

For convenience, the code was modified such that it will generate the geometry input for six standard source-shield configurations. The six configurations are: a slab with a shield parallel with a face, a cylinder or an annular cylinder with a slab shield either parallel or perpendicular to its axis, and a sphere with a slab shield. For historical reasons, the input to the code for these configurations has been changed to resemble that of the SDC code (see Reference 3). For shielding problems that do not conform to one of these standard geometries, the option of user input of the FASTER geometry has been retained.

An exact indication of the running time for a general problem cannot be set down, because the time consumed depends on the care used in preparation of the input (which, to some extent, is a function of familiarity with the program) and the number of intersections of the various source-receiver lines with the surfaces defining the geometry. A typical problem requires about 0.015 seconds per source point per receiver point on the IBM 3084, with no readily observable dependence on the number of materials and energy groups.

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III. GAMMA KERNEL

For each source energy group, i , the gamma ray dose rate is computed as a point kernel numerically integrated throughout the source region:

$$D_{ui} = \sum_{l=1}^L \sum_{m=1}^M \sum_{n=1}^N \frac{E_i K_i S_{l,m,n}}{4\pi \rho_{l,m,n}^2} e^{-X_i} \quad (1)$$

The terms in Equation 1 have the definitions:

D_{ui}	= detector response without buildup (uncollided flux for energy group i)
K_i	= a flux-to-dose conversion factor
E_i	= source strength of the i th energy group
$S_{l,m,n}$	= the volume fraction associated with the (l,m,n) source point
$\rho_{l,m,n}$	= the distance from the (l,m,n) source point to the detector point
X_i	= the distance from the (l,m,n) source point to the detector point in mean-free-paths

Also,

$$D_{Bi} = D_{ui} * B_i \quad (2)$$

where

B_i	= the build-up factor
D_{Bi}	= detector response with buildup (total flux for energy group)

A consistent set of units must be employed. The units of the result are given by the product of those of E and K divided by distance squared.

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In QAD-P5Z, the source (E) is in photon/sec and the conversion factor (K) is in (rem/hr)/(photons/cm²-s). See Table 3 in Appendix A for values of K.

Berger's Formula is used to estimate the buildup factor. The coefficients for the library materials available are built into a subroutine. The Berger's Formula used in QAD-P5Z is

$$B = B_0 + B_1 \mu \rho_{1,n,n} e^{B_2 \mu \rho_{1,n,n}} \quad (3)$$

where

$$B_0 = 1.00$$

$$B = \text{build-up factor}$$

$$\mu = \text{attenuation coefficient}$$

$$B_1 = C, \text{ see Appendix F}$$

$$B_2 = D, \text{ see Appendix F}$$

IV. QAD-P5Z GEOMETRY

The code builds geometric bodies, i.e., boxes, cylinders, spheres, etc., from the combination of quadric surfaces. A quadric surface is defined through a second order equation.

A. Quadric Surfaces

The general quadric equation for a specified surface i is:

$$\begin{aligned} u_i(\vec{r}) = & a_{0,i} + a_{1,i}x + a_{2,i}y + a_{3,i}z \\ & + a_{4,i}x^2 + a_{5,i}y^2 + a_{6,i}z^2 \\ & + a_{7,i}xy + a_{8,i}yz + a_{9,i}zx \end{aligned} \quad (4)$$

where $a_{i,j}$, $i = 0, 1, 2, \dots, 9$ are constants,

$$\vec{r} = x\vec{i} + y\vec{j} + z\vec{k} \quad (5)$$

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x, y, z are rectangular coordinates, and $\vec{i}, \vec{j}, \vec{k}$ are unit vectors parallel to the x -, y -, and z - axes, respectively. The value of this equation, $u(\vec{r})$, is zero for points r on the surface.

These surfaces are described independently of the regions which define the material distributions to eliminate redundant input. Provision has been made in the program for recognizing more simple surfaces such as planes, cones, elliptical cylinders and ellipsoids. The equations for these simple surfaces are expanded by subroutine GEOMIN to obtain the coefficients of the general equation above. These special surfaces are shown in Figures 11, 12, and 13 and the equations are tabulated in Table VIII.1 of the QAD-P5Z Input Section.

For the six standard geometries described in Section II, General Descriptions, the code internally calculates the parameters required to describe the surfaces.

B. Surface Calculations

Since surfaces are described independent of geometric regions, it is possible to define several quantities which are used in geometric calculations. For this discussion, the following are defined:

$\vec{r} = (x, y, z)$, the position vector of any point in space

$\vec{\Omega} = (\alpha, \beta, \gamma)$, a unit vector defining the direction of a straight line, or ray, emanating from r , where α, β, γ are direction cosines with respect to the x, y , and z axes, respectively.

$s, 0 \leq s < \infty$ the scalar distance from r along $\vec{\Omega}$

$\vec{r}' = \vec{r} + s\vec{\Omega}$ a point on the ray
 $= (x + \alpha s, y + \beta s, z + \gamma s)$

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1. Intersection of a Line and a Surface

The value of the quadric equation at $\vec{r}'$ is given by:

$$u_1(\vec{r}') = u_1(\vec{r}) + 2s v_1(\vec{r}, \vec{\Omega}) + s^2 w_1(\vec{r}, \vec{\Omega}) \quad (6)$$

where $u_1(\vec{r})$ is given by equation 4 above and $v_1(\vec{r}, \vec{\Omega})$ and $w_1(\vec{r}, \vec{\Omega})$ are obtained by expanding this equation for $\vec{r}'$, and collecting the coefficients of s and s^2 :

$$\begin{aligned} v_1(\vec{r}, \vec{\Omega}) = & \frac{1}{2} [\alpha a_{1,i} + \beta a_{2,i} + \gamma a_{3,i}] + \alpha x a_{4,i} + \beta y a_{5,i} + \gamma z a_{6,i} \\ & + \frac{1}{2} [(\alpha y + \beta x) a_{7,i} + (\beta z + \gamma y) a_{8,i} + (\gamma x + \alpha z) a_{9,i}] \end{aligned} \quad (7)$$

$$w_1(\vec{r}, \vec{\Omega}) = \alpha^2 a_{4,i} + \beta^2 a_{5,i} + \gamma^2 a_{6,i} + \alpha \beta a_{7,i} + \beta \gamma a_{8,i} + \gamma \alpha a_{9,i} \quad (8)$$

Intersections of the ray with the surface are obtained by requiring:

$u_1(\vec{r}') = 0$, i.e., this condition defines points on the surface using equation 6.

$$u_1(\vec{r}) + 2s_1 v_1(\vec{r}, \vec{\Omega}) + s_1^2 w_1(\vec{r}, \vec{\Omega})$$

a) one intersection if $w_1(\vec{r}, \vec{\Omega}) = 0$, $v_1(\vec{r}, \vec{\Omega}) \neq 0$

$$s_1 = -u_1(\vec{r}) / 2v_1(\vec{r}, \vec{\Omega}) \quad (10)$$

b) two intersections if $w_1(\vec{r}, \vec{\Omega}) \neq 0$, $v_1^2(\vec{r}, \vec{\Omega}) > u_1(\vec{r}) w_1(\vec{r}, \vec{\Omega})$

$$s_{1,2} = \frac{-v_1(\vec{r}, \vec{\Omega}) \pm \sqrt{v_1^2(\vec{r}, \vec{\Omega}) - u_1(\vec{r}) w_1(\vec{r}, \vec{\Omega})}}{w_1(\vec{r}, \vec{\Omega})} \quad (11)$$

2. Surface Crossing

For rays that have multiple intersections with a surface, define an inner volume as all points inside the surface (value of equation 6 less than 0), and an outer volume as all points outside the surface (value of equation 6 greater than 0). If a ray crosses a surface going from an inner volume to an outer volume, the positive sign should be used in equation 11. Similarly, when crossing

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from the outer volume to the inner volume, the negative sign should be used in equation 11. The mathematical derivation of this process is given in reference 8, pages 45-48.

C. Regions

1. Region Boundaries

A combination of surfaces together with a point inside the region enclosed by the surfaces defines a region. The surfaces are each designated by a numerical index. The point inside the region, which is chosen arbitrarily, is used to calculate the "ambiguity index."

The ambiguity index determines on which side of the surface the region is located. To calculate the index, the coordinates of the point are substituted into equation 6. The sign of the negative of the result is the ambiguity index. If the index is negative, the region lies on one side of the surface, if positive on the other. The code remembers this designation by attaching the ambiguity index to the surface index in the description of the region.

2. Possible Region Description Errors

Restriction must be imposed on possible region shapes to ensure that all points in a region are always on the same side of each region boundary. For example, the single region indicated in Figure 1A is unacceptable since there are points which are inside cylinder A and outside cylinder B. The obvious solution is to use two regions to describe such geometric shapes.

It is sometimes necessary to introduce fictitious boundaries. Figure 1B shows a typical situation requiring these boundaries. Examination of the shaded and cross-hatched regions reveals that they form two sections of a single region since ambiguity indices of the boundaries have the same values for both sections. This condition can cause trouble if only one section of the region is desired, even if other regions occupy the second section. The specification of the fictitious boundary eliminates the problem without otherwise affecting the geometric calculations. These fictitious boundaries must be included in the initial surface descriptions.

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Figure 1. Problems in Region Descriptions

A. AMBIGUOUS REGION BOUNDARIES

B. DISJOINT REGIONS

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3. Standard Geometries

For the six standard geometries, the program calculates the required surfaces that delineate the appropriate configuration. For geometries that do not fit any of the standard geometries, the user must define the surfaces that make up the regions. Detailed instructions are given in the input section.

D. Ray Tracing

Multiple intersections with the surfaces of a zone may be mathematically possible (for the surfaces described by the equations may extend well beyond the zone), so a distance selection criterion is required. All such intersections behind the source on the source-receiver line are rejected by a sign test; if there are multiple intersections with the zone bounding surfaces in the direction of the receiver point, the distance to the nearest intersection (i.e., the smallest distance) is the one employed.

The coordinates are advanced along the ray from the source point to the receiver point by the distance calculated plus a small value, δ , which is added in an attempt to move the advanced coordinates beyond the boundary. See Figure 2 for an example. (If the point is still on a boundary, a so-called type 2 geometry error is indicated by a printout). A selected adjoining zone on the boundary of interest is then checked to ascertain if it indeed was the zone entered. If so, the program continues; if not, other zones are checked cyclically until the correct zone is located. If no zone satisfies the conditions, a type 1 geometry error is indicated and a "distance print" (described in the section on output) is produced. Assuming the correct zone is established, distances to its boundaries along the original direction are again computed, the coordinates advanced, and so forth. This process continues until the receiver point is reached.

When the receiver point has been reached, the distance calculation for this particular source point is likewise complete. If the receiver point is very close to a distance δ away from a boundary along a particular source-receiver path, a type 2 geometry error will occur. Type 2 geometry errors are extremely rare.

Upon determination of all the above distances, the products of the distances and attenuation coefficients for the various zones are summed. From this, and from the total source-receiver separation distance, the exponential attenuation, build-up factor, and geometrical attenuation are computed for each energy group.

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This process is continued until the contribution to this receiver point from all source points has been determined. After the application of energy-dependent flux-to-dose conversion factors, the results for each energy group and the total response, both with and without buildup, are recorded for output. The next receiver point is then treated in the same manner until all receivers have been computed.

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Figure 2. An Example of δ and ϵ

FUDGE (δ)

When the source and detector are connected, the computer adds FUDGE (10(-5)) in order to identify region 2, and then continue from that point (point x) to the next surface.

FUDGE defaults to 10(-5).

EPSLN (ϵ)

Determines to what accuracy the code will use in determining the distance to the surface or detector

EPSLN defaults to 10(-7)

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V. FIXED SOURCES

The technique used in describing the source geometry is general enough to permit the description of a variety of sources. QAD-P5Z can only handle one source per run. This source may be expressed in rectangular, cylindrical, or spherical geometry. The geometry for the source is superimposed over the various geometric regions. In all geometries, there are three spatial variables (v_1 , v_2 , v_3).

The source model used in describing the fixed model is based upon the point kernel methodology, in which the source is divided up into small elements, and the geometric center of the source element is used as the source point. If the user has chosen one of the six standard geometries, the code automatically calculates the source divisions. The number of source divisions on any axis must be less than 300. For one of the six standard geometries, the code will use no more than approximately 50,000 source elements.

A. Rectangular Geometry

The simplest geometry is that used for describing rectangular source volumes. The spatial variables (v_1 , v_2 , v_3) are the rectangular coordinates (x , y , z).

B. Cylindrical Geometry

The next geometry involves a cylinder parallel to the z -axis. The spatial variables are:

$$v_1 = r = \sqrt{x^2 + y^2}, \quad \text{the radius}$$

$$v_2 = z, \quad \text{the axial coordinate}$$

$$v_3 = \phi = \tan^{-1}(y/x), \quad \text{the azimuthal angle measured from the } x\text{-axis}$$

C. Spherical Geometry

The final geometry, useful in describing a source such as the hemi-spherical top of the containment shell, involves the spatial variables:

$$v_1 = \rho = \sqrt{x^2 + y^2 + z^2}, \quad \text{the radius}$$

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$v_2 = \phi = \tan^{-1} (y/x)$ the azimuthal angle measured from the
x-axis

$v_3 = \theta = \cos^{-1} (z/\rho)$, the polar angle measured from the
z-axis.

The relationships between the coordinate systems are indicated in Figure 3.

The user must exercise caution in defining the spatial variables. The source volume specified must not overlap non-source regions specified in the geometry region.

With the use of symmetry, efficiency can be increased by describing only a portion of the source. The calculated dose rate must then be multiplied by the inverse of the source fraction used. For example, if a detector is located at the side of a cylindrical source parallel to the center line, then only one side of the source has to be described and the resulting answer multiplied by two. For a slab source, only one quadrant needs to be modeled, as long as the detector is on the center line of the source, and the calculated answer must be multiplied by 4.

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Figure 3. Relationships Between Coordinate Systems

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VI. MATERIALS AND COMPOSITIONS

QAD-P5Z requires the mass attenuation coefficients and buildup factors as a function of energy for each material used. The materials are specified in the input (see Section VIII). A library of attenuation coefficients is provided in file FORT10. If the boundaries of the energy groups do not coincide with the points for which these data are given, the code interpolates to obtain the data. Parameters for materials not in the library may be read in at execution time; however, the code cannot perform interpolations for these data. Materials for which attenuation coefficients are to be read in must be specified by a material number less than 10. Attenuation factors for seven materials frequently required for nuclear plant calculations are calculated by the program. These materials are water, aluminum, iron, lead, uranium, ordinary concrete and air. Material numbers for these are listed in Section VIII. The composition of ordinary concrete (143lb/ft³) for which the program calculates the attenuation coefficients is listed in Table VI.1.

Table VI.1

Element	Weight %
H	0.004809
C	0.063714
O	0.503392
Mg	0.001057
Al	0.006111
Si	0.156704
S	0.004785
Ca	0.256055
Fe	0.003371

Since the materials in FORT10 are listed by atomic number, this precludes the use of H, He, Li, Be, B, C and N. Note, however, that nitrogen is used as a surrogate for air, so that material is really not lost. The materials that are contained in the library along with the corresponding information, the energies at which the attenuation coefficients are tabulated and the attenuation coefficients, are shown in Appendix E.

The code can handle up to ten materials but due to input limitations, only five materials, with one being air, may be used per problem.

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The user has the choice of selecting buildup factors calculated with a geometric progression fitting function (GP buildup factors) or Berger's approximation (Berger buildup factors). The Berger buildup coefficients are available only for the seven common materials listed above. Therefore, the user must make sure that another material is not used by the code to determine the buildup factor. Berger buildup factors are invoked by using material numbers 1 through 7; this implies that the user has to furnish attenuation coefficients for these materials. Berger buildup coefficients are given in Appendix F. GP buildup factors can be calculated for beryllium, boron, carbon, nitrogen, oxygen, sodium, magnesium, aluminum, silicon, phosphorus, sulphur, argon, potassium, calcium, iron, copper, molybdenum, tin, lanthanum, gadolinium, tungsten, lead, uranium, water, concrete and air. Parameters for calculating the buildup factors are taken from file FORT11 and are listed in Appendix G.***

In calculating the total distance from source point (l,m,n) to the detector point in mean-free-paths (X_i of equation 1 in section III), the code uses the following formula for calculating the distance:

$$X_i = \sum_{m_o=1}^{M_o} \sum_{h=1}^H \rho_h \theta_{m_o,h} \mu_{m_o,i}$$

where

ρ_h = the path length through the h^{th} region along the source-detector line

$\mu_{m_o,i}$ = the gamma attenuation coefficient of the m_o^{th} material for the i^{th} group

$\theta_{m_o,h}$ = the fractional density or absolute density of material m_o in region h depending upon the units of $\mu_{m_o,i}$.

VII. HINTS AND CAUTIONS

Facility with QAD is best gained through experience. However, in making the program available to many people, some common difficulties have been identified. Discussion of these might assist the potential user.

A. Geometry

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Most of the difficulties with the mechanics of the program occur in the geometrical representation of the system which is to be calculated.

1. Closed Surfaces

When sketching the geometry for a calculation, it is common to indicate only that portion of the surface touching the region one wishes to depict, whereas the program logic considers the entire surface, however extended in space. For example, consider the description of a cylinder with a hemispherical end cap as shown in cross section by the solid lines on Figure 4. There is a strong temptation to describe such a configuration as being to the right of Surface 1, inside Surface 2, and inside Surface 3. However, since the equation for Surface 3 is really that of a sphere, careful consideration will show that a region so described is only that cross-hatched on the figure. A proper description requires two regions: the first to the right of Surface 1, inside Surface 2, and to the left of Surface 4 and the second to the right of Surface 4 and inside of Surface 3. Note that Surface 2 is not listed as a bounding surface for Zone 2. This avoids another error, which can result from attempting to have more than two surfaces define a line in space. While one can sketch the point (in two dimensions) of the intersection of Surfaces 2, 3, and 4, the finite number of decimal places available for input and carried in the computer may make the intersection inexact. Thus, it is difficult to avoid a situation as depicted in the enlarged view in Figure 4, where the hatched region might be undefined and give rise to a type 2 geometry error.

2. Reflected Zones

Consider the geometry shown in cross section in Figure 5, which represents the attempt to define a cylinder with a conical cap. Both shaded regions have identical geometrical descriptions. The reflection can be circumvented by passing a boundary plane through the apex of the cone and using it as a surface of the zone.

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B. The Buildup Factor

A buildup factor may be considered as the ratio of the correct answer to a tentative result which is amenable to calculation. More formally, it is a multiplier for including the effects of scattered photons in a simple exponential kernel that would yield uncollided flux. QAD employs a single medium buildup factor which is functionally related to energy and the number of mean free paths between source and receiver point. It can be rigorously correct only when applied under the specific conditions for which the buildup factor was derived. No recipe for buildup factor selection exists which is applicable to all situations. This is taken into consideration in the QAD output by printing out results with and without buildup applied. Scrutiny of the two quantities will often lend insight into the applicability of the factor for the problem being considered.

It is stressed that QAD offers great flexibility and rigor in the geometrical sense, but relies heavily upon the user for understanding of the nuclear approximations. Increasing the geometric detail of a calculation does not necessarily improve the accuracy of the calculation.

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Figure 4. Cross Section of Cylinder with a Hemispherical End Cap

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Figure 5. Illustration of Reflected Zones

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VIII. QAD-P5Z INPUT

Geometry Input Description

QAD-P5Z requires as input for the geometry one of two types of input. The first type taken from QAD-P5F is a representation of the surfaces with the use of quadratic equations. Regions and bodies are described by listing the equations that bound the sides of the body. A point in the body is used by the code to determine the ambiguity indices for all of the surfaces. The source description is next given the starting point along with the number and size of the divisions for all the spatial variables. The location of the receiver points is last. The receiver points can be given in any of the three different coordinate systems.

The second geometry similar to SDC geometry input requires only simple dimensions to be given as input. However, at the current time only slabs with a shield on one side parallel with the face, cylinders with the shield at the top or side, spheres with a shield, and annular cylinders with the shield at the top or side can be modeled with this type of geometry. The code takes simple dimensions given as input and creates internally the above geometry type including the source description. The code uses one mean-free-path of the lowest source energy in the source medium as the basis for the source division. The program then places a detector at contact to the source volume outside of the clad and at equal divisions of the shield according to the number of detectors requested.

RADMODL Input Files

The main input file that is generated by the user for use with RADMODL is INFILE.DEF. RADMODL builds the QAD-P5Z input using this file and the output file GSPECTRA which is created by STP.

The first record (or "card") for each entry is a title card. The title card defines the room and the time step. The time has to be entered in the format found in the file GSPECTRA. Also, the room or volume name has to match exactly with the room or volume name found in GSPECTRA. RADMODL searches INFILE.DEF for this information in order to match the time step with the time step from GSPECTRA. RADMODL replaces this card with a Card 1 which it creates.

The second card for each entry specifies the geometry of the room, the source, materials, number of detectors, and the number of energy groups. The number of energy groups should be the same as specified in the STP model. The second card is

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the same as the Card 2 of the QAD-P5Z input which is described in the section Physical Card Input. Card 3 when required is also included.

RADMODL also needs the *SPECTRA card in order to determine where to insert the photon spectra from GSPECTRA. The *END card indicates to RADMODL that the next case follows. For the simple geometry cases the *SPECTRA card is placed right after the second card or the third card when present. Also, no additional cards are inserted between the *SPECTRA and the *END cards. However, for the general geometry cases additional input is required as described in the section Physical Card Input.

If the geometry of the source and room stopped changing as a function of time *LAST is used. *LAST indicates that the cards which follow in this time step are to be used for the time step in which the *LAST appears and for any time steps which follow. This command is entered in column 50 on the first card.

In addition to INFILE.DEF, the user must also provide a file containing the reference elevations for use with the post-processor. If the model type selected is liquid, the input file for use is QADLIQ.EL. The post-processor requires each volume name to begin in column 1, and each reference location needed to begin in column 20.

If the model type selected is air, the file needed is QADAIR.EL. Each volume name begins in column 1, and the height of that volume above the reference or nominal floor elevation begins in column 20. The reference elevation for use with the post-processor begins in column 30. This information is used in the graphic display by the post-processor.

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Physical Card Input

Card 1: (One record in length)

Columns: 1 - 72 Title of Case to be run.

Card 2: (One record in length)

Columns: 1 - 2 Geometry Classification (I2)

Geometry Type	Description
1-4	General Geometry
5	Rectangular parallelepiped with shield parallel to a face, Figure 6
6	Cylinder with a shield at the side, Figure 7
7	Cylinder with a shield at the end, Figure 8
8	Sphere, Figure 9
9-11	General Geometry (same as 1-4)
12	Cylindrical annulus with shield at the side, similar to Figure 7
13	Cylindrical annulus with shield at the end, similar to Figure 8

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Figure 6. Geometry Type 5

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Figure 7. Geometry Type 6

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Figure 8. Geometry Type 7

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Figure 9. Geometry Type 8

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Columns: 4 - 5 Shield Material (I2)

Material #	Material
11	Water
12	Aluminum
13	Iron
14	Lead
15	Uranium
16	Ordinary Concrete
17	Air

Columns: 6 - 7 Clad Material (I2)

The clad material can be a material other than one available in the library, but if the new material is chosen by the code to be the buildup material, erroneous results or errors will occur. Also, the cross sections for the materials, if other than one in the library, must be given after the energy group structure input.

Columns: 8 - 9 Source Material (I2),

Same note as for the Clad

Columns: 10 - 11 Fill Material (I2)

The fill material is placed in the center cylinder when a cylindrical annulus geometry configuration is used.

Columns: 14 - 18 Slab Width, in Units of Cm. (W) (F5.1)

The slab width is the width of the source for Geometry Type 5 (see Figure 6). For all other geometry types, this variable is meaningless.

Columns: 19 - 23 Shield Thickness, in Units of Cm. (T,) (F5.1)

For all non-general geometry configurations, this variable refers to the thickness of the shield (see Figures 6 - 9). If $T_s = 0.0$, the shield material is set to void.

For general geometry configurations, this variable is used in determining the choice of buildup material. This variable along with R_s and clad thickness T_c (to be defined later) are used in determining the buildup factor material for each detector in the following manner:

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- (1) The source material is assigned as the buildup medium.
- (2) If the clad thickness is greater than three mean free paths of the highest energy group, the clad material is assigned as the buildup medium.
- (3) If the shield thickness is greater than three mean free paths of the highest energy group, the shield material is assigned as the buildup medium. If there is more than one detector, the three mfp's comparison is performed on the shield thickness multiplied by x/n , where x = current detector number, and n = total number of detectors. This is because the shield thickness is divided by the number of detectors to determine the shield divisions for each detector.

So by putting an excessively large number in for one of the three variables and a small number for the other two, the user can choose the buildup medium.

Columns: 24 - 28 Distance from the Clad to the Shield, in Units of Cm. (Z)(F5.1)

For geometry types 5, 6, 7, 8, 12, and 13, this variable is the shortest distance between the clad and the shield (see Figures 6-9).*

Columns: 29 - 33 Distance from the Shield to the Detector, in Units of Cm. (DD) (F5.1)

For geometry types 5, 6, 7, 8, 12 and 13, this variable is the distance from the shield to the detector (see Figures 6-9).*

Columns: 34 - 38 Length of the source, in Units of Cm. (H_L) (F5.1)

For geometry types 5, 6, 7, 12 and 13, this variable is the height or length of the source (see Figures 6-9).* For Geometry Type 8, this variable is set equal to zero.

Columns: 39 - 43 Height of Detector, in Units of Cm. (H_i) (F5.1)

For general geometry types refer to note under Shield Thickness.

If the geometry type is 7 or 13 and H_i is zero, then H_i is set equal to $H_L + T_s + Z + DD$.

*For all other geometry types, these variables are meaningless.

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If H_i is equal to zero, then for all other geometry types H_i is set equal to half of H_L .

If H_i is not zero, then the detector height is taken from the bottom of the source.

For general geometry configuration, H_i is meaningless.

Columns: 44 - 48 Radius or Depth of the Source, in Units of Cm.
(R_s) (F5.1).

For all non-general geometry types, refer to Figures 6-9 for an exact definition of this dimension.

Columns: 49 - 53 Displacement Distance in Units of cm. (Disp) (F5.1)

This variable refers to the detector offset. See Figures 6-9 for use of Disp.

For general geometry configurations, Disp is meaningless.

Columns: 54 - 58 Clad Thickness, in Units of Cm. (T_c) (F5.3)

T_c defines the thickness of the Clad. Refer to Figures 6 - 9 for examples. If $T_c = 0.0$, the clad material is set to void.

For general geometry types refer to note under Shield Thickness.

Columns: 61 - 62 Number of Detectors (I2)

The maximum number of detectors is 99. For simple geometries, the number of detectors refers to the number of divisions the shield is to be divided into for dose rate calculations (defaults to 4).

Columns: 63 - 64 Number of Energy Groups (I2)

The maximum number of energy groups is 30.

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Column: 65

Vary (I1)

Vary refers to the information that is kept from the previous problem when several calculations are run in one job step. For the first calculation, VARY always has to be 0. The following defines the values of VARY (see also Figure 10).

VARY

EQ 1, 3, 5, 7	repeat energy group structure
GE 2	repeat geometry
EQ 4, 5, 8	repeat detector points
GE 6	repeat source descriptions

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Figure 10. Effects of Vary

Do Not Vary

Vary	Parameters Repeated From Previous Case			
	Photon Spectra	Geometry	Detector Pts	Source Desc
0				
1
2
3
4
5
6
7
8
9

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Column: 68 ITAPE (I1)

If ITAPE is not zero or blank, punched output will be produced. The punched output is written to unit 1.

Column: 70 RD-3 (I1)

If RD-3 is greater than zero, the code will read Card Number 3. RD-3 must be greater than zero for Geometry Types 12 and 13.

Column: 72 KDEBUG (I1)

Prints out additional information depending on whether KDEBUG = 0 (default), 1, 2, or 3. The higher values cause progressively more information to be printed.

Card 3: (One record in length)

Columns: 9 - 16 Volume in Units of cc (V) (D8.4)

If the source strength is in photons/see and the exact volume of the source is known, and it is not the volume of the box, cylinder, or spherical source model, then it should be placed here.

Columns: 17 - 20 FACTV, No Units (F4.3)

This factor modifies the attenuation in the source medium, which may be used to take into account density correction, material modification, etc. (defaults to 1).

Columns: 21 - 25 FACTC, No Units (F5.3)

This factor modifies the attenuation in the clad medium; however, if the clad medium is zero, then FACTC will modify the shield medium (defaults to 1).

Columns: 26 - 30 FACTS, No Units (F5.3)

This factor modifies the attenuation in the shield medium (defaults to 1).

Columns: 31 - 40 FUDGE (δ), No Units (D10.2)

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See the write up on δ in the geometry section. If δ is 0.0, then the variable defaults to 1.0×10^5 .

Columns: 41 - 50 EPSLN (ϵ), No Units (D10.2)

See the write up on ϵ in the geometry section. If ϵ is 0.0, then the variable defaults to 1.0×10^7 .

Columns: 52 - 56 RMIN in Units of Cm (F5.1)

This is the inner radius of a Geometry Type 12 or 13 cylindrical annulus.

Columns: 66 - 72 UNITSC, No Units (D7.3)

UNITSC must be non-zero if the source is in any units except photons/sec. In the case where the source is not in units of photons/sec, UNITSC must convert the units of the source over to photons/sec/cc. If the source is in units of photons/sec/cc, then UNITSC should equal 1.0.

General Geometry Input

If general geometry was chosen, i.e., geometry type equal to 1, 2, 3, 4, 9, 10 or 11, then the geometry input is placed here. If the geometry type was 5, 6, 7, 8, 12 or 13 skip to Card 4 - Energy Group Structure.

Card G1, Input Controls for General Geometry Data

NOTE: This card is always required.

Column	Format	Symbol	Definition
1-3	I3	IN1	Dummy
4-6	I3	IN2	Input control for Card G2 (surfaces). Omit Card G2 if $IN2 \leq 0$. Supply IN2 physical cards if $IN2 \geq 1$, i.e., IN2 surfaces will be described, maximum of 200.
7-9	I3	IN3	Input control for Card G3 (regions). Omit Card G3 if $IN3 \leq 0$. Supply IN3 physical cards if $IN3 \geq 1$, i.e., IN3 regions will be described, maximum of 200.

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9-72	21I3	---	These columns are not used and should be left blank.
73-80	2A4	---	Any desired information for card identification.

Card G2, Surface Description

- NOTE:**
- a) Omit this card if $IN2 \leq 0$.
 - b) Supply $IN2$ physical cards if $IN2 \geq 1$.

Column Format Symbol Definition

1-3	I3	J	Index of the surface being described.
4-6	I3	NTP(L)	Index (j) of the last non-zero coefficient if the surface is in the expanded form; calculated internally for all other surfaces.
7-9	I3	NEX	Form (n_s) of the surface as input. 0, already in expanded form. $1 \leq NEX \leq 13$, special form as indicated in Figures 11, 12, 13 and Table VIII.1.
10-18	E9.0	A(1)	First parameter defining the surface.
19-27	E9.0	A(2)	Second parameter defining the surface.
		.	.
		.	.
		.	.
64-72	E9.0	A(7)	Seventh parameter defining the surface.
73-80	2A4	H	Any desired information for card identification.

The requisite parameters are listed in the last column of Table VIII.1 and are input in the order shown. If the surface is in the expanded form and rotational terms are involved, supply these on Card G2', before supplying Card G2 for the next input surface.

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Card G2', Rotated Surface Equation Terms

NOTE: a) Supply this card as required to finish the description of a surface, omit otherwise

Column	Format	Symbol	Definition
1-9	E9.0	A(8)	Eighth parameter defining the surface.
10-18	E9.0	A(9)	Ninth parameter defining the surface.
		.	.
		.	.
		.	.
63-72	E9.0	A(15)	Fifteenth parameter defining the surface.
73-80	2A4	H	Any desired information for card identification.

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Figure 11. Plane Surfaces

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Figure 12. Conical Surface

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Figure 13. Elliptical Cylinders and Ellipsoids

Table VIII.1
Special Surface Equations

Surface Type	Surface Equation	Last Term	Type n_i	Input
quadric	$a_0 + a_1x + a_2y + a_3z + a_4x^2 + a_5y^2 + a_6z^2 + a_7xy + a_8yz + a_9zx = 0$	j (input)	0	$a_0, a_1, \dots, a_9$
plane $\perp$ x-axis	$x = c$	1	1	c
plane $\perp$ y-axis	$y = c$	2	2	c
plane $\perp$ z-axis	$z = c$	3	3	c
plane $\parallel$ x-axis	$(y-y_0)/(z-z_0) = (y_1-y_0)/(z_1-z_0)$	3	4	y_0, z_0, y_1, z_1
plane $\parallel$ y-axis	$(x-x_0)/(z-z_0) = (x_1-x_0)/(z_1-z_0)$	3	5	x_0, z_0, x_1, z_1
plane $\parallel$ z-axis	$(x-x_0)/(y-y_0) = (x_1-x_0)/(y_1-y_0)$	2	6	x_0, y_0, x_1, y_1
cone $\parallel$ x-axis	$[(y-y_0)^2 + (z-z_0)^2]^{1/2} - r_0 = (x-x_0) = (r_1-r_0)/(x_1-x_0)$	6	7	$y_0, z_0, r_0, x_0, r_1, x_1$
cone $\parallel$ y-axis	$[(x-x_0)^2 + (z-z_0)^2]^{1/2} - r_0 = (y-y_0) = (r_1-r_0)/(y_1-y_0)$	6	8	$x_0, z_0, r_0, y_0, r_1, y_1$
cone $\parallel$ z-axis	$[(x-x_0)^2 + (y-y_0)^2]^{1/2} - r_0 = (z-z_0) = (r_1-r_0)/(z_1-z_0)$	6	9	$x_0, y_0, r_0, z_0, r_1, z_1$
cylinder $\parallel$ x-axis	$(y-y_0)^2/a^2 + (z-z_0)^2/b^2 = 1$	6	10	y_0, a, z_0, b
cylinder $\parallel$ y-axis	$(x-x_0)^2/a^2 + (z-z_0)^2/b^2 = 1$	6	11	x_0, a, z_0, b
cylinder $\parallel$ z-axis	$(x-x_0)^2/a^2 + (y-y_0)^2/b^2 = 1$	5	12	x_0, a, y_0, b
ellipsoid	$(x-x_0)^2/a^2 + (y-y_0)^2/b^2 + (z-z_0)^2/c^2 = 1$	6	13	x_0, a, y_0, b, z_0, c

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Card G3, Region Description

- NOTE:**
- a) Omit this card if $IN3 \leq 0$.
 - b) Supply $IN3$ physical cards if $IN3 \geq 1$.

Column	Format	Symbol	Definition
1-3	I3	J	Index of the region being described.
4-6	I3	NZSO	Index of the most probable source region. 0, indicates use best guess.
7-9	I3	NCMPZN	Index of the composition for the region. See Table VIII.2 for index cross reference to material list.
10-12	I3	LBD(1,1)	First boundary surface index.
13-15	I3	LBD(2,1)	Second boundary surface index. 0 or blank if all boundaries have been listed.
		.	
		.	
		.	
	I3	LBD(J,1)	J th boundary surface index. 0 or blank if all boundaries have been listed.
		.	
		.	
		.	
34-36	I3	LBD(9.1)	> 0, ninth boundary surface index if the region has exactly nine boundaries. 0 or blank if all boundaries have been listed (less than nine boundaries). -1, if the region has more than nine boundaries; the ninth and remaining boundaries are listed on Card G3'.
37-45	E9.0	FST	Dummy
46-54	E9.0	BBD(1,1)	x-coordinate of any point in the region (cm).
55-63	E9.0	BBD(2,1)	y-coordinate of the point in the region (cm).

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Table VIII.2

Region Card's Material Cross Reference

64-72	E9.0	BBD(3,1)	z-coordinate of the point in the region (cm).
73-80	2A4	H	Any desired information for card identification.

Index on Card G3		Material Cross Referenced on Card 1	
	1		The Material in the Shield Position
	2		The Material in the Clad Position
	3		The Material in the Source Position
	4		The Material in the Fill Position
	5		Air

Card G3', Additional Region Boundaries

- NOTE:**
- a) Supply this card(s) for each region having more than nine boundaries immediately behind Card G3 for the region; omit otherwise.
 - b) This card contains data up to and including the maximum number of boundaries (15).

Column	Format	Symbol	Definition
1-72	24I3	NS(9,1)	Ninth boundary surface index.
		NS(10,1)	Tenth boundary surface index.
		NS(11,1)	Eleventh boundary surface index. 0 or blank if all boundaries have been listed.
		.	
		.	
		NS(15,1)	Maximum boundary surface index. 0 or blank if all boundaries have been listed.
73-80	2A4	H	Any desired information for card identification.

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Card 4, Energy Group Structure* (May be more than one record in length)

Column	Format	Symbol	Definition
1-5	F5.4	EG(1)	Upper edge of lowest energy group.
6-10	F5.4	EG(2)	Upper edge of second energy group.
	.	.	.
66-70	F5.4	EG(14)	Upper edge of fourteenth energy group.

This card must be repeated until all energy groups specified in card 2 have been defined.

Card 5, Material Cross Sections (May be more than one record in length)

Include Card 5 only if an external material is being used.

Column	Format	Symbol	Definition
1-9	D9.5	XSECG(L)	Cross section for first energy group.
10-18	D9.5	XSECG(2)	Cross section for second energy group.
	.	.	.
63-72	D9.5	XSECG(8)	Cross section for eighth energy group.

This card must be repeated until all cross sections have been specified for each energy group and each area. The external materials' cross sections must be placed in the corresponding order -- source material, clad material, and then shield material. However, even if the cross section for the shield material are given, the code will halt execution if an external material is used for the shield.

Also, the cross sections must be given for each area, if an external material is being used, even though the same material is used for different areas.

*The bottom energy is 0.03. Also, the energy group structure must be given in ascending order.

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Card 6, Source Strength (May be more than one record in length)

Column	Format	Symbol	Definition
1-7	D7.3	GAMEN(L)	Source strength for the first energy group.
8-14	D7.3	GAMEN(2)	Source strength for the second energy group.
	.		
	.		
64-70	D7.3	GAMEN(10)	Source strength for the tenth energy group

This card must be repeated until all source strengths have been specified for each energy g
For simple geometries Geometry Type 5, 6, 7, 8, 12, or 13, this ends the input for one cas

Cards GS: Source Region for General Geometry

Cards GS1, Number of Increments in Each Direction

Column	Format	Symbol	Definition
1-5	I5	LSO*	For cylindrical and spherical sources, LSO is the number of radial increments. For cartesian coordinates, LSO is the number of increments in the x-direction (must be less than 300).

Column	Format	Symbol	Definition
6-10	I5	MSO*	For cylindrical and cartesian sources, MSO is the number of increments in the z-direction. For spherical sources, MS is the number of angular bins in the polar (θ) direction (must be less than 300).

*(LSO*MSO*NSO*) must be less than 27 million

11-15	I5	NSO*	For cartesian coordinates, MSO is the number of increments in the y-direction. For cylindrical and spherical coordinates
-------	----	------	--

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NSO is the number of angular bins in the azimuthal (ϕ) direction (must be less than 300).

16-20	I5	NSOPT	Defines the coordinate system in which the source will be defined. 0 - Cylindrical 1 - Cartesian 2 - Spherical
-------	----	-------	---

Cards GS2, Source Region

Column	Format	Symbol	Definition
1-9	D9.5	RSO(1)	For cylindrical and spherical sources, RSO(1) is starting p of the radius. For cartesian coordinates sources, RSO(1) is the starting point of the source in the x-direction.
10-18	D9.5	DRO	For cylindrical and spherical sources, DRO is the radius increment size. For cartesian sources, DRO is the x-dire increment.
19-27	D9.5	PHISO(1)	For cylindrical and spherical sources, PHISO(1) is the sta azimuthal (ϕ) point. For cartesian sources, PHISO(1) is the starting point of the source in the y-direction.
28-36	D9.5	DPHIO	For cylindrical and spherical sources, DPHIO is the azim angle (ϕ) bin size. For cartesian sources, DPHIO is the y-direction increment size.
37-45	D9.5	ZSO(1)	For cylindrical and cartesian sources, ZSO(1) is the starti point of the source in the z-direction. For spherical sour ZSO(1) is the starting polar angle (θ).

*(LSO*MSO*NSO*) msut be less than 27 million

46-54,	D9.5	DZO	For cylindrical and cartesian sources, DZO is the z-direct increment size. For spherical sources, DZO is the polar angle (θ) bin size.
--------	------	-----	---

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Note: All measurements for the radius, x-direction, y-direction and z-direction are in units of Cm. The angles are in units of radians. See Figure 3 for the relationship between coordinate systems.

Cards GA, ASO Card

Column	Format	Symbol	Definition
1-9	ASO	D9.5	The total source strength multiplier.

Cards GD, Detector Card (one needed for each detector)

Column	Format	Symbol	Definition
1-9	RRC1	D9.5	The r, X, or ρ detector* coordinate (units of cm).
10-18	PHIRC1	D9.5	The ϕ , Y, or ϕ detector coordinate ϕ - units of radians Y - units of cm
19-27	ZRC1	D9.5	The Z, Z or θ detector coordinate Z - units of cm θ - units of radians
28-32	NRCOP1	I5	Enter 0 for cylindrical coordinates. Enter 1 for cartesian coordinates. Enter 2 for spherical coordinates.

*The first classification is cylindrical, the second is cartesian, and the last is spherical.

Column	Format	Symbol	Definition
33-37	NGPF	I5	First source - detector traverse for which a geometry print is required.
38-42	NGPL	I5	Last source - detector traverse for which a geometry print is required.
43-47	NGPI	I5	Increment in the geometry print.
57-72	IDETA IDETB	2A8	Detector identification (Punched out on output cards)

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This ends QAD-P5Z input. If another case needs to be run, it should be placed here. Also, if another case does need to be run, a special review of the variable VARY should be done to determine its usefulness in the second case.

An example input sheet is given in Figure 14.

Figure 14. Sample Input Sheets

-IF CARD 3 IS TO BE READ, THERE MUST BE A 1 PUNCHED IN COL. 70 OF CARD 2.

-NOTE: DIMENSIONS ARE IN CM

-IF 1 TAPE IS NOT ZERO, THEN THE JOB DESCRIPTIONS, DETIME, AND ROSE RATE WILL BE PUNCHED TO UNIT 1 FOR EACH DETECTOR.

MATERIAL OPTIONS

	1	2	3	4	5	6	7
WATER							
ALUMINUM							
IRON							
LEAD							
URANIUM							
ORDINARY CONCRETE							
AIR							

-GEOME TRY SOURCE OPTIONS

1	GENERAL GEOMETRY	5	SLAB
2		6	CYLINDER, SHIELD AT SIDE
3		7	CYLINDER, SHIELD AT END
4			

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IX. QAD P5Z OUTPUT

The output from a QAD-P5Z calculation is, for the most part, self-explanatory. The only difficulty likely to be encountered is in the distance print, either as requested on Card 2 or resulting from a type 2 geometry error. This print consists of the receiver number, coordinates of the detector point, the source point identification by the triplet (l,m,n) heading a listing of the numbers of the zones traversed, the bounding surface crossed in leaving the zone, the distance through the zone, and the cartesian coordinates of the point of entering the zone. Due to the method of treating δ , the point of entering the zone is actually recorded as

$$x' = x + \alpha\delta$$

$$y' = y + \beta\delta$$

$$z' = z + \gamma\delta$$

where x' , y' and z' are printed; x , y , and z are the coordinates of the actual point of crossing the surface (or, in the case of the first entry, the source point locations); and α , β and γ are the direction cosines of the source-receiver line.

It is noted that the order of cycling the three subscripts on the source point is m,l,n -- that is, m is in the inner loop and n the outer. The effect is that source points l,m,n are taken up in order of succession
 $P = M[L(n - 1) + (l - 1)] + m.$

The greatest utility of the distance print has been in verifying the geometry description. In recognition of this, QAD-P5Z was programmed to automatically generate a distance print for the ray path from a source point located at the coordinate origin (0, 0, 0) to each detector point. It may be noted that this choice of location (0, 0, 0) for the pseudo source point results in a type 1 geometry error for a detector point placed exactly on a plane bounding surface which contains the origin of the coordinate system.

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REFERENCES

1. "Nuclear Power Station Shielding Manual," Niagara Mohawk Power Corporation, 1965.
2. "Description of the TERP System a FORTRAN V/63, IV 163, 360 System for Efficient Interpolation," D. I. Putzulu, P. Aebersold, and W. R. Burrus, ORNL-TM-1706, 1966.
3. "SDC, A Shielding - Design Calculation Code for Fuel Handling Facilities," E. D. Arnold and B. F. Maskewitz, ORNL-3041, 1966.
4. "Reactor Shielding Design Manual." T. Rockwell III ed., 1956.
5. "Reactor Shielding for Nuclear Engineers," N. M. Schaeffer, TID-25951, 1973.
6. "Photon Attenuation and Energy Transfer Coefficients Tabulations and Discussion," J. H. Hubbell and M. J. Berger, NBS Report 8681, 1965, pages 74-76, Table 1.
7. "QAD: A Series of Point Kernel General Purpose Shielding Programs," RSIC-CCC-48, LASL-LA-3573, UC-32, TID-4500, R. Z. Malenfant, April 5, 1967.
8. "FASTER - A FORTRAN Analytic Solution of the Transport Equation by Random Sampling," T. M. Jordon, WANL-PR-(LL)-010, CCC-98.
9. "Polynomial Expressions Fitted to NDA Gamma-Ray Buildup Data," XDC-55-6-174, June 1955.
10. "American National Standard Neutron and Gamma-Ray Flux-to-Dose-Rate Factors," ANSI/ANS-6.1.1, 1977.
11. "Computer Program QAD-P5Z," TVA calculation TI-266-4, (NEB 841023 235).
12. "AKERN - Aerojet Point Kernel Integration Computational System," RSIC-CCC-190, Contributed by Aerojet Nuclear System Company.

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13. "X-Ray Attenuation Coefficients from 10 KeV to 100 MeV," Gladys White Gradstein, NBS-583-533, April 1957.

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Appendix A

Photon Mass Attenuation Coefficients μ/ρ (cm²/g)

28

1.000E-2 1.500E-2 2.000E-2 3.000E-2 4.000E-2 5.000E-2 6.000E-2 8.000E-2
1.000E-1 1.500E-1 2.000E-1 3.000E-1 4.000E-1 5.000E-1 6.000E-1 8.000E-1
1.000E+0 1.500E+0 2.000E+0 3.000E+0 4.000E+0 5.000E+0 6.000E+0 8.000E+0
1.000E+1 1.500E+1 2.000E+1 3.000E+1

1 H HYDROGEN

3.854E-1 3.764E-1 3.695E-1 3.570E-1 3.458E-1 3.355E-1 3.260E-1 3.091E-1
2.944E-1 2.650E-1 2.429E-1 2.112E-1 1.892E-1 1.728E-1 1.598E-1 1.404E-1
1.262E-1 1.026E-1 8.758E-2 6.910E-2 5.793E-2 5.036E-2 4.486E-2 3.735E-2
3.244E-2 2.530E-2 2.145E-2 1.741E-2

2HE HELIUM

2.220E-1 1.966E-1 1.887E-1 1.804E-1 1.743E-1 1.691E-1 1.642E-1 1.558E-1
1.483E-1 1.334E-1 1.223E-1 1.063E-1 9.530E-2 8.701E-2 8.049E-2 7.070E-2
6.355E-2 5.167E-2 4.414E-2 3.495E-2 2.941E-2 2.569E-2 2.301E-2 1.935E-2
1.698E-2 1.358E-2 1.179E-2 9.972E-3

3LI LITHIUM

3.027E-1 1.985E-1 1.741E-1 1.588E-1 1.519E-1 1.467E-1 1.423E-1 1.348E-1
1.283E-1 1.155E-1 1.058E-1 9.197E-2 8.242E-2 7.526E-2 6.963E-2 6.116E-2
5.497E-2 4.469E-2 3.824E-2 3.037E-2 2.566E-2 2.252E-2 2.025E-2 1.721E-2
1.525E-2 1.248E-2 1.105E-2 9.654E-3

4BE BERYLLIUM

5.941E-1 2.782E-1 2.072E-1 1.705E-1 1.588E-1 1.520E-1 1.469E-1 1.387E-1
1.319E-1 1.186E-1 1.086E-1 9.449E-2 8.466E-2 7.732E-2 7.150E-2 6.280E-2
5.645E-2 4.590E-2 3.931E-2 3.132E-2 2.658E-2 2.342E-2 2.116E-2 1.814E-2
1.623E-2 1.356E-2 1.223E-2 1.097E-2

5 B BORON

1.182E+0 4.407E-1 2.746E-1 1.930E-1 1.714E-1 1.612E-1 1.546E-1 1.450E-1
1.377E-1 1.237E-1 1.132E-1 9.845E-2 8.819E-2 8.055E-2 7.448E-2 6.546E-2
5.883E-2 4.785E-2 4.102E-2 3.277E-2 2.793E-2 2.471E-2 2.242E-2 1.940E-2
1.750E-2 1.491E-2 1.365E-2 1.252E-2

6 C CARBON

2.268E+0 7.476E-1 4.035E-1 2.368E-1 1.960E-1 1.794E-1 1.698E-1 1.578E-1
1.493E-1 1.338E-1 1.223E-1 1.063E-1 9.527E-2 8.700E-2 8.047E-2 7.070E-2
6.352E-2 5.167E-2 4.435E-2 3.555E-2 3.040E-2 2.701E-2 2.463E-2 2.148E-2
1.954E-2 1.693E-2 1.571E-2 1.468E-2

7 N NITROGEN

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3.736E+0 1.156E+0 5.667E-1 2.807E-1 2.133E-1 1.877E-1 1.743E-1 1.596E-1
1.501E-1 1.340E-1 1.225E-1 1.064E-1 9.535E-2 8.703E-2 8.049E-2 7.073E-2
6.355E-2 5.173E-2 4.444E-2 3.571E-2 3.066E-2 2.736E-2 2.505E-2 2.203E-2
2.019E-2 1.778E-2 1.669E-2 1.584E-2

8 O OXYGEN

5.758E+0 1.731E+0 7.985E-1 3.440E-1 2.382E-1 1.997E-1 1.811E-1 1.622E-1
1.514E-1 1.344E-1 1.227E-1 1.066E-1 9.538E-2 8.708E-2 8.056E-2 7.077E-2
6.362E-2 5.178E-2 4.450E-2 3.589E-2 3.093E-2 2.770E-2 2.546E-2 2.258E-2
2.084E-2 1.861E-2 1.766E-2 1.702E-2

9 F FLUORINE

7.965E+0 2.363E+0 1.051E+0 4.074E-1 2.581E-1 2.050E-1 1.803E-1 1.571E-1
1.452E-1 1.278E-1 1.164E-1 1.010E-1 9.039E-2 8.254E-2 7.632E-2 6.705E-2
6.026E-2 4.905E-2 4.220E-2 3.415E-2 2.953E-2 2.657E-2 2.451E-2 2.190E-2
2.034E-2 1.842E-2 1.765E-2 1.722E-2

10 NE NEON

1.164E+1 3.441E+0 1.498E+0 5.376E-1 3.146E-1 2.362E-1 2.007E-1 1.691E-1
1.542E-1 1.343E-1 1.221E-1 1.057E-1 9.461E-2 8.636E-2 7.987E-2 7.015E-2
6.303E-2 5.135E-2 4.423E-2 3.588E-2 3.115E-2 2.811E-2 2.605E-2 2.343E-2
2.192E-2 2.008E-2 1.942E-2 1.915E-2

11 NA SODIUM

1.520E+1 4.498E+0 1.934E+0 6.576E-1 3.595E-1 2.555E-1 2.091E-1 1.693E-1
1.518E-1 1.305E-1 1.181E-1 1.021E-1 9.136E-2 8.339E-2 7.711E-2 6.774E-2
6.087E-2 4.958E-2 4.274E-2 3.478E-2 3.031E-2 2.747E-2 2.553E-2 2.314E-2
2.176E-2 2.018E-2 1.966E-2 1.958E-2

12 MG MAGNESIUM

2.063E+1 6.124E+0 2.616E+0 8.562E-1 4.431E-1 2.993E-1 2.357E-1 1.827E-1
1.605E-1 1.357E-1 1.224E-1 1.055E-1 9.434E-2 8.608E-2 7.960E-2 6.990E-2
6.283E-2 5.118E-2 4.415E-2 3.604E-2 3.153E-2 2.866E-2 2.675E-2 2.439E-2
2.308E-2 2.163E-2 2.123E-2 2.134E-2

13 AL ALUMINUM

2.575E+1 7.697E+0 3.279E+0 1.045E+0 5.184E-1 3.347E-1 2.539E-1 1.880E-1
1.614E-1 1.337E-1 1.199E-1 1.031E-1 9.213E-2 8.403E-2 7.769E-2 6.821E-2
6.132E-2 4.995E-2 4.316E-2 3.533E-2 3.101E-2 2.829E-2 2.649E-2 2.432E-2
2.313E-2 2.191E-2 2.164E-2 2.192E-2

14 SI SILICON

3.334E+1 1.004E+1 4.275E+0 1.340E+0 6.425E-1 3.993E-1 2.927E-1 2.065E-1
1.729E-1 1.399E-1 1.247E-1 1.069E-1 9.542E-2 8.698E-2 8.041E-2 7.058E-2
6.344E-2 5.171E-2 4.469E-2 3.670E-2 3.233E-2 2.960E-2 2.781E-2 2.568E-2
2.457E-2 2.347E-2 2.334E-2 2.381E-2

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15 P PHOSPHORUS

3.978E+1 1.207E+1 5.148E+0 1.596E+0 7.459E-1 4.489E-1 3.188E-1 2.146E-1
1.749E-1 1.379E-1 1.219E-1 1.041E-1 9.279E-2 8.458E-2 7.815E-2 6.859E-2
6.164E-2 5.027E-2 4.348E-2 3.580E-2 3.165E-2 2.908E-2 2.741E-2 2.547E-2
2.447E-2 2.360E-2 2.359E-2 2.422E-2

16 S SULFUR

4.950E+1 1.513E+1 6.475E+0 1.993E+0 9.144E-1 5.358E-1 3.701E-1 2.381E-1
1.886E-1 1.444E-1 1.267E-1 1.075E-1 9.574E-2 8.722E-2 8.059E-2 7.071E-2
6.353E-2 5.181E-2 4.487E-2 3.706E-2 3.287E-2 3.031E-2 2.866E-2 2.677E-2
2.585E-2 2.512E-2 2.525E-2 2.609E-2

17CL CHLORINE

5.659E+1 1.745E+1 7.492E+0 2.299E+0 1.039E+0 5.959E-1 4.019E-1 2.476E-1
1.906E-1 1.414E-1 1.228E-1 1.037E-1 9.214E-2 8.388E-2 7.747E-2 6.796E-2
6.107E-2 4.981E-2 4.317E-2 3.577E-2 3.182E-2 2.944E-2 2.792E-2 2.623E-2
2.543E-2 2.491E-2 2.516E-2 2.614E-2

18AR ARGON

6.249E+1 1.943E+1 8.375E+0 2.566E+0 1.148E+0 6.470E-1 4.273E-1 2.531E-1
1.893E-1 1.359E-1 1.166E-1 9.773E-2 8.672E-2 7.890E-2 7.286E-2 6.389E-2
5.740E-2 4.682E-2 4.062E-2 3.375E-2 3.013E-2 2.797E-2 2.660E-2 2.512E-2
2.446E-2 2.414E-2 2.449E-2 2.558E-2

19 K POTASSIUM

7.832E+1 2.457E+1 1.063E+1 3.260E+0 1.447E+0 8.042E-1 5.220E-1 2.981E-1
2.168E-1 1.501E-1 1.273E-1 1.059E-1 9.373E-2 8.520E-2 7.864E-2 6.894E-2
6.192E-2 5.053E-2 4.388E-2 3.657E-2 3.274E-2 3.047E-2 2.908E-2 2.761E-2
2.699E-2 2.682E-2 2.733E-2 2.866E-2

20CA CALCIUM

9.259E+1 2.929E+1 1.273E+1 3.209E+0 1.726E+0 9.483E-1 6.067E-1 3.355E-1
2.374E-1 1.583E-1 1.324E-1 1.092E-1 9.548E-2 8.761E-2 8.083E-2 7.083E-2
6.361E-2 5.191E-2 4.512E-2 3.771E-2 3.386E-2 3.163E-2 3.027E-2 2.887E-2
2.834E-2 2.833E-2 2.899E-2 3.055E-2

21SC SCANDIUM

9.872E+1 3.152E+1 1.376E+1 4.237E+0 1.864E+0 1.015E+0 6.415E-1 3.446E-1
2.377E-1 1.527E-1 1.257E-1 1.028E-1 9.055E-2 8.215E-2 7.574E-2 6.635E-2
5.957E-2 4.862E-2 4.231E-2 3.545E-2 3.193E-2 2.992E-2 2.872E-2 2.752E-2
2.711E-2 2.728E-2 2.800E-2 2.963E-2

22TI TITANIUM

1.099E+2 3.535E+1 1.550E+1 4.789E+0 2.101E+0 1.137E+0 7.111E-1 3.726E-1
2.508E-1 1.551E-1 1.253E-1 1.017E-1 8.934E-2 8.096E-2 7.460E-2 6.531E-2
5.863E-2 4.785E-2 4.168E-2 3.502E-2 3.165E-2 2.974E-2 2.862E-2 2.753E-2

RADMODL
MODELING MANUAL
ANNEX 5

2.723E-2 2.758E-2 2.840E-2 3.017E-2

23 V VANADIUM

1.209E+2 3.928E+1 1.731E+1 5.371E+0 2.355E+0 1.267E+0 7.855E-1 4.026E-1

2.649E-1 1.577E-1 1.258E-1 1.007E-1 8.809E-2 7.972E-2 7.341E-2 6.423E-2

5.764E-2 4.704E-2 4.102E-2 3.456E-2 3.133E-2 2.953E-2 2.848E-2 2.754E-2

2.733E-2 2.782E-2 2.873E-2 3.064E-2

24CR CHROMIUM

1.377E+2 4.512E+1 1.998E+1 6.221E+0 2.725E+0 1.462E+0 8.998E-1 4.523E-1

2.917E-1 1.674E-1 1.312E-1 1.037E-1 9.040E-2 8.168E-2 7.518E-2 6.572E-2

5.897E-2 4.814E-2 4.200E-2 3.549E-2 3.227E-2 3.050E-2 2.950E-2 2.864E-2

2.850E-2 2.916E-2 3.022E-2 3.232E-2

25MN MANGANESE

1.504E+2 4.965E+1 2.211E+1 6.917E+0 3.031E+0 1.621E+0 9.922E-1 4.903E-1

3.102E-1 1.715E-1 1.321E-1 1.030E-1 8.950E-2 8.073E-2 7.424E-2 6.487E-2

5.817E-2 4.749E-2 4.148E-2 3.514E-2 3.204E-2 3.038E-2 2.945E-2 2.870E-2

2.866E-2 2.947E-2 3.064E-2 3.287E-2

26FE IRON

1.696E+2 5.641E+1 2.522E+1 7.930E+0 3.478E+0 1.854E+0 1.131E+0 5.510E-1

3.425E-1 1.829E-1 1.383E-1 1.064E-1 9.200E-2 8.282E-2 7.611E-2 6.644E-2

5.957E-2 4.862E-2 4.250E-2 3.611E-2 3.303E-2 3.139E-2 3.050E-2 2.985E-2

2.989E-2 3.088E-2 3.220E-2 3.465E-2

27CO COBALT

1.829E+2 6.130E+1 2.754E+1 8.703E+0 3.821E+0 2.036E+0 1.236E+0 5.948E-1

3.640E-1 1.881E-1 1.395E-1 1.057E-1 9.098E-2 8.178E-2 7.505E-2 6.546E-2

5.867E-2 4.789E-2 4.189E-2 3.569E-2 3.274E-2 3.119E-2 3.039E-2 2.985E-2

2.997E-2 3.111E-2 3.252E-2 3.508E-2

28NI NICKEL

2.077E+2 7.003E+1 3.167E+1 1.005E+1 4.422E+0 2.354E+0 1.425E+0 6.786E-1

4.097E-1 2.049E-1 1.490E-1 1.113E-1 9.529E-2 8.545E-2 7.835E-2 6.827E-2

6.116E-2 4.991E-2 4.370E-2 3.734E-2 3.435E-2 3.281E-2 3.202E-2 3.158E-2

3.180E-2 3.316E-2 3.472E-2 3.755E-2

29CU COPPER

2.146E+2 7.325E+1 3.325E+1 1.062E+1 4.680E+0 2.490E+0 1.504E+0 7.097E-1

4.232E-1 2.053E-1 1.466E-1 1.076E-1 9.170E-2 8.204E-2 7.513E-2 6.540E-2

5.856E-2 4.780E-2 4.188E-2 3.588E-2 3.309E-2 3.169E-2 3.102E-2 3.068E-2

3.099E-2 3.243E-2 3.404E-2 3.690E-2

30ZN ZINC

2.317E+2 8.032E+1 3.662E+1 1.175E+1 5.190E+0 2.761E+0 1.664E+0 7.797E-1

4.597E-1 2.168E-1 1.518E-1 1.096E-1 9.280E-2 8.283E-2 7.576E-2 6.587E-2

RADMODL
MODELING MANUAL
ANNEX 5

5.894E-2 4.810E-2 4.219E-2 3.624E-2 3.351E-2 3.217E-2 3.155E-2 3.133E-2
3.171E-2 3.330E-2 3.506E-2 3.808E-2

31GA GALLIUM

3.273E+1 8.450E+1 3.869E+1 1.249E+1 5.526E+0 2.940E+0 1.770E+0 8.239E-1
4.810E-1 2.207E-1 1.516E-1 1.076E-1 9.057E-2 8.061E-2 7.364E-2 6.394E-2
5.719E-2 4.666E-2 4.096E-2 3.527E-2 3.271E-2 3.149E-2 3.092E-2 3.080E-2
3.125E-2 3.295E-2 3.476E-2 3.785E-2

32GE GERMANIUM

3.589E+1 9.063E+1 4.161E+1 1.351E+1 5.998E+0 3.194E+0 1.920E+0 8.890E-1
5.144E-1 2.302E-1 1.552E-1 1.082E-1 9.045E-2 8.031E-2 7.325E-2 6.353E-2
5.679E-2 4.631E-2 4.069E-2 3.513E-2 3.266E-2 3.152E-2 3.101E-2 3.098E-2
3.151E-2 3.337E-2 3.525E-2 3.846E-2

33AS ARSENIC

3.954E+1 9.760E+1 4.500E+1 1.470E+1 6.540E+0 3.485E+0 2.094E+0 9.652E-1
5.541E-1 2.423E-1 1.604E-1 1.097E-1 9.115E-2 8.066E-2 7.345E-2 6.361E-2
5.682E-2 4.634E-2 4.075E-2 3.527E-2 3.287E-2 3.180E-2 3.134E-2 3.140E-2
3.202E-2 3.401E-2 3.599E-2 3.936E-2

34SE SELENIUM

4.249E+1 1.022E+2 4.752E+1 1.560E+1 6.956E+0 3.709E+0 2.229E+0 1.023E+0
5.835E-1 2.496E-1 1.623E-1 1.090E-1 8.992E-2 7.929E-2 7.208E-2 6.232E-2
5.564E-2 4.536E-2 3.991E-2 3.464E-2 3.238E-2 3.137E-2 3.099E-2 3.113E-2
3.182E-2 3.391E-2 3.596E-2 3.938E-2

35BR BROMINE

4.737E+1 1.109E+2 5.195E+1 1.714E+1 7.657E+0 4.097E+0 2.462E+0 1.127E+0
6.387E-1 2.678E-1 1.711E-1 1.128E-1 9.227E-2 8.113E-2 7.363E-2 6.355E-2
5.669E-2 4.620E-2 4.069E-2 3.540E-2 3.317E-2 3.221E-2 3.188E-2 3.212E-2
3.289E-2 3.517E-2 3.734E-2 4.097E-2

36KR KRYPTON

5.079E+1 1.157E+2 5.476E+1 1.813E+1 8.138E+0 4.352E+0 2.615E+0 1.193E+0
6.732E-1 2.770E-1 1.741E-1 1.126E-1 9.141E-2 8.007E-2 7.253E-2 6.249E-2
5.570E-2 4.538E-2 4.000E-2 3.489E-2 3.276E-2 3.188E-2 3.161E-2 3.194E-2
3.276E-2 3.514E-2 3.737E-2 4.108E-2

37RB RUBIDIUM

5.582E+1 1.797E+1 5.905E+1 1.967E+1 8.846E+0 4.738E+0 2.848E+0 1.297E+0
7.282E-1 2.946E-1 1.821E-1 1.156E-1 9.311E-2 8.124E-2 7.344E-2 6.316E-2
5.625E-2 4.580E-2 4.040E-2 3.532E-2 3.325E-2 3.242E-2 3.221E-2 3.262E-2
3.352E-2 3.605E-2 3.841E-2 4.229E-2

38SR STRONTIUM

6.082E+1 1.962E+1 6.308E+1 2.112E+1 9.542E+0 5.116E+0 3.077E+0 1.400E+0

RADMODL
MODELING MANUAL
ANNEX 5

7.823E-1 3.115E-1 1.897E-1 1.181E-1 9.428E-2 8.198E-2 7.392E-2 6.345E-2
5.647E-2 4.596E-2 4.058E-2 3.555E-2 3.355E-2 3.278E-2 3.261E-2 3.312E-2
3.409E-2 3.679E-2 3.923E-2 4.325E-2

39 Y YTTRIUM

6.672E+1 2.156E+1 6.773E+1 2.284E+1 1.036E+1 5.564E+0 3.348E+0 1.522E+0
8.474E-1 3.326E-1 1.994E-1 1.218E-1 9.655E-2 8.356E-2 7.518E-2 6.439E-2
5.724E-2 4.656E-2 4.114E-2 3.615E-2 3.418E-2 3.347E-2 3.334E-2 3.393E-2
3.499E-2 3.786E-2 4.044E-2 4.466E-2

40ZR ZIRCONIUM

7.212E+1 2.335E+1 7.151E+1 2.438E+1 1.109E+1 5.966E+0 3.592E+0 1.631E+0
9.061E-1 3.509E-1 2.075E-1 1.244E-1 9.764E-2 8.420E-2 7.560E-2 6.459E-2
5.736E-2 4.663E-2 4.123E-2 3.630E-2 3.441E-2 3.376E-2 3.367E-2 3.435E-2
3.549E-2 3.851E-2 4.118E-2 4.553E-2

41NB NIOBIUM

7.826E+1 2.539E+1 7.623E+1 2.616E+1 1.191E+1 6.426E+0 3.874E+0 1.759E+0
9.731E-1 3.728E-1 2.174E-1 1.279E-1 9.954E-2 8.546E-2 7.655E-2 6.524E-2
5.788E-2 4.703E-2 4.160E-2 3.672E-2 3.488E-2 3.427E-2 3.424E-2 3.502E-2
3.623E-2 3.940E-2 4.220E-2 4.672E-2

42MO MOLYBDENUM

8.358E+1 2.716E+1 7.862E+1 2.759E+1 1.261E+1 6.812E+0 4.110E+0 1.864E+0
1.031E+0 3.902E-1 2.246E-1 1.298E-1 1.001E-1 8.553E-2 7.638E-2 6.497E-2
5.757E-2 4.673E-2 4.138E-2 3.661E-2 3.485E-2 3.430E-2 3.433E-2 3.517E-2
3.645E-2 3.974E-2 4.261E-2 4.721E-2

43TC TECHNETIUM

9.009E+1 2.935E+1 1.314E+1 2.940E+1 1.346E+1 7.289E+0 4.400E+0 1.997E+0
1.101E+0 4.129E-1 2.349E-1 1.334E-1 1.018E-1 8.655E-2 7.716E-2 6.543E-2
5.792E-2 4.699E-2 4.163E-2 3.690E-2 3.521E-2 3.473E-2 3.479E-2 3.572E-2
3.707E-2 4.051E-2 4.349E-2 4.825E-2

44RU RUTHENIUM

9.573E+1 3.125E+1 1.401E+1 3.086E+1 1.417E+1 7.681E+0 4.646E+0 2.110E+0
1.162E+0 4.316E-1 2.427E-1 1.353E-1 1.024E-1 8.664E-2 7.704E-2 6.516E-2
5.759E-2 4.667E-2 4.137E-2 3.676E-2 3.516E-2 3.473E-2 3.483E-2 3.585E-2
3.725E-2 4.079E-2 4.383E-2 4.869E-2

45RH RHODIUM

1.030E+2 3.367E+1 1.512E+1 3.274E+1 1.508E+1 8.196E+0 4.963E+0 2.255E+0
1.241E+0 4.570E-1 2.542E-1 1.394E-1 1.045E-1 8.793E-2 7.797E-2 6.572E-2
5.803E-2 4.700E-2 4.169E-2 3.712E-2 3.557E-2 3.520E-2 3.534E-2 3.644E-2
3.791E-2 4.161E-2 4.477E-2 4.977E-2

46PD PALLADIUM

RADMODL
MODELING MANUAL
ANNEX 5

1.086E+2 3.562E+1 1.600E+1 3.407E+1 1.577E+1 8.590E+0 5.210E+0 2.368E+0
1.302E+0 4.759E-1 2.621E-1 1.412E-1 1.049E-1 8.785E-2 7.762E-2 6.530E-2
5.756E-2 4.657E-2 4.133E-2 3.688E-2 3.540E-2 3.509E-2 3.529E-2 3.645E-2
3.796E-2 4.177E-2 4.497E-2 5.002E-2

47AG SILVER

1.168E+2 3.839E+1 1.727E+1 3.608E+1 1.680E+1 9.173E+0 5.568E+0 2.532E+0
1.391E+0 5.053E-1 2.756E-1 1.461E-1 1.075E-1 8.955E-2 7.890E-2 6.613E-2
5.823E-2 4.706E-2 4.179E-2 3.737E-2 3.594E-2 3.568E-2 3.593E-2 3.717E-2
3.876E-2 4.272E-2 4.605E-2 5.129E-2

48CD CADMIUM

1.219E+2 4.018E+1 1.809E+1 3.704E+1 1.739E+1 9.504E+0 5.774E+0 2.630E+0
1.444E+0 5.213E-1 2.818E-1 1.471E-1 1.071E-1 8.878E-2 7.799E-2 6.518E-2
5.729E-2 4.625E-2 4.109E-2 3.681E-2 3.547E-2 3.527E-2 3.555E-2 3.685E-2
3.848E-2 4.249E-2 4.584E-2 5.108E-2

49IN INDIUM

1.296E+2 4.281E+1 1.930E+1 3.886E+1 1.832E+1 1.002E+1 6.098E+0 2.782E+0
1.526E+0 5.481E-1 2.939E-1 1.510E-1 1.090E-1 8.980E-2 7.865E-2 6.548E-2
5.747E-2 4.634E-2 4.120E-2 3.698E-2 3.570E-2 3.554E-2 3.588E-2 3.724E-2
3.893E-2 4.307E-2 4.650E-2 5.186E-2

50SN TIN

1.359E+2 4.499E+1 2.030E+1 4.058E+1 1.902E+1 1.041E+1 6.355E+0 2.901E+0
1.592E+0 5.690E-1 3.026E-1 1.532E-1 1.095E-1 8.976E-2 7.831E-2 6.503E-2
5.696E-2 4.588E-2 4.081E-2 3.670E-2 3.550E-2 3.539E-2 3.576E-2 3.717E-2
3.891E-2 4.312E-2 4.659E-2 5.200E-2

51SB ANTIMONY

1.432E+2 4.754E+1 2.150E+1 6.974E+0 1.985E+1 1.090E+1 6.659E+0 3.045E+0
1.670E+0 5.946E-1 3.140E-1 1.567E-1 1.109E-1 9.042E-2 7.864E-2 6.504E-2
5.688E-2 4.576E-2 4.072E-2 3.669E-2 3.555E-2 3.549E-2 3.590E-2 3.739E-2
3.915E-2 4.346E-2 4.700E-2 5.250E-2

52TE TELLURIUM

1.475E+2 4.910E+1 2.223E+1 7.221E+0 2.022E+1 1.115E+1 6.821E+0 3.123E+0
1.713E+0 6.075E-1 3.186E-1 1.568E-1 1.099E-1 8.915E-2 7.728E-2 6.369E-2
5.558E-2 4.466E-2 3.977E-2 3.589E-2 3.482E-2 3.482E-2 3.526E-2 3.677E-2
3.854E-2 4.286E-2 4.638E-2 5.184E-2

53 I IODINE

1.599E+2 5.336E+1 2.419E+1 7.867E+0 2.165E+1 1.201E+1 7.348E+0 3.370E+0
1.849E+0 6.535E-1 3.406E-1 1.654E-1 1.149E-1 9.262E-2 8.002E-2 6.568E-2
5.722E-2 4.592E-2 4.090E-2 3.697E-2 3.594E-2 3.598E-2 3.647E-2 3.809E-2
3.996E-2 4.451E-2 4.819E-2 5.393E-2

RADMODL
MODELING MANUAL
ANNEX 5

54XE XENON

1.663E+2 5.566E+1 2.526E+1 8.225E+0 2.225E+1 1.241E+1 7.589E+0 3.491E+0
1.915E+0 6.750E-1 3.497E-1 1.677E-1 1.154E-1 9.254E-2 7.961E-2 6.515E-2
5.668E-2 4.537E-2 4.043E-2 3.662E-2 3.564E-2 3.573E-2 3.625E-2 3.791E-2
3.981E-2 4.441E-2 4.811E-2 5.385E-2

55CS CESIUM

1.765E+2 5.924E+1 2.693E+1 8.780E+0 2.334E+1 1.307E+1 8.007E+0 3.688E+0
2.025E+0 7.123E-1 3.669E-1 1.737E-1 1.185E-1 9.443E-2 8.101E-2 6.599E-2
5.731E-2 4.583E-2 4.085E-2 3.705E-2 3.612E-2 3.625E-2 3.681E-2 3.854E-2
4.051E-2 4.525E-2 4.906E-2 5.494E-2

56BA BARIUM

1.832E+2 6.164E+1 2.808E+1 9.167E+0 2.410E+1 1.346E+1 8.264E+0 3.813E+0
2.095E+0 7.352E-1 3.768E-1 1.763E-1 1.192E-1 9.446E-2 8.075E-2 6.553E-2
5.676E-2 4.532E-2 4.041E-2 3.672E-2 3.585E-2 3.602E-2 3.661E-2 3.838E-2
4.037E-2 4.514E-2 4.898E-2 5.486E-2

57LA LANTHANUM

1.938E+2 6.545E+1 2.985E+1 9.760E+0 2.529E+1 1.413E+1 8.706E+0 4.022E+0
2.211E+0 7.747E-1 3.952E-1 1.829E-1 1.225E-1 9.654E-2 8.223E-2 6.643E-2
5.744E-2 4.578E-2 4.084E-2 3.717E-2 3.633E-2 3.653E-2 3.717E-2 3.900E-2
4.108E-2 4.599E-2 4.992E-2 5.596E-2

58CE CERIUM

2.052E+2 6.948E+1 3.174E+1 1.040E+1 4.708E+0 1.484E+1 9.183E+0 4.248E+0
2.337E+0 8.175E-1 4.153E-1 1.901E-1 1.263E-1 9.894E-2 8.392E-2 6.756E-2
5.826E-2 4.637E-2 4.137E-2 3.770E-2 3.691E-2 3.715E-2 3.783E-2 3.974E-2
4.188E-2 4.694E-2 5.100E-2 5.722E-2

59PR PRASEODYMIUM

2.178E+2 7.397E+1 3.383E+1 1.110E+1 5.031E+0 1.562E+1 9.703E+0 4.494E+0
2.475E+0 8.644E-1 4.374E-1 1.983E-1 1.306E-1 1.017E-1 8.597E-2 6.888E-2
5.928E-2 4.708E-2 4.203E-2 3.836E-2 3.759E-2 3.789E-2 3.861E-2 4.060E-2
4.282E-2 4.804E-2 5.222E-2 5.863E-2

60ND NEODYMIUM

2.268E+2 7.719E+1 3.538E+1 1.162E+1 5.272E+0 1.612E+1 1.005E+1 4.668E+0
2.573E+0 8.973E-1 4.524E-1 2.030E-1 1.327E-1 1.028E-1 8.652E-2 6.903E-2
5.926E-2 4.696E-2 4.194E-2 3.834E-2 3.761E-2 3.795E-2 3.870E-2 4.074E-2
4.298E-2 4.828E-2 5.253E-2 5.897E-2

61PM PROMETHIUM

2.407E+2 8.199E+1 3.765E+1 1.239E+1 5.620E+0 1.696E+1 1.058E+1 4.927E+0
2.720E+0 9.478E-1 4.764E-1 2.118E-1 1.373E-1 1.057E-1 8.873E-2 7.044E-2
6.034E-2 4.777E-2 4.264E-2 3.902E-2 3.834E-2 3.871E-2 3.950E-2 4.162E-2

RADMODL
MODELING MANUAL
ANNEX 5

4.395E-2 4.941E-2 5.376E-2 6.042E-2

62SM SAMARIUM

2.466E+2 8.418E+1 3.873E+1 1.277E+1 5.799E+0 1.735E+1 1.078E+1 5.030E+0

2.780E+0 9.693E-1 4.854E-1 2.140E-1 1.376E-1 1.054E-1 8.806E-2 6.965E-2

5.949E-2 4.700E-2 4.196E-2 3.845E-2 3.782E-2 3.822E-2 3.903E-2 4.117E-2

4.349E-2 4.895E-2 5.331E-2 5.990E-2

63EU EUROPIUM

2.595E+2 8.869E+1 4.085E+1 1.351E+1 6.136E+0 1.809E+1 1.125E+1 5.269E+0

2.914E+0 1.016E+0 5.076E-1 2.219E-1 1.416E-1 1.079E-1 8.978E-2 7.065E-2

6.027E-2 4.747E-2 4.240E-2 3.890E-2 3.829E-2 3.873E-2 3.957E-2 4.178E-2

4.416E-2 4.976E-2 5.419E-2 6.096E-2

64GD GADOLINIUM

2.659E+2 9.115E+1 4.204E+1 1.393E+1 6.335E+0 3.450E+0 1.144E+1 5.385E+0

2.982E+0 1.040E+0 5.181E-1 2.247E-1 1.424E-1 1.078E-1 8.941E-2 7.005E-2

5.958E-2 4.682E-2 4.183E-2 3.841E-2 3.786E-2 3.832E-2 3.919E-2 4.140E-2

4.378E-2 4.939E-2 5.381E-2 6.054E-2

65TB TERBIUM

2.779E+2 9.572E+1 4.425E+1 1.469E+1 6.683E+0 3.640E+0 1.191E+1 5.629E+0

3.122E+0 1.088E+0 5.408E-1 2.328E-1 1.465E-1 1.104E-1 9.117E-2 7.107E-2

6.031E-2 4.728E-2 4.225E-2 3.884E-2 3.832E-2 3.882E-2 3.971E-2 4.199E-2

4.443E-2 5.012E-2 5.466E-2 6.152E-2

66DY DYSPROSIUM

2.866E+2 9.928E+1 4.600E+1 1.529E+1 6.965E+0 3.795E+0 1.227E+1 5.815E+0

3.226E+0 1.124E+0 5.578E-1 2.385E-1 1.490E-1 1.116E-1 9.185E-2 7.131E-2

6.034E-2 4.719E-2 4.217E-2 3.880E-2 3.832E-2 3.884E-2 3.976E-2 4.207E-2

4.454E-2 5.029E-2 5.489E-2 6.178E-2

67HO HOLMIUM

2.975E+2 1.036E+2 4.813E+1 1.603E+1 7.306E+0 3.982E+0 1.276E+1 6.038E+0

3.355E+0 1.170E+0 5.792E-1 2.460E-1 1.527E-1 1.138E-1 9.328E-2 7.205E-2

6.080E-2 4.747E-2 4.240E-2 3.905E-2 3.860E-2 3.915E-2 4.010E-2 4.246E-2

4.498E-2 5.084E-2 5.547E-2 6.250E-2

68ER ERBIUM

3.091E+2 1.081E+2 5.030E+1 1.679E+1 7.663E+0 4.177E+0 1.328E+1 6.269E+0

3.486E+0 1.217E+0 6.017E-1 2.540E-1 1.566E-1 1.161E-1 9.481E-2 7.291E-2

6.134E-2 4.776E-2 4.266E-2 3.932E-2 3.890E-2 3.949E-2 4.046E-2 4.287E-2

4.543E-2 5.136E-2 5.609E-2 6.323E-2

69TM THULIUM

2.791E+2 1.132E+2 5.273E+1 1.764E+1 8.063E+0 4.398E+0 1.374E+1 6.526E+0

3.634E+0 1.270E+0 6.272E-1 2.631E-1 1.612E-1 1.189E-1 9.677E-2 7.403E-2

RADMODL
MODELING MANUAL
ANNEX 5

6.212E-2 4.824E-2 4.310E-2 3.975E-2 3.936E-2 3.997E-2 4.098E-2 4.345E-2
4.606E-2 5.211E-2 5.694E-2 6.420E-2

70YB YTTERBIUM

2.904E+2 1.167E+2 5.447E+1 1.827E+1 8.358E+0 4.560E+0 2.791E+0 6.690E+0
3.732E+0 1.307E+0 6.443E-1 2.688E-1 1.637E-1 1.201E-1 9.734E-2 7.416E-2
6.205E-2 4.805E-2 4.294E-2 3.962E-2 3.926E-2 3.989E-2 4.091E-2 4.340E-2
4.603E-2 5.214E-2 5.696E-2 6.423E-2

71LU LUTETIUM

2.170E+2 1.221E+2 5.698E+1 1.915E+1 8.770E+0 4.787E+0 2.931E+0 6.935E+0
3.879E+0 1.361E+0 6.700E-1 2.781E-1 1.683E-1 1.230E-1 9.928E-2 7.524E-2
6.282E-2 4.848E-2 4.330E-2 4.001E-2 3.967E-2 4.032E-2 4.136E-2 4.391E-2
4.658E-2 5.278E-2 5.769E-2 6.510E-2

72HF HAFNIUM

2.259E+2 1.263E+2 5.899E+1 1.988E+1 9.112E+0 4.978E+0 3.048E+0 7.119E+0
3.997E+0 1.402E+0 6.899E-1 2.850E-1 1.716E-1 1.247E-1 1.004E-1 7.569E-2
6.300E-2 4.848E-2 4.331E-2 4.002E-2 3.971E-2 4.039E-2 4.145E-2 4.402E-2
4.671E-2 5.296E-2 5.792E-2 6.538E-2

73TA TANTALUM

2.336E+2 1.313E+2 6.142E+1 2.075E+1 9.518E+0 5.205E+0 3.188E+0 7.351E+0
4.140E+0 1.454E+0 7.148E-1 2.938E-1 1.760E-1 1.273E-1 1.021E-1 7.660E-2
6.358E-2 4.882E-2 4.355E-2 4.028E-2 3.999E-2 4.068E-2 4.177E-2 4.438E-2
4.711E-2 5.345E-2 5.848E-2 6.602E-2

74 W TUNGSTEN

9.256E+1 1.361E+2 6.376E+1 2.158E+1 9.922E+0 5.426E+0 3.324E+0 7.568E+0
4.273E+0 1.502E+0 7.383E-1 3.023E-1 1.801E-1 1.297E-1 1.036E-1 7.738E-2
6.403E-2 4.902E-2 4.373E-2 4.046E-2 4.019E-2 4.089E-2 4.199E-2 4.464E-2
4.741E-2 5.380E-2 5.889E-2 6.650E-2

75RE RHENIUM

9.667E+1 1.411E+2 6.635E+1 2.251E+1 1.036E+1 5.669E+0 3.473E+0 7.823E+0
4.418E+0 1.556E+0 7.645E-1 3.118E-1 1.848E-1 1.326E-1 1.055E-1 7.840E-2
6.469E-2 4.937E-2 4.405E-2 4.075E-2 4.049E-2 4.123E-2 4.235E-2 4.503E-2
4.784E-2 5.432E-2 5.949E-2 6.720E-2

76OS OSMIUM

1.000E+2 1.449E+2 6.834E+1 2.325E+1 1.071E+1 5.869E+0 3.598E+0 8.037E+0
4.526E+0 1.597E+0 7.845E-1 3.187E-1 1.881E-1 1.342E-1 1.065E-1 7.879E-2
6.481E-2 4.930E-2 4.395E-2 4.069E-2 4.046E-2 4.120E-2 4.233E-2 4.503E-2
4.785E-2 5.437E-2 5.952E-2 6.727E-2

77IR IRIDIUM

1.044E+2 1.500E+2 7.111E+1 2.425E+1 1.119E+1 6.135E+0 3.759E+0 8.326E+0

RADMODL
MODELING MANUAL
ANNEX 5

4.680E+0 1.656E+0 8.130E-1 3.293E-1 1.934E-1 1.376E-1 1.087E-1 8.001E-2
6.562E-2 4.976E-2 4.436E-2 4.107E-2 4.084E-2 4.160E-2 4.275E-2 4.550E-2
4.838E-2 5.497E-2 6.020E-2 6.806E-2

78PT PLATINUM

1.086E+2 1.548E+2 7.362E+1 2.518E+1 1.164E+1 6.383E+0 3.916E+0 8.469E+0
4.814E+0 1.709E+0 8.387E-1 3.386E-1 1.980E-1 1.402E-1 1.105E-1 8.095E-2
6.618E-2 5.001E-2 4.459E-2 4.128E-2 4.104E-2 4.181E-2 4.299E-2 4.576E-2
4.865E-2 5.532E-2 6.060E-2 6.853E-2

79AU GOLD

1.134E+2 1.606E+2 7.665E+1 2.626E+1 1.215E+1 6.673E+0 4.094E+0 1.915E+0
4.974E+0 1.770E+0 8.692E-1 3.499E-1 2.038E-1 1.437E-1 1.129E-1 8.229E-2
6.712E-2 5.053E-2 4.501E-2 4.168E-2 4.145E-2 4.224E-2 4.343E-2 4.625E-2
4.919E-2 5.593E-2 6.132E-2 6.937E-2

80HG MERCURY

1.173E+2 1.650E+2 7.905E+1 2.713E+1 1.257E+1 6.907E+0 4.241E+0 1.985E+0
5.090E+0 1.819E+0 8.923E-1 3.585E-1 2.079E-1 1.461E-1 1.143E-1 8.299E-2
6.745E-2 5.065E-2 4.508E-2 4.173E-2 4.151E-2 4.231E-2 4.350E-2 4.635E-2
4.930E-2 5.608E-2 6.150E-2 6.958E-2

81TL THALLIUM

1.212E+2 1.465E+2 8.138E+1 2.799E+1 1.299E+1 7.146E+0 4.391E+0 2.054E+0
5.206E+0 1.865E+0 9.152E-1 3.668E-1 2.120E-1 1.484E-1 1.158E-1 8.361E-2
6.777E-2 5.070E-2 4.512E-2 4.176E-2 4.154E-2 4.233E-2 4.354E-2 4.639E-2
4.936E-2 5.617E-2 6.158E-2 6.972E-2

82PB LEAD

1.257E+2 1.084E+2 8.411E+1 2.900E+1 1.349E+1 7.426E+0 4.563E+0 2.135E+0
5.355E+0 1.921E+0 9.432E-1 3.772E-1 2.172E-1 1.514E-1 1.178E-1 8.472E-2
6.844E-2 5.102E-2 4.536E-2 4.199E-2 4.175E-2 4.257E-2 4.379E-2 4.667E-2
4.965E-2 5.653E-2 6.202E-2 7.019E-2

83BI BISMUTH

1.310E+2 1.127E+2 8.720E+1 3.017E+1 1.406E+1 7.747E+0 4.764E+0 2.231E+0
5.538E+0 1.985E+0 9.761E-1 3.897E-1 2.236E-1 1.555E-1 1.205E-1 8.625E-2
6.947E-2 5.161E-2 4.586E-2 4.243E-2 4.220E-2 4.301E-2 4.425E-2 4.716E-2
5.018E-2 5.716E-2 6.272E-2 7.103E-2

84PO POLONIUM

1.376E+2 1.185E+2 9.115E+1 3.164E+1 1.477E+1 8.150E+0 5.014E+0 2.348E+0
5.784E+0 2.070E+0 1.018E+0 4.057E-1 2.322E-1 1.609E-1 1.244E-1 8.858E-2
7.112E-2 5.265E-2 4.673E-2 4.325E-2 4.300E-2 4.383E-2 4.509E-2 4.807E-2
5.117E-2 5.830E-2 6.394E-2 7.246E-2

85AT ASTATINE

RADMODL
MODELING MANUAL
ANNEX 5

1.437E+2 1.243E+2 9.459E+1 3.301E+1 1.544E+1 8.525E+0 5.249E+0 2.460E+0
5.962E+0 2.146E+0 1.057E+0 4.205E-1 2.399E-1 1.656E-1 1.277E-1 9.057E-2
7.248E-2 5.345E-2 4.743E-2 4.386E-2 4.359E-2 4.444E-2 4.572E-2 4.874E-2
5.188E-2 5.913E-2 6.489E-2 7.354E-2

86RN RADON

1.427E+2 1.225E+2 9.327E+1 3.269E+1 1.532E+1 8.471E+0 5.221E+0 2.447E+0
5.879E+0 2.114E+0 1.042E+0 4.139E-1 2.355E-1 1.622E-1 1.246E-1 8.799E-2
7.021E-2 5.161E-2 4.575E-2 4.227E-2 4.201E-2 4.281E-2 4.405E-2 4.696E-2
5.000E-2 5.699E-2 6.256E-2 7.090E-2

87FR FRANCIUM

1.488E+2 5.231E+1 9.690E+1 3.408E+1 1.599E+1 8.854E+0 5.461E+0 2.561E+0
1.442E+0 2.190E+0 1.080E+0 4.290E-1 2.433E-1 1.670E-1 1.280E-1 8.997E-2
7.161E-2 5.242E-2 4.641E-2 4.286E-2 4.259E-2 4.341E-2 4.466E-2 4.760E-2
5.070E-2 5.781E-2 6.346E-2 7.196E-2

88RA RADIUM

1.537E+2 5.413E+1 9.983E+1 3.520E+1 1.654E+1 9.169E+0 5.659E+0 2.656E+0
1.496E+0 2.249E+0 1.109E+0 4.401E-1 2.491E-1 1.705E-1 1.304E-1 9.123E-2
7.237E-2 5.277E-2 4.669E-2 4.309E-2 4.280E-2 4.362E-2 4.487E-2 4.784E-2
5.095E-2 5.810E-2 6.379E-2 7.233E-2

89AC ACTINIUM

1.600E+2 5.646E+1 1.036E+2 3.664E+1 1.725E+1 9.571E+0 5.911E+0 2.778E+0
1.564E+0 2.325E+0 1.149E+0 4.556E-1 2.572E-1 1.756E-1 1.339E-1 9.331E-2
7.380E-2 5.361E-2 4.740E-2 4.369E-2 4.338E-2 4.420E-2 4.546E-2 4.847E-2
5.164E-2 5.890E-2 6.469E-2 7.339E-2

90TH THORIUM

1.636E+2 5.787E+1 9.113E+1 3.743E+1 1.766E+1 9.816E+0 6.066E+0 2.851E+0
1.606E+0 2.362E+0 1.169E+0 4.633E-1 2.610E-1 1.778E-1 1.352E-1 9.385E-2
7.398E-2 5.353E-2 4.726E-2 4.355E-2 4.322E-2 4.403E-2 4.528E-2 4.827E-2
5.142E-2 5.866E-2 6.443E-2 7.312E-2

91PA PROTACTINIUM

1.715E+2 6.075E+1 6.763E+1 3.924E+1 1.855E+1 1.032E+1 6.385E+0 3.005E+0
1.692E+0 2.461E+0 1.221E+0 4.834E-1 2.718E-1 1.847E-1 1.401E-1 9.684E-2
7.612E-2 5.486E-2 4.840E-2 4.454E-2 4.419E-2 4.501E-2 4.627E-2 4.933E-2
5.254E-2 5.995E-2 6.588E-2 7.476E-2

92 U URANIUM

1.737E+2 6.162E+1 6.845E+1 3.976E+1 1.881E+1 1.048E+1 6.489E+0 3.057E+0
1.722E+0 2.477E+0 1.230E+0 4.873E-1 2.735E-1 1.854E-1 1.403E-1 9.662E-2
7.569E-2 5.436E-2 4.789E-2 4.403E-2 4.365E-2 4.445E-2 4.569E-2 4.869E-2
5.187E-2 5.921E-2 6.507E-2 7.387E-2

RADMODL
MODELING MANUAL
ANNEX 5

93NP NEPTUNIUM

1.819E+2 6.463E+1 7.176E+1 4.158E+1 1.972E+1 1.101E+1 6.823E+0 3.217E+0
1.813E+0 2.578E+0 1.283E+0 5.080E-1 2.847E-1 1.925E-1 1.454E-1 9.970E-2
7.789E-2 5.571E-2 4.902E-2 4.502E-2 4.460E-2 4.540E-2 4.665E-2 4.971E-2
5.296E-2 6.045E-2 6.647E-2 7.548E-2

94PU PLUTONIUM

1.879E+2 6.683E+1 7.434E+1 4.292E+1 2.040E+1 1.140E+1 7.077E+0 3.342E+0
1.883E+0 2.647E+0 1.319E+0 5.225E-1 2.925E-1 1.974E-1 1.488E-1 1.017E-1
7.915E-2 5.639E-2 4.955E-2 4.546E-2 4.500E-2 4.579E-2 4.702E-2 5.010E-2
5.337E-2 6.095E-2 6.701E-2 7.613E-2

95AM AMERICIUM

1.923E+2 6.853E+1 7.658E+1 4.389E+1 2.093E+1 1.171E+1 7.278E+0 3.440E+0
1.939E+0 2.696E+0 1.345E+0 5.331E-1 2.980E-1 2.007E-1 1.510E-1 1.028E-1
7.981E-2 5.660E-2 4.966E-2 4.551E-2 4.502E-2 4.579E-2 4.700E-2 5.007E-2
5.335E-2 6.093E-2 6.700E-2 7.614E-2

96CM CURIUM

1.969E+2 7.025E+1 7.866E+1 4.486E+1 2.146E+1 1.204E+1 7.486E+0 3.543E+0
1.998E+0 2.746E+0 1.370E+0 5.439E-1 3.037E-1 2.042E-1 1.533E-1 1.039E-1
8.049E-2 5.684E-2 4.981E-2 4.558E-2 4.505E-2 4.580E-2 4.698E-2 5.005E-2
5.331E-2 6.092E-2 6.701E-2 7.617E-2

97BK BERKELIUM

2.045E+2 7.315E+1 8.104E+1 4.657E+1 2.236E+1 1.255E+1 7.819E+0 3.706E+0
2.091E+0 2.842E+0 1.420E+0 5.637E-1 3.145E-1 2.111E-1 1.581E-1 1.068E-1
8.251E-2 5.802E-2 5.078E-2 4.639E-2 4.582E-2 4.655E-2 4.772E-2 5.084E-2
5.416E-2 6.187E-2 6.808E-2 7.743E-2

98CF CALIFORNIUM

2.088E+2 7.486E+1 8.287E+1 4.753E+1 2.291E+1 1.289E+1 8.031E+0 3.810E+0
2.152E+0 2.896E+0 1.446E+0 5.748E-1 3.202E-1 2.147E-1 1.605E-1 1.081E-1
8.325E-2 5.829E-2 5.093E-2 4.647E-2 4.585E-2 4.656E-2 4.770E-2 5.080E-2
5.411E-2 6.184E-2 6.807E-2 7.744E-2

99ES EINSTEINIUM

2.158E+2 7.755E+1 3.712E+1 4.909E+1 2.375E+1 1.338E+1 8.344E+0 3.966E+0
2.241E+0 2.984E+0 1.491E+0 5.929E-1 3.302E-1 2.210E-1 1.650E-1 1.107E-1
8.500E-2 5.930E-2 5.172E-2 4.711E-2 4.644E-2 4.715E-2 4.825E-2 5.137E-2
5.474E-2 6.255E-2 6.885E-2 7.838E-2

**RADMODL
MODELING MANUAL
ANNEX 5**

100FM FERMIIUM

2.196E+2 7.901E+1 3.788E+1 4.998E+1 2.421E+1 1.366E+1 8.532E+0 4.061E+0
2.296E+0 3.008E+0 1.512E+0 6.019E-1 3.351E-1 2.239E-1 1.669E-1 1.116E-1
8.547E-2 5.937E-2 5.170E-2 4.702E-2 4.630E-2 4.698E-2 4.804E-2 5.113E-2
5.447E-2 6.227E-2 6.857E-2 7.807E-2

RADMODL MODELING MANUAL

ANNEX 5

Appendix B

Berger Buildup Factor Coefficients

E_γ (MeV)	H_2O		<u>Aluminum</u>		<u>Iron</u>		<u>Lead</u>		<u>Uranium</u>		<u>Concrete</u>		<u>Air</u>	
	C	D	C	D	C	D	C	D	C	D	C	D	C	D
0.03	1.3	-0.045	0.12	-0.048	0.12	0.009	0.023	-1.76	0.0065	-0.121	0.105	-0.038	3.43	0.288
0.04	2.7	-0.015	0.32	-0.037	0.175	0.012	0.029	-1.5	0.009	-0.116	0.26	-0.035	3.24	0.268
0.05	3.4	0.015	0.66	-0.025	0.23	0.016	0.035	-1.32	0.0115	-0.111	0.52	-0.025	3.1	0.254
0.06	3.7	0.046	1.0	-0.015	0.27	0.019	0.04	-1.16	0.014	-0.108	0.86	-0.014	2.98	0.242
0.08	3.8	0.1	1.72	0.007	0.37	0.025	0.05	-0.96	0.0195	-0.102	1.45	0.01	2.79	0.223
0.1	3.5	0.135	2.1	0.026	0.44	0.03	0.06	-0.79	0.026	-0.098	1.6	0.036	2.64	0.208
0.15	3.1	0.17	2.05	0.07	0.6	0.039	0.084	-0.53	0.04	-0.088	1.85	0.064	2.37	0.181
0.2	2.8	0.17	1.95	0.098	0.72	0.045	0.11	-0.38	0.056	-0.082	1.9	0.078	2.18	0.162
0.3	2.4	0.16	1.75	0.115	0.86	0.052	0.15	-0.2	0.09	-0.0725	1.85	0.078	1.92	0.135
0.4	2.1	0.14	1.6	0.098	0.95	0.054	0.185	-0.11	0.125	-0.065	1.7	0.074	1.74	0.116
0.5	1.8	0.12	1.45	0.086	0.98	0.055	0.22	-0.05	0.16	-0.06	1.6	0.066	1.6	0.102
0.6	1.65	0.11	1.35	0.076	0.98	0.054	0.25	-0.03	0.2	-0.055	1.47	0.059	1.46	0.089
0.8	1.4	0.08	1.2	0.062	0.94	0.05	0.32	-0.02	0.25	-0.046	1.3	0.048	1.27	0.071
1.0	1.2	0.065	1.1	0.053	0.9	0.045	0.35	-0.02	0.295	-0.039	1.2	0.038	1.16	0.057
1.5	1.0	0.04	0.88	0.037	0.8	0.032	0.38	-0.01	0.33	-0.022	0.98	0.024	0.94	0.036
2.0	0.84	0.024	0.77	0.0265	0.7	0.028	0.37	0.0021	0.32	-0.008	0.86	0.016	0.84	0.025

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3.0	0.68	0.0074	0.63	0.014	0.56	0.026	0.32	0.027	0.27	0.023	0.68	0.0088	0.7	0.010
4.0	0.58	0.0014	0.52	0.0082	0.45	0.027	0.25	0.056	0.225	0.05	0.58	0.004	0.61	0.003
5.0	0.5	-0.0044	0.45	0.0068	0.39	0.03	0.19	0.089	0.18	0.077	0.51	0.0013	0.55	-0.001
6.0	0.45	-0.0082	0.4	0.0062	0.33	0.034	0.15	0.113	0.14	0.1	0.46	0.001	0.52	-0.30
8.0	0.37	-0.0124	0.32	0.0058	0.26	0.042	0.105	0.143	0.1	0.125	0.37	0.002	0.46	-0.40
10.0	0.32	-0.0139	0.27	0.0074	0.19	0.055	0.08	0.155	0.07	0.14	0.32	0.001	0.42	-0.40

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Appendix C

Geometric Progression Buildup Factor Parameters

BERYLLIUM MEDIUM, BERYLLIUM RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	2.597	0.964	0.020	12.81	-0.0195	2.76%	0.5	1.234%
0.020	3.819	1.501	-0.086	16.20	0.0274	2.77%	0.5	0.869%
0.030	5.682	2.348	-0.190	14.96	0.0674	1.84%	15.0	1.153%
0.040	5.706	2.771	-0.222	14.91	0.0771	2.04%	15.0	1.289%
0.050	5.186	2.923	-0.229	15.43	0.0747	2.00%	15.0	1.126%
0.060	4.750	2.950	-0.227	16.03	0.0689	2.03%	0.5	0.971%
0.080	4.196	2.877	-0.217	17.74	0.0596	2.75%	0.5	1.034%
0.100	3.842	2.783	-0.210	19.63	0.0630	2.56%	0.5	1.019%
0.150	3.212	2.600	-0.199	19.35	0.0582	1.58%	0.5	0.660%
0.200	3.098	2.416	-0.189	17.56	0.0573	1.71%	0.5	0.625%
0.300	2.722	2.183	-0.175	15.88	0.0592	1.47%	15.0	0.807%
0.400	2.519	2.060	-0.168	15.38	0.0640	2.88%	0.5	1.251%
0.500	2.395	1.912	-0.154	14.75	0.0605	2.20%	15.0	1.160%
0.600	2.287	1.810	-0.144	14.46	0.0619	2.26%	15.0	1.300%
0.800	2.159	1.632	-0.121	13.99	0.0528	1.74%	25.0	1.176%
1.000	2.081	1.491	-0.099	14.06	0.0439	1.51%	1.0	1.016%
1.500	1.933	1.296	-0.065	13.59	0.0291	1.49%	0.5	0.758%
2.000	1.837	1.182	-0.042	13.81	0.0193	1.30%	0.5	0.622%
3.000	1.712	1.060	-0.015	13.20	0.0073	0.74%	0.5	0.298%
4.000	1.639	0.978	0.006	13.80	-0.0039	0.89%	0.5	0.316%
5.000	1.575	0.941	0.015	13.97	-0.0071	0.39%	2.0	0.196%
6.000	1.535	0.897	0.028	13.94	-0.0143	0.49%	25.0	0.304%
8.000	1.455	0.869	0.036	10.77	-0.0140	0.58%	30.0	0.287%
10.000	1.405	0.842	0.044	13.44	-0.0218	0.64%	35.0	0.371%
15.000	1.313	0.818	0.051	13.60	-0.0256	1.21%	0.5	0.474%

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BERYLLIUM MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	2.527	0.957	0.023	12.01	-0.0216	3.01%	0.5	1.237%
0.020	3.834	1.517	-0.089	16.27	0.0000	2.25%	0.5	0.788%
0.030	6.543	2.464	-0.204	14.71	0.0774	2.52%	25.0	1.471%
0.040	8.672	3.150	-0.260	14.20	0.1068	3.59%	10.0	2.348%
0.050	9.770	3.613	-0.292	14.02	0.1238	4.49%	10.0	2.847%
0.060	9.823	3.916	-0.311	13.93	0.1334	4.85%	10.0	3.133%
0.080	8.582	4.200	-0.328	14.01	0.1398	4.98%	25.0	3.145%
0.100	7.303	4.252	-0.333	14.11	0.1406	4.64%	25.0	2.996%
0.150	4.983	4.136	-0.331	14.43	0.1391	4.28%	35.0	2.596%
0.200	4.396	3.877	-0.323	14.44	0.1425	4.45%	35.0	2.612%
0.300	3.448	3.442	-0.304	14.20	0.1422	4.80%	25.0	2.833%
0.400	3.218	3.046	-0.280	14.18	0.1370	4.37%	15.0	2.652%
0.500	2.793	2.934	-0.281	13.44	0.1494	5.92%	35.0	3.826%
0.600	2.654	2.672	-0.261	13.20	0.1435	5.82%	10.0	3.747%
0.800	2.505	2.225	-0.215	13.24	0.1211	6.14%	1.0	3.848%
1.000	2.330	1.997	-0.190	12.98	0.1115	7.37%	1.0	4.366%
1.500	2.150	1.549	-0.122	13.00	0.0757	6.41%	0.5	3.260%
2.000	2.061	1.284	-0.069	13.26	0.0434	4.27%	0.5	1.857%
3.000	1.863	1.087	-0.024	13.06	0.0168	2.95%	0.5	1.072%
4.000	1.740	0.986	0.002	9.42	0.0022	1.59%	0.5	0.593%
5.000	1.641	0.732	0.017	17.21	-0.0085	1.30%	0.5	0.487%
6.000	1.584	0.886	0.031	14.51	-0.0159	0.96%	0.5	0.450%
8.000	1.480	0.851	0.041	14.63	-0.0207	0.69%	25.0	0.393%
10.000	1.437	0.772	0.071	14.24	-0.0469	3.49%	0.5	1.311%
15.000	1.306	0.802	0.057	12.34	-0.0247	0.83%	35.0	0.445%

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BORON MEDIUM, BORON RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.752	0.678	0.097	15.02	-0.0473	2.16%	0.5	0.813%
0.020	2.694	0.953	0.023	15.10	-0.0242	2.59%	0.5	1.018%
0.030	4.721	1.627	-0.110	14.85	0.0449	1.31%	15.0	0.705%
0.040	5.549	2.219	-0.182	14.33	0.0778	2.46%	35.0	1.455%
0.050	5.727	2.489	-0.204	14.75	0.0837	2.43%	15.0	1.228%
0.060	5.340	2.667	-0.218	14.84	0.0878	2.40%	15.0	1.140%
0.080	4.566	2.791	-0.226	14.99	0.0860	2.05%	15.0	1.065%
0.100	4.037	2.781	-0.224	15.38	0.0818	1.92%	15.0	0.989%
0.150	3.648	2.431	-0.189	17.16	0.0543	7.34%	3.0	3.542%
0.200	3.253	2.328	-0.183	17.94	0.0629	6.91%	3.0	3.361%
0.300	2.723	2.212	-0.183	15.15	0.0714	2.54%	3.0	1.109%
0.400	2.533	2.027	-0.167	14.34	0.0653	2.02%	15.0	1.129%
0.500	2.430	1.860	-0.148	14.53	0.0607	2.02%	15.0	1.062%
0.600	2.358	1.720	-0.129	14.73	0.0510	2.14%	2.0	1.067%
0.800	2.186	1.588	-0.113	14.15	0.0485	1.86%	25.0	1.030%
1.000	2.086	1.475	-0.096	13.96	0.0419	1.76%	1.0	1.118%
1.500	1.935	1.285	-0.062	14.35	0.0279	1.65%	0.5	0.798%
2.000	1.833	1.183	-0.042	14.13	0.0192	1.16%	0.5	0.572%
3.000	1.715	1.054	-0.013	12.91	0.0054	0.90%	0.5	0.292%
4.000	1.630	0.986	0.004	14.96	-0.0035	0.48%	0.5	0.186%
5.000	1.571	0.938	0.017	13.83	-0.0100	0.57%	1.0	0.233%
6.000	1.525	0.903	0.027	13.17	-0.0144	0.75%	0.5	0.329%
8.000	1.451	0.856	0.043	11.15	-0.0230	0.59%	20.0	0.316%
10.000	1.389	0.856	0.040	14.51	-0.0208	0.79%	1.0	0.395%
15.000	1.295	0.834	0.047	14.05	-0.0265	1.25%	0.5	0.516%

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BORON MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.728	0.683	0.095	15.02	-0.0460	1.78%	0.5	0.740%
0.020	2.629	0.959	0.021	13.74	-0.0179	2.87%	0.5	1.125%
0.030	4.699	1.665	-0.117	14.48	0.0497	1.44%	35.0	0.854%
0.040	6.906	2.243	-0.184	14.61	0.0788	2.32%	35.0	1.257%
0.050	8.247	2.657	-0.223	14.47	0.0972	2.83%	25.0	1.611%
0.060	8.580	2.947	-0.247	14.36	0.1080	3.27%	15.0	1.842%
0.080	8.089	3.170	-0.262	14.66	0.1119	2.83%	15.0	1.645%
0.100	8.262	2.951	-0.238	16.05	0.0956	1.77%	3.0	1.043%
0.150	5.943	3.081	-0.256	15.38	0.1057	0.0 %	0.0	0.0 %
0.200	3.927	3.222	-0.279	14.14	0.1225	3.73%	15.0	2.159%
0.300	3.156	2.928	-0.265	13.98	0.1270	5.20%	1.0	2.668%
0.400	2.862	2.630	-0.245	12.58	0.1109	3.08%	10.0	2.092%
0.500	2.679	2.375	-0.222	12.68	0.1043	3.44%	1.0	2.261%
0.600	2.547	2.161	-0.198	13.69	0.1020	4.06%	10.0	2.710%
0.800	2.359	1.894	-0.167	13.38	0.0876	4.38%	1.0	2.824%
1.000	2.258	1.674	-0.135	13.53	0.0718	3.65%	0.5	2.392%
1.500	2.075	1.372	-0.083	13.78	0.0470	3.29%	0.5	1.539%
2.000	1.955	1.213	-0.050	14.44	0.0278	2.86%	0.5	1.202%
3.000	1.785	1.069	-0.018	12.74	0.0106	1.82%	0.5	0.638%
4.000	1.684	0.978	0.006	17.12	-0.0045	1.07%	0.5	0.342%
5.000	1.599	0.933	0.018	14.95	-0.0099	0.70%	2.0	0.275%
6.000	1.541	0.904	0.026	14.92	-0.0142	0.58%	1.0	0.260%
8.000	1.447	0.873	0.035	14.16	-0.0200	0.75%	35.0	0.332%
10.000	1.383	0.853	0.041	13.43	-0.0179	0.79%	0.5	0.369%
15.000	1.286	0.830	0.048	14.00	-0.0243	1.08%	1.0	0.469%

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CARBON MEDIUM, CARBON RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.398	0.526	0.153	14.42	-0.0777	1.92%	0.5	0.819%
0.020	1.900	0.739	0.076	16.46	-0.0363	0.74%	25.0	0.327%
0.030	3.725	1.153	-0.027	12.57	0.0085	0.96%	0.5	0.373%
0.040	5.068	1.735	-0.127	14.10	0.0554	1.91%	15.0	1.207%
0.050	5.594	2.066	-0.164	14.48	0.0692	2.68%	2.0	1.395%
0.060	5.424	2.287	-0.186	14.66	0.0790	2.17%	25.0	1.300%
0.080	4.862	2.488	-0.204	14.81	0.0832	2.38%	15.0	1.307%
0.100	4.305	2.548	-0.209	14.88	0.0834	2.34%	15.0	1.197%
0.150	3.523	2.491	-0.205	14.96	0.0796	1.90%	15.0	1.028%
0.200	3.173	2.365	-0.196	14.77	0.0757	1.95%	15.0	0.989%
0.300	2.797	2.129	-0.175	14.96	0.0694	2.62%	35.0	1.397%
0.400	2.629	1.925	-0.153	14.84	0.0631	1.64%	35.0	0.904%
0.500	2.456	1.801	-0.138	16.05	0.0618	2.75%	2.0	1.200%
0.600	2.399	1.663	-0.119	14.98	0.0457	1.15%	2.0	0.650%
0.800	2.198	1.563	-0.109	14.09	0.0461	1.76%	1.0	1.105%
1.000	2.087	1.461	-0.093	14.20	0.0406	2.31%	0.5	1.149%
1.500	1.941	1.275	-0.060	14.29	0.0266	1.92%	0.5	0.809%
2.000	1.843	1.167	-0.037	14.53	0.0143	1.63%	0.5	0.596%
3.000	1.715	1.050	-0.011	14.52	0.0027	0.93%	0.5	0.285%
4.000	1.626	0.990	0.003	12.82	-0.0020	0.57%	2.0	0.262%
5.000	1.564	0.947	0.014	15.05	-0.0068	0.49%	5.0	0.271%
6.000	1.519	0.900	0.030	12.35	-0.0186	1.73%	0.5	0.607%
8.000	1.430	0.884	0.033	12.11	-0.0158	0.69%	1.0	0.359%
10.000	1.378	0.859	0.040	14.32	-0.0221	1.03%	0.5	0.500%
15.000	1.283	0.838	0.047	15.91	-0.0324	0.96%	0.5	0.512%

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CARBON MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.386	0.539	0.146	14.31	-0.0718	1.81%	0.5	0.692%
0.020	1.877	0.732	0.079	16.57	-0.0395	0.77%	0.5	0.411%
0.030	3.511	1.153	-0.027	12.82	0.0087	0.84%	2.0	0.399%
0.040	5.260	1.745	-0.129	13.91	0.0571	2.28%	35.0	1.397%
0.050	6.706	2.108	-0.170	14.34	0.0735	2.96%	2.0	1.506%
0.060	7.209	2.383	-0.198	14.53	0.0878	2.66%	15.0	1.551%
0.080	6.765	2.691	-0.227	14.44	0.0998	3.28%	15.0	1.834%
0.100	5.890	2.824	-0.239	14.40	0.1046	3.32%	15.0	1.784%
0.150	4.381	2.866	-0.246	14.14	0.1067	3.22%	15.0	1.856%
0.200	3.750	2.698	-0.233	15.08	0.1060	4.12%	35.0	2.212%
0.300	3.147	2.413	-0.211	14.41	0.0944	4.33%	3.0	1.973%
0.400	2.843	2.197	-0.192	13.47	0.0805	3.04%	2.0	1.664%
0.500	2.657	2.011	-0.171	14.19	0.0795	4.22%	2.0	1.885%
0.600	2.543	1.851	-0.151	13.60	0.0610	4.40%	2.0	1.971%
0.800	2.312	1.691	-0.133	13.80	0.0643	2.76%	1.0	1.814%
1.000	2.192	1.544	-0.110	13.78	0.0533	2.91%	1.0	1.654%
1.500	2.011	1.311	-0.069	13.69	0.0332	2.47%	0.5	1.140%
2.000	1.898	1.192	-0.044	13.99	0.0206	1.85%	0.5	0.739%
3.000	1.752	1.058	-0.014	11.98	0.0060	1.47%	0.5	0.468%
4.000	1.653	0.986	0.004	25.64	-0.0080	0.60%	0.5	0.302%
5.000	1.575	0.939	0.017	14.50	-0.0109	0.85%	35.0	0.313%
6.000	1.525	0.908	0.026	14.36	-0.0149	0.97%	1.0	0.380%
8.000	1.440	0.868	0.038	17.08	-0.0351	0.69%	1.0	0.402%
10.000	1.373	0.855	0.042	12.35	-0.0208	0.63%	4.0	0.351%
15.000	1.276	0.841	0.046	15.27	-0.0296	1.29%	0.5	0.614%

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NITROGEN MEDIUM, NITROGEN RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.236	0.485	0.163	14.57	-0.0784	1.52%	0.5	0.646%
0.020	1.559	0.578	0.134	14.90	-0.0661	1.93%	0.5	0.753%
0.030	2.712	0.843	0.052	16.05	-0.0373	2.05%	0.5	0.809%
0.040	3.984	1.272	-0.051	13.80	0.0170	0.82%	5.0	0.457%
0.050	4.894	1.630	-0.111	13.96	0.0473	1.78%	10.0	1.095%
0.060	5.144	1.919	-0.151	13.77	0.0689	2.96%	35.0	1.732%
0.080	4.913	2.225	-0.186	13.43	0.0824	2.80%	25.0	1.867%
0.100	4.661	2.248	-0.183	14.48	0.0770	2.62%	15.0	1.454%
0.150	3.749	2.299	-0.189	14.41	0.0764	2.64%	35.0	1.472%
0.200	3.365	2.195	-0.179	14.80	0.0761	2.28%	1.0	1.188%
0.300	2.841	2.056	-0.168	14.21	0.0668	2.53%	25.0	1.404%
0.400	2.620	1.898	-0.151	14.21	0.0602	2.10%	35.0	1.282%
0.500	2.462	1.785	-0.138	14.12	0.0555	1.96%	35.0	1.206%
0.600	2.363	1.680	-0.124	14.24	0.0499	1.85%	1.0	1.167%
0.800	2.202	1.544	-0.105	14.20	0.0434	1.94%	1.0	1.138%
1.000	2.108	1.429	-0.086	14.72	0.0355	1.84%	1.0	0.949%
1.500	1.931	1.277	-0.060	14.38	0.0261	1.58%	0.5	0.725%
2.000	1.835	1.176	-0.040	13.95	0.0172	1.28%	0.5	0.490%
3.000	1.708	1.057	-0.013	12.50	0.0042	0.62%	0.5	0.262%
4.000	1.629	0.980	0.007	14.32	-0.0070	0.49%	0.5	0.227%
5.000	1.567	0.931	0.021	13.51	-0.0148	0.68%	25.0	0.353%
6.000	1.495	0.935	0.018	17.14	-0.0156	0.65%	30.0	0.274%
8.000	1.430	0.869	0.040	12.04	-0.0237	0.68%	3.0	0.329%
10.000	1.364	0.870	0.038	14.33	-0.0223	1.16%	1.0	0.507%
15.000	1.272	0.839	0.049	15.00	-0.0355	1.46%	0.5	0.645%

RADMODL
MODELING MANUAL

ANNEX 5

NITROGEN MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.234	0.475	0.171	14.27	-0.0858	1.56%	0.5	0.677%
0.020	1.543	0.586	0.130	15.00	-0.0632	1.97%	0.5	0.762%
0.030	2.621	0.842	0.053	15.71	-0.0398	1.97%	0.5	0.831%
0.040	3.945	1.279	-0.053	13.58	0.0191	0.86%	25.0	0.490%
0.050	5.039	1.640	-0.113	13.85	0.0489	1.60%	25.0	1.099%
0.060	5.510	1.937	-0.154	13.68	0.0714	2.81%	0.5	1.892%
0.080	5.432	2.283	-0.194	13.30	0.0892	3.31%	35.0	2.192%
0.100	5.208	2.311	-0.191	14.39	0.0825	2.88%	15.0	1.572%
0.150	3.970	2.453	-0.209	14.11	0.0943	3.41%	35.0	1.982%
0.200	3.395	2.408	-0.208	13.32	0.0891	3.19%	1.0	2.001%
0.300	2.962	2.142	-0.180	14.06	0.0755	2.66%	25.0	1.645%
0.400	2.700	1.976	-0.163	14.05	0.0690	2.47%	35.0	1.626%
0.500	2.538	1.835	-0.146	14.13	0.0612	2.34%	1.0	1.499%
0.600	2.406	1.737	-0.134	14.11	0.0572	2.16%	10.0	1.434%
0.800	2.241	1.580	-0.112	14.03	0.0484	1.86%	1.0	1.326%
1.000	2.123	1.474	-0.096	13.97	0.0426	3.56%	1.0	1.417%
1.500	1.968	1.270	-0.058	14.81	0.0246	2.13%	0.5	0.806%
2.000	1.858	1.176	-0.040	13.95	0.0175	1.34%	0.5	0.575%
3.000	1.718	1.061	-0.014	13.95	0.0047	0.96%	0.5	0.343%
4.000	1.631	0.989	0.004	15.65	-0.0044	0.58%	2.0	0.275%
5.000	1.562	0.940	0.018	13.58	-0.0128	0.51%	1.0	0.260%
6.000	1.517	0.901	0.030	12.46	-0.0186	1.05%	0.5	0.488%
8.000	1.423	0.887	0.033	11.67	-0.0159	0.89%	0.5	0.463%
10.000	1.361	0.873	0.037	14.21	-0.0221	1.38%	1.0	0.521%
15.000	1.271	0.841	0.048	15.04	-0.0339	1.51%	0.5	0.710%

RADMODL
MODELING MANUAL

ANNEX 5

OXYGEN MEDIUM, OXYGEN RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.154	0.425	0.198	13.15	-0.1036	1.28%	0.5	0.538%
0.020	1.361	0.502	0.164	14.47	-0.0845	1.91%	0.5	0.784%
0.030	2.173	0.657	0.116	11.54	-0.0467	2.95%	0.5	1.256%
0.040	3.219	0.990	0.012	13.23	-0.0133	1.19%	0.5	0.385%
0.050	4.168	1.313	-0.058	13.41	0.0204	1.01%	35.0	0.610%
0.060	4.739	1.577	-0.103	13.67	0.0436	1.93%	35.0	1.215%
0.080	4.943	1.912	-0.150	13.71	0.0674	2.85%	10.0	1.865%
0.100	4.628	2.082	-0.170	13.71	0.0770	2.93%	35.0	1.926%
0.150	3.921	2.118	-0.170	14.40	0.0691	2.53%	15.0	1.465%
0.200	3.365	2.126	-0.174	13.98	0.0714	2.58%	35.0	1.568%
0.300	2.901	1.974	-0.158	14.10	0.0623	2.37%	25.0	1.462%
0.400	2.650	1.846	-0.144	14.09	0.0569	1.92%	1.0	1.303%
0.500	2.479	1.746	-0.132	14.28	0.0526	1.86%	10.0	1.206%
0.600	2.367	1.656	-0.120	14.31	0.0476	1.59%	35.0	1.135%
0.800	2.214	1.519	-0.100	14.38	0.0396	2.23%	0.5	1.137%
1.000	2.104	1.427	-0.086	14.20	0.0347	1.69%	0.5	0.882%
1.500	1.943	1.261	-0.056	14.31	0.0223	1.38%	0.5	0.614%
2.000	1.839	1.167	-0.037	14.62	0.0144	1.49%	0.5	0.468%
3.000	1.710	1.052	-0.011	14.36	0.0018	0.73%	0.5	0.241%
4.000	1.621	0.986	0.006	12.97	-0.0070	0.55%	1.0	0.251%
5.000	1.556	0.942	0.018	13.28	-0.0128	0.58%	35.0	0.345%
6.000	1.506	0.906	0.029	15.08	-0.0259	0.90%	3.0	0.509%
8.000	1.411	0.896	0.031	12.33	-0.0166	0.64%	0.5	0.329%
10.000	1.356	0.867	0.041	13.90	-0.0273	1.20%	0.5	0.588%
15.000	1.259	0.848	0.048	14.75	-0.0365	1.23%	0.5	0.696%

RADMODL
MODELING MANUAL

ANNEX 5

OXYGEN MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.153	0.432	0.189	14.49	-0.0965	1.38%	0.5	0.519%
0.020	1.355	0.505	0.162	14.65	-0.0825	2.23%	0.5	0.804%
0.030	2.054	0.718	0.086	16.37	-0.0456	3.17%	0.5	1.147%
0.040	3.137	0.990	0.012	13.45	-0.0134	1.27%	0.5	0.412%
0.050	4.063	1.305	-0.056	13.54	0.0184	0.97%	4.0	0.590%
0.060	4.610	1.562	-0.100	13.75	0.0412	1.73%	0.5	1.177%
0.080	4.783	1.887	-0.146	13.73	0.0643	2.71%	35.0	1.754%
0.100	4.492	2.043	-0.164	13.85	0.0718	2.61%	25.0	1.781%
0.150	3.877	2.069	-0.163	14.48	0.0637	2.50%	2.0	1.380%
0.200	3.320	2.090	-0.169	14.03	0.0678	2.38%	25.0	1.446%
0.300	2.870	1.948	-0.154	14.20	0.0595	2.32%	25.0	1.344%
0.400	2.629	1.828	-0.141	14.19	0.0546	1.85%	10.0	1.165%
0.500	2.475	1.723	-0.128	14.20	0.0488	1.85%	1.0	1.146%
0.600	2.362	1.635	-0.116	14.32	0.0439	1.81%	1.0	1.056%
0.800	2.185	1.532	-0.103	14.24	0.0427	1.95%	0.5	1.174%
1.000	2.098	1.418	-0.084	14.35	0.0333	1.58%	0.5	0.829%
1.500	1.929	1.265	-0.057	14.45	0.0235	1.61%	0.5	0.633%
2.000	1.837	1.164	-0.036	15.40	0.0137	1.45%	0.5	0.483%
3.000	1.711	1.052	-0.011	12.88	0.0020	0.77%	0.5	0.247%
4.000	1.624	0.990	0.004	20.49	-0.0070	0.55%	4.0	0.297%
5.000	1.553	0.947	0.016	14.42	-0.0111	0.70%	0.5	0.379%
6.000	1.505	0.917	0.025	15.64	-0.0229	0.99%	1.0	0.467%
8.000	1.417	0.891	0.033	12.30	-0.0194	1.16%	0.5	0.467%
10.000	1.358	0.872	0.039	13.99	-0.0252	1.14%	0.5	0.542%
15.000	1.265	0.842	0.050	15.03	-0.0387	1.19%	3.0	0.728%

RADMODL
MODELING MANUAL

ANNEX 5

SODIUM MEDIUM, SODIUM RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.051	0.409	0.197	11.44	-0.0913	0.78%	0.5	0.267%
0.020	1.121	0.410	0.202	14.55	-0.1108	1.31%	0.5	0.464%
0.030	1.401	0.472	0.180	14.69	-0.0944	2.07%	0.5	0.757%
0.040	1.849	0.629	0.114	16.17	-0.0596	1.35%	2.0	0.566%
0.050	2.535	0.737	0.088	14.98	-0.0626	2.26%	0.5	1.051%
0.060	3.171	0.922	0.033	14.39	-0.0303	1.23%	0.5	0.557%
0.080	4.169	1.220	-0.038	11.66	0.0065	1.44%	0.5	0.567%
0.100	4.509	1.444	-0.079	13.36	0.0260	2.39%	0.5	1.110%
0.150	4.045	1.730	-0.124	13.53	0.0491	2.84%	0.5	1.686%
0.200	3.614	1.784	-0.131	13.78	0.0503	2.97%	0.5	1.587%
0.300	3.024	1.769	-0.130	13.87	0.0478	2.03%	10.0	1.397%
0.400	2.721	1.702	-0.122	14.15	0.0440	1.80%	10.0	1.206%
0.500	2.538	1.635	-0.114	14.25	0.0410	1.84%	0.5	1.065%
0.600	2.402	1.569	-0.104	14.56	0.0366	1.89%	0.5	0.958%
0.800	2.227	1.469	-0.090	14.86	0.0327	1.66%	0.5	0.833%
1.000	2.112	1.387	-0.077	14.85	0.0282	1.57%	0.5	0.697%
1.500	1.936	1.253	-0.054	14.28	0.0205	1.22%	0.5	0.505%
2.000	1.845	1.154	-0.034	14.75	0.0125	1.07%	0.5	0.379%
3.000	1.706	1.050	-0.009	10.63	-0.0012	0.61%	0.5	0.215%
4.000	1.614	0.983	0.009	13.16	-0.0120	0.63%	35.0	0.323%
5.000	1.542	0.946	0.019	12.67	-0.0150	1.15%	1.0	0.589%
6.000	1.479	0.929	0.024	15.97	-0.0271	1.20%	0.5	0.536%
8.000	1.388	0.903	0.033	12.28	-0.0233	0.86%	1.0	0.472%
10.000	1.324	0.894	0.036	13.93	-0.0286	1.19%	1.0	0.619%
15.000	1.225	0.892	0.038	14.72	-0.0327	2.07%	0.5	0.768%

RADMODL
MODELING MANUAL

ANNEX 5

SODIUM MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.052	0.379	0.223	11.69	-0.1146	0.66%	0.5	0.279%
0.020	1.122	0.398	0.212	13.54	-0.1140	1.20%	0.5	0.432%
0.030	1.388	0.480	0.176	14.60	-0.0921	1.99%	0.5	0.765%
0.040	1.779	0.662	0.099	16.41	-0.0479	2.05%	2.0	0.747%
0.050	2.394	0.740	0.087	14.31	-0.0552	2.23%	0.5	1.153%
0.060	2.836	0.910	0.038	13.27	-0.0339	1.23%	0.5	0.609%
0.080	3.300	1.183	-0.028	13.57	-0.0025	0.30%	1.0	0.141%
0.100	3.388	1.368	-0.062	14.35	0.0115	0.83%	4.0	0.394%
0.150	3.190	1.575	-0.095	14.71	0.0260	0.95%	1.0	0.621%
0.200	2.968	1.627	-0.103	14.63	0.0281	0.95%	1.0	0.550%
0.300	2.658	1.633	-0.106	14.12	0.0279	0.73%	25.0	0.485%
0.400	2.481	1.587	-0.101	15.09	0.0285	0.98%	15.0	0.559%
0.500	2.350	1.548	-0.098	14.86	0.0307	1.02%	25.0	0.542%
0.600	2.253	1.498	-0.090	15.42	0.0264	0.89%	0.5	0.496%
0.800	2.117	1.421	-0.080	15.18	0.0250	0.89%	25.0	0.464%
1.000	2.023	1.356	-0.070	15.70	0.0234	0.65%	1.0	0.346%
1.500	1.879	1.234	-0.049	15.21	0.0168	0.91%	0.5	0.331%
2.000	1.795	1.154	-0.034	14.43	0.0122	0.80%	0.5	0.332%
3.000	1.684	1.056	-0.011	10.47	0.0009	0.50%	0.5	0.214%
4.000	1.606	0.992	0.006	12.86	-0.0089	0.54%	3.0	0.326%
5.000	1.536	0.956	0.016	15.20	-0.0205	0.70%	25.0	0.383%
6.000	1.494	0.914	0.031	11.38	-0.0247	0.54%	8.0	0.345%
8.000	1.406	0.902	0.033	13.53	-0.0260	0.99%	1.0	0.657%
10.000	1.347	0.876	0.043	13.19	-0.0335	1.62%	0.5	0.735%
15.000	1.263	0.823	0.064	14.35	-0.0562	1.79%	3.0	1.064%

RADMODL
MODELING MANUAL

ANNEX 5

MAGNESIUM MEDIUM, MAGNESIUM RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.037	0.401	0.211	13.33	-0.1332	0.65%	0.5	0.330%
0.020	1.087	0.426	0.185	14.50	-0.0945	0.57%	0.5	0.331%
0.030	1.294	0.445	0.191	14.26	-0.1008	1.58%	0.5	0.655%
0.040	1.644	0.557	0.142	15.31	-0.0745	0.97%	0.5	0.517%
0.050	2.216	0.623	0.130	13.60	-0.0692	2.70%	0.5	1.395%
0.060	2.778	0.780	0.077	13.14	-0.0522	1.71%	0.5	0.904%
0.080	3.778	1.058	-0.001	14.35	-0.0150	0.44%	15.0	0.239%
0.100	4.260	1.285	-0.049	12.62	0.0081	1.79%	0.5	0.731%
0.150	4.099	1.591	-0.103	13.28	0.0364	3.22%	0.5	1.461%
0.200	3.649	1.684	-0.116	13.69	0.0411	3.24%	0.5	1.540%
0.300	3.056	1.704	-0.120	14.17	0.0423	2.23%	0.5	1.327%
0.400	2.751	1.649	-0.113	14.51	0.0377	2.32%	0.5	1.119%
0.500	2.552	1.597	-0.107	14.44	0.0365	1.92%	0.5	0.976%
0.600	2.416	1.544	-0.100	14.58	0.0343	1.84%	0.5	0.876%
0.800	2.238	1.449	-0.086	14.82	0.0299	1.48%	0.5	0.749%
1.000	2.115	1.378	-0.075	15.12	0.0268	1.74%	0.5	0.705%
1.500	1.940	1.249	-0.053	14.51	0.0202	1.38%	0.5	0.497%
2.000	1.834	1.165	-0.036	14.42	0.0130	0.65%	2.0	0.304%
3.000	1.696	1.061	-0.012	14.79	0.0004	0.48%	2.0	0.180%
4.000	1.607	0.992	0.006	14.46	-0.0093	0.80%	1.0	0.345%
5.000	1.549	0.922	0.029	13.02	-0.0274	2.18%	0.5	0.917%
6.000	1.474	0.929	0.025	15.42	-0.0285	0.79%	3.0	0.519%
8.000	1.380	0.909	0.032	11.96	-0.0231	1.19%	0.5	0.522%
10.000	1.309	0.918	0.029	14.57	-0.0249	1.82%	0.5	0.754%
15.000	1.231	0.844	0.058	14.16	-0.0516	1.77%	4.0	0.970%

RADMODL
MODELING MANUAL

ANNEX 5

MAGNESIUM MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.037	0.401	0.211	13.33	-0.1332	0.65%	0.5	0.330%
0.020	1.085	0.439	0.178	14.34	-0.0910	0.72%	0.5	0.379%
0.030	1.288	0.449	0.189	14.38	-0.1020	1.92%	0.5	0.756%
0.040	1.617	0.557	0.143	15.17	-0.0757	1.39%	0.5	0.632%
0.050	2.099	0.633	0.125	14.15	-0.0657	2.77%	0.5	1.542%
0.060	2.467	0.794	0.071	14.91	-0.0563	2.47%	0.5	1.088%
0.080	2.950	1.039	0.005	13.70	-0.0201	0.72%	10.0	0.454%
0.100	3.102	1.229	-0.035	12.29	-0.0037	0.49%	6.0	0.202%
0.150	3.032	1.454	-0.075	15.08	0.0138	0.73%	1.0	0.314%
0.200	2.856	1.537	-0.088	15.99	0.0200	0.78%	4.0	0.411%
0.300	2.599	1.564	-0.094	15.96	0.0228	0.89%	15.0	0.373%
0.400	2.437	1.541	-0.093	15.45	0.0236	0.70%	1.0	0.332%
0.500	2.315	1.505	-0.089	16.00	0.0236	0.64%	15.0	0.284%
0.600	2.221	1.473	-0.086	15.28	0.0246	0.69%	35.0	0.291%
0.800	2.100	1.401	-0.076	15.64	0.0233	0.48%	1.0	0.247%
1.000	2.004	1.350	-0.069	15.69	0.0235	0.70%	15.0	0.330%
1.500	1.867	1.233	-0.049	14.52	0.0168	0.51%	0.5	0.292%
2.000	1.787	1.155	-0.033	16.11	0.0108	0.52%	0.5	0.248%
3.000	1.674	1.064	-0.013	16.49	0.0022	0.36%	1.0	0.150%
4.000	1.598	0.997	0.005	13.02	-0.0091	0.80%	0.5	0.382%
5.000	1.538	0.941	0.024	10.17	-0.0216	0.51%	30.0	0.338%
6.000	1.484	0.934	0.024	12.01	-0.0192	1.02%	0.5	0.447%
8.000	1.405	0.902	0.034	13.85	-0.0285	1.06%	1.0	0.684%
10.000	1.342	0.886	0.041	13.09	-0.0332	1.88%	0.5	0.828%
15.000	1.253	0.847	0.057	14.24	-0.0511	1.69%	4.0	1.093%

RADMODL
MODELING MANUAL

ANNEX 5

ALUMINUM MEDIUM, ALUMINUM RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.029	0.364	0.240	14.12	-0.1704	0.46%	25.0	0.236%
0.020	1.072	0.349	0.241	14.25	-0.1280	0.33%	8.0	0.168%
0.030	1.226	0.415	0.206	14.06	-0.1131	1.61%	0.5	0.690%
0.040	1.504	0.492	0.172	14.83	-0.0948	1.99%	0.5	0.750%
0.050	1.935	0.570	0.148	14.64	-0.0888	4.07%	0.5	1.411%
0.060	2.436	0.683	0.109	14.74	-0.0784	2.72%	0.5	1.314%
0.080	3.399	0.926	0.033	14.11	-0.0328	0.89%	35.0	0.541%
0.100	3.991	1.148	-0.020	13.53	-0.0085	0.84%	2.0	0.401%
0.150	4.141	1.441	-0.076	14.24	0.0185	1.99%	0.5	0.779%
0.200	3.690	1.585	-0.100	14.16	0.0316	3.23%	0.5	1.309%
0.300	3.101	1.636	-0.109	14.26	0.0349	2.83%	0.5	1.263%
0.400	2.791	1.593	-0.103	14.76	0.0306	1.05%	3.0	0.656%
0.500	2.609	1.528	-0.093	15.47	0.0249	2.47%	0.5	0.832%
0.600	2.428	1.521	-0.096	14.79	0.0322	1.73%	0.5	0.750%
0.800	2.237	1.439	-0.084	14.68	0.0284	1.53%	0.5	0.642%
1.000	2.119	1.368	-0.073	15.07	0.0257	1.26%	0.5	0.531%
1.500	1.940	1.245	-0.052	14.72	0.0196	1.41%	0.5	0.527%
2.000	1.835	1.160	-0.034	14.89	0.0107	0.69%	0.5	0.237%
3.000	1.694	1.059	-0.011	10.74	-0.0011	0.35%	1.0	0.179%
4.000	1.605	0.992	0.006	12.74	-0.0087	0.93%	1.0	0.444%
5.000	1.533	0.945	0.021	14.17	-0.0223	2.36%	1.0	0.782%
6.000	1.464	0.936	0.024	15.05	-0.0290	1.08%	1.0	0.525%
8.000	1.374	0.913	0.031	14.15	-0.0269	1.47%	0.5	0.721%
10.000	1.308	0.904	0.036	14.30	-0.0322	1.79%	0.5	0.797%
15.000	1.228	0.833	0.064	14.20	-0.0587	2.12%	3.0	1.186%

RADMODL
MODELING MANUAL

ANNEX 5

ALUMINUM MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.029	0.394	0.206	15.51	-0.1388	0.45%	6.0	0.223%
0.020	1.067	0.384	0.220	13.81	-0.1204	0.71%	0.5	0.312%
0.030	1.223	0.422	0.198	15.10	-0.1042	1.83%	0.5	0.635%
0.040	1.480	0.503	0.166	14.78	-0.0893	1.72%	0.5	0.697%
0.050	1.765	0.666	0.099	16.34	-0.0493	2.10%	2.0	0.722%
0.060	2.189	0.697	0.104	12.90	-0.0580	3.00%	0.5	1.356%
0.080	2.640	0.924	0.035	12.99	-0.0351	1.54%	0.5	0.666%
0.100	2.847	1.110	-0.009	12.98	-0.0187	0.63%	0.5	0.413%
0.150	2.877	1.357	-0.058	21.73	0.0071	0.48%	4.0	0.243%
0.200	2.762	1.455	-0.074	17.02	0.0114	0.44%	1.0	0.196%
0.300	2.546	1.510	-0.085	16.22	0.0172	0.48%	4.0	0.215%
0.400	2.403	1.498	-0.085	16.45	0.0189	0.54%	1.0	0.237%
0.500	2.287	1.474	-0.083	16.41	0.0194	0.31%	1.0	0.181%
0.600	2.197	1.448	-0.081	17.03	0.0227	0.67%	15.0	0.293%
0.800	2.080	1.384	-0.072	16.24	0.0202	0.64%	0.5	0.283%
1.000	1.994	1.336	-0.066	15.85	0.0215	0.60%	6.0	0.282%
1.500	1.855	1.230	-0.048	16.01	0.0171	0.45%	15.0	0.226%
2.000	1.781	1.153	-0.032	15.32	0.0091	0.32%	0.5	0.142%
3.000	1.673	1.057	-0.010	10.79	-0.0025	0.42%	1.0	0.202%
4.000	1.607	0.974	0.013	12.22	-0.0164	1.05%	0.5	0.498%
5.000	1.529	0.957	0.018	10.90	-0.0157	0.92%	0.5	0.413%
6.000	1.481	0.933	0.026	12.33	-0.0239	1.13%	0.5	0.524%
8.000	1.396	0.917	0.030	13.88	-0.0262	1.37%	0.5	0.677%
10.000	1.334	0.902	0.038	13.03	-0.0332	1.48%	0.5	0.719%
15.000	1.244	0.869	0.050	14.91	-0.0476	1.97%	0.5	1.098%

RADMODL
MODELING MANUAL

ANNEX 5

SILICON MEDIUM, SILICON RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.022	0.415	0.190	11.16	-0.0775	0.62%	0.5	0.288%
0.020	1.051	0.426	0.179	17.64	-0.1078	0.81%	0.5	0.298%
0.030	1.180	0.395	0.215	14.40	-0.1170	1.44%	0.5	0.588%
0.040	1.401	0.455	0.189	14.61	-0.1049	1.91%	0.5	0.760%
0.050	1.677	0.604	0.119	16.85	-0.0604	1.81%	2.0	0.694%
0.060	2.178	0.604	0.139	13.56	-0.0780	3.08%	0.5	1.521%
0.080	3.059	0.820	0.064	13.99	-0.0488	1.41%	10.0	0.887%
0.100	3.712	1.027	0.009	13.77	-0.0262	0.87%	4.0	0.514%
0.150	4.043	1.348	-0.060	13.94	0.0100	2.24%	0.5	0.798%
0.200	3.678	1.506	-0.087	14.36	0.0243	2.46%	0.5	1.120%
0.300	3.110	1.582	-0.100	14.45	0.0290	2.49%	0.5	1.051%
0.400	2.781	1.571	-0.100	14.57	0.0299	2.02%	0.5	0.870%
0.500	2.570	1.541	-0.097	14.87	0.0301	1.65%	0.5	0.785%
0.600	2.433	1.497	-0.091	15.01	0.0283	1.45%	0.5	0.706%
0.800	2.242	1.424	-0.081	15.08	0.0267	1.81%	0.5	0.622%
1.000	2.124	1.358	-0.071	14.98	0.0243	1.49%	0.5	0.521%
1.500	1.941	1.241	-0.051	14.38	0.0185	1.48%	0.5	0.479%
2.000	1.838	1.155	-0.033	14.32	0.0100	0.83%	0.5	0.305%
3.000	1.699	1.051	-0.008	11.58	-0.0039	0.43%	2.0	0.221%
4.000	1.596	0.998	0.006	12.80	-0.0112	0.87%	1.0	0.375%
5.000	1.528	0.948	0.021	14.62	-0.0256	1.67%	0.5	0.794%
6.000	1.456	0.944	0.022	15.19	-0.0273	0.95%	1.0	0.553%
8.000	1.367	0.907	0.036	11.95	-0.0307	0.94%	1.0	0.533%
10.000	1.298	0.916	0.033	13.35	-0.0293	1.67%	1.0	0.751%
15.000	1.202	0.913	0.037	14.31	-0.0360	1.48%	1.0	0.713%

RADMODL
MODELING MANUAL

ANNEX 5

SILICON MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.023	0.349	0.262	11.98	-0.1791	0.50%	0.5	0.266%
0.020	1.051	0.426	0.179	17.64	-0.1078	0.81%	0.5	0.298%
0.030	1.179	0.395	0.216	13.99	-0.1163	1.50%	0.5	0.591%
0.040	1.385	0.460	0.188	14.33	-0.1065	1.95%	0.5	0.788%
0.050	1.640	0.579	0.135	15.12	-0.0715	0.94%	4.0	0.582%
0.060	1.894	0.702	0.092	15.29	-0.0516	3.02%	0.5	1.219%
0.080	2.400	0.838	0.058	14.66	-0.0505	2.36%	0.5	1.133%
0.100	2.627	1.018	0.012	13.65	-0.0298	1.54%	0.5	0.805%
0.150	2.733	1.273	-0.042	10.39	-0.0062	0.66%	0.5	0.237%
0.200	2.669	1.390	-0.063	20.50	0.0073	0.49%	15.0	0.294%
0.300	2.483	1.469	-0.078	16.89	0.0136	0.57%	0.5	0.225%
0.400	2.355	1.473	-0.081	15.82	0.0161	0.50%	35.0	0.226%
0.500	2.252	1.455	-0.080	16.30	0.0182	0.44%	40.0	0.155%
0.600	2.177	1.424	-0.076	18.67	0.0215	0.41%	5.0	0.215%
0.800	2.053	1.385	-0.073	15.28	0.0211	0.44%	35.0	0.203%
1.000	1.980	1.323	-0.063	15.81	0.0184	0.51%	1.0	0.192%
1.500	1.842	1.230	-0.048	15.12	0.0161	0.43%	35.0	0.227%
2.000	1.771	1.155	-0.033	14.57	0.0100	0.45%	40.0	0.167%
3.000	1.669	1.058	-0.010	10.43	-0.0026	0.40%	4.0	0.174%
4.000	1.585	1.011	0.002	15.91	-0.0125	0.94%	1.0	0.351%
5.000	1.522	0.967	0.016	11.03	-0.0170	1.26%	0.5	0.414%
6.000	1.474	0.953	0.019	14.09	-0.0190	1.54%	0.5	0.637%
8.000	1.389	0.930	0.027	13.47	-0.0249	1.73%	0.5	0.758%
10.000	1.331	0.908	0.036	13.36	-0.0319	1.64%	0.5	0.829%
15.000	1.236	0.887	0.047	13.39	-0.0432	2.39%	0.5	0.993%

RADMODL
MODELING MANUAL

ANNEX 5

PHOSPHORUS MEDIUM, PHOSPHORUS RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.018	0.398	0.212	12.01	-0.1279	0.52%	4.0	0.286%
0.020	1.041	0.411	0.194	13.58	-0.0962	0.59%	8.0	0.244%
0.030	1.141	0.390	0.219	13.87	-0.1228	0.97%	0.5	0.390%
0.040	1.321	0.439	0.194	14.66	-0.1070	1.79%	0.5	0.702%
0.050	1.573	0.525	0.156	15.24	-0.0836	1.49%	0.5	0.645%
0.060	1.984	0.535	0.168	13.70	-0.0873	3.52%	0.5	1.820%
0.080	2.767	0.726	0.096	13.52	-0.0655	2.06%	0.5	1.165%
0.100	3.452	0.924	0.036	13.69	-0.0410	1.27%	35.0	0.836%
0.150	3.949	1.255	-0.042	20.00	0.0	1.28%	0.5	0.523%
0.200	3.711	1.410	-0.069	16.17	0.0124	1.52%	0.5	0.589%
0.300	3.132	1.528	-0.091	14.16	0.0233	2.48%	0.5	0.942%
0.400	2.805	1.527	-0.092	15.23	0.0252	2.47%	0.5	0.853%
0.500	2.590	1.504	-0.090	15.30	0.0253	1.91%	0.5	0.734%
0.600	2.443	1.475	-0.087	14.94	0.0257	1.92%	0.5	0.654%
0.800	2.245	1.410	-0.078	15.21	0.0241	1.35%	0.5	0.535%
1.000	2.115	1.358	-0.071	15.01	0.0242	1.22%	0.5	0.522%
1.500	1.943	1.234	-0.049	14.99	0.0169	0.89%	0.5	0.361%
2.000	1.837	1.155	-0.033	13.92	0.0100	0.79%	0.5	0.281%
3.000	1.693	1.056	-0.009	11.30	-0.0040	0.43%	25.0	0.228%
4.000	1.596	0.994	0.008	12.63	-0.0141	0.87%	1.0	0.444%
5.000	1.524	0.948	0.022	14.53	-0.0280	1.82%	0.5	0.755%
6.000	1.452	0.946	0.022	15.59	-0.0289	1.22%	1.0	0.580%
8.000	1.361	0.911	0.036	11.74	-0.0309	1.38%	1.0	0.691%
10.000	1.298	0.903	0.039	13.70	-0.0358	1.38%	0.5	0.798%
15.000	1.193	0.930	0.033	14.49	-0.0333	2.21%	1.0	0.866%

RADMODL
MODELING MANUAL

ANNEX 5

PHOSPHORUS MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.018	0.398	0.212	12.01	-0.1279	0.52%	4.0	0.286%
0.020	1.041	0.432	0.175	13.83	-0.0771	0.45%	0.5	0.249%
0.030	1.141	0.394	0.213	14.41	-0.1150	0.99%	0.5	0.372%
0.040	1.314	0.439	0.195	14.43	-0.1084	2.14%	0.5	0.811%
0.050	1.533	0.520	0.162	14.69	-0.0901	1.72%	0.5	0.773%
0.060	1.751	0.633	0.117	14.78	-0.0635	0.99%	0.5	0.582%
0.080	2.204	0.757	0.084	12.94	-0.0516	2.79%	0.5	1.399%
0.100	2.434	0.940	0.031	14.07	-0.0402	2.70%	0.5	1.169%
0.150	2.611	1.198	-0.027	11.68	-0.0137	0.82%	0.5	0.496%
0.200	2.590	1.319	-0.048	9.03	-0.0088	0.68%	3.0	0.383%
0.300	2.431	1.433	-0.072	19.17	0.0125	1.06%	0.5	0.328%
0.400	2.325	1.440	-0.075	17.17	0.0139	0.39%	0.5	0.246%
0.500	2.224	1.433	-0.076	16.31	0.0157	0.70%	0.5	0.250%
0.600	2.147	1.416	-0.075	16.44	0.0180	0.30%	6.0	0.153%
0.800	2.035	1.375	-0.071	15.64	0.0205	0.67%	0.5	0.226%
1.000	1.959	1.323	-0.063	17.02	0.0204	0.37%	15.0	0.165%
1.500	1.834	1.226	-0.047	15.36	0.0155	0.37%	10.0	0.184%
2.000	1.763	1.156	-0.033	14.97	0.0099	0.40%	0.5	0.190%
3.000	1.664	1.059	-0.010	13.40	-0.0030	0.36%	1.0	0.231%
4.000	1.590	1.003	0.005	15.05	-0.0156	0.74%	4.0	0.419%
5.000	1.521	0.968	0.016	11.99	-0.0176	1.30%	0.5	0.503%
6.000	1.470	0.958	0.018	14.30	-0.0190	1.73%	0.5	0.742%
8.000	1.389	0.928	0.029	13.67	-0.0279	1.71%	0.5	0.840%
10.000	1.330	0.907	0.038	13.34	-0.0349	1.67%	0.5	0.890%
15.000	1.235	0.879	0.053	13.06	-0.0508	2.40%	0.5	1.027%

RADMODL
MODELING MANUAL

ANNEX 5

SULPHUR MEDIUM, SULPHUR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.016	0.294	0.302	11.36	-0.1627	0.51%	8.0	0.286%
0.020	1.040	0.303	0.264	28.62	-0.5075	0.43%	2.0	0.214%
0.030	1.115	0.387	0.215	13.89	-0.1155	0.73%	3.0	0.396%
0.040	1.267	0.405	0.213	14.75	-0.1239	1.86%	0.5	0.734%
0.050	1.476	0.480	0.178	14.71	-0.0989	1.66%	0.5	0.731%
0.060	1.733	0.578	0.136	15.24	-0.0744	5.01%	0.5	1.779%
0.080	2.529	0.648	0.126	13.15	-0.0819	2.43%	0.5	1.373%
0.100	3.177	0.841	0.060	13.60	-0.0536	1.97%	0.5	1.137%
0.150	3.835	1.165	-0.023	12.88	-0.0107	0.90%	2.0	0.425%
0.200	3.680	1.339	-0.056	19.72	0.0054	1.34%	0.5	0.539%
0.300	3.151	1.473	-0.081	16.17	0.0191	1.91%	0.5	0.735%
0.400	2.840	1.475	-0.082	16.92	0.0191	1.00%	0.5	0.325%
0.500	2.599	1.477	-0.085	15.49	0.0223	1.79%	0.5	0.589%
0.600	2.444	1.455	-0.083	15.62	0.0234	1.50%	0.5	0.531%
0.800	2.252	1.395	-0.075	15.38	0.0225	1.68%	0.5	0.512%
1.000	2.130	1.336	-0.066	15.62	0.0209	1.18%	0.5	0.394%
1.500	1.938	1.234	-0.049	14.81	0.0167	0.73%	0.5	0.325%
2.000	1.840	1.146	-0.030	15.78	0.0070	0.97%	0.5	0.304%
3.000	1.691	1.059	-0.010	11.88	-0.0022	0.53%	1.0	0.253%
4.000	1.591	0.998	0.007	13.09	-0.0130	1.18%	1.0	0.447%
5.000	1.513	0.962	0.018	14.66	-0.0251	1.75%	1.0	0.774%
6.000	1.444	0.953	0.021	15.16	-0.0294	1.17%	0.5	0.599%
8.000	1.351	0.931	0.029	13.09	-0.0258	1.71%	0.5	0.777%
10.000	1.291	0.908	0.039	13.43	-0.0369	1.71%	0.5	0.851%
15.000	1.190	0.922	0.038	14.24	-0.0391	2.00%	0.5	0.902%

RADMODL
MODELING MANUAL

ANNEX 5

SULPHUR MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.017	0.293	0.325	10.44	-0.2521	0.43%	6.0	0.245%
0.020	1.039	0.340	0.228	27.88	-0.3834	0.52%	8.0	0.264%
0.030	1.115	0.387	0.215	13.89	-0.1155	0.73%	3.0	0.396%
0.040	1.257	0.418	0.204	14.60	-0.1126	1.66%	0.5	0.686%
0.050	1.440	0.487	0.176	14.61	-0.0988	1.89%	0.5	0.786%
0.060	1.635	0.576	0.140	14.63	-0.0781	1.54%	0.5	0.786%
0.080	1.965	0.763	0.074	14.91	-0.0445	3.72%	0.5	1.329%
0.100	2.276	0.868	0.051	12.99	-0.0441	2.56%	0.5	1.275%
0.150	2.492	1.133	-0.014	12.60	-0.0196	1.66%	0.5	0.723%
0.200	2.500	1.269	-0.039	10.97	-0.0123	1.14%	0.5	0.506%
0.300	2.385	1.393	-0.065	25.71	0.0135	1.36%	0.5	0.526%
0.400	2.285	1.417	-0.071	20.45	0.0155	0.70%	0.5	0.306%
0.500	2.201	1.415	-0.073	16.28	0.0148	0.58%	0.5	0.318%
0.600	2.135	1.392	-0.070	18.06	0.0158	0.44%	3.0	0.269%
0.800	2.029	1.353	-0.066	16.59	0.0166	0.28%	3.0	0.156%
1.000	1.951	1.313	-0.061	15.85	0.0173	0.32%	40.0	0.175%
1.500	1.832	1.215	-0.044	16.11	0.0131	0.34%	8.0	0.158%
2.000	1.761	1.149	-0.031	15.18	0.0082	0.39%	0.5	0.167%
3.000	1.660	1.059	-0.009	10.21	-0.0054	0.60%	1.0	0.248%
4.000	1.587	0.995	0.010	10.20	-0.0171	0.54%	4.0	0.300%
5.000	1.515	0.979	0.013	12.27	-0.0161	1.61%	0.5	0.605%
6.000	1.468	0.957	0.020	13.46	-0.0224	1.80%	0.5	0.742%
8.000	1.388	0.927	0.031	13.43	-0.0316	1.74%	0.5	0.901%
10.000	1.325	0.919	0.035	13.72	-0.0335	1.94%	0.5	0.975%
15.000	1.228	0.898	0.048	13.24	-0.0471	2.78%	0.5	1.079%

RADMODL
MODELING MANUAL

ANNEX 5

ARGON MEDIUM, ARGON RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.009	0.495	0.141	29.38	-0.2851	0.46%	0.5	0.285%
0.020	1.022	0.465	0.151	30.59	-0.3021	0.65%	0.5	0.280%
0.030	1.081	0.344	0.252	13.45	-0.1508	0.69%	0.5	0.281%
0.040	1.180	0.397	0.211	14.36	-0.1139	1.46%	0.5	0.537%
0.050	1.337	0.420	0.209	14.32	-0.1214	1.60%	0.5	0.747%
0.060	1.522	0.509	0.162	15.42	-0.0887	1.37%	0.5	0.643%
0.080	2.134	0.540	0.170	13.50	-0.1007	3.47%	0.5	1.811%
0.100	2.716	0.699	0.107	13.30	-0.0760	3.45%	0.5	1.602%
0.150	3.558	1.007	0.014	13.47	-0.0308	1.24%	4.0	0.814%
0.200	3.599	1.199	-0.027	12.18	-0.0147	0.78%	5.0	0.488%
0.300	3.161	1.378	-0.064	21.31	0.0125	1.16%	2.0	0.439%
0.400	2.829	1.426	-0.074	16.70	0.0152	1.22%	0.5	0.441%
0.500	2.615	1.424	-0.075	17.17	0.0174	0.93%	0.5	0.343%
0.600	2.456	1.410	-0.074	17.12	0.0183	1.00%	0.5	0.354%
0.800	2.248	1.375	-0.071	15.67	0.0202	1.08%	0.5	0.374%
1.000	2.118	1.334	-0.066	14.93	0.0208	0.83%	35.0	0.387%
1.500	1.943	1.222	-0.046	15.07	0.0146	0.99%	0.5	0.330%
2.000	1.831	1.154	-0.032	15.62	0.0088	0.60%	0.5	0.251%
3.000	1.692	1.052	-0.007	12.91	-0.0061	0.47%	1.0	0.263%
4.000	1.592	0.985	0.013	12.56	-0.0204	1.12%	1.0	0.631%
5.000	1.501	0.970	0.017	15.63	-0.0287	0.94%	10.0	0.518%
6.000	1.437	0.944	0.027	13.04	-0.0330	0.94%	4.0	0.566%
8.000	1.342	0.924	0.035	12.28	-0.0338	1.32%	1.0	0.730%
10.000	1.280	0.911	0.041	13.91	-0.0434	1.54%	1.0	0.980%
15.000	1.176	0.948	0.033	14.53	-0.0363	2.00%	1.0	0.964%

RADMODL
MODELING MANUAL

ANNEX 5

ARGON MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.009	0.495	0.141	29.38	-0.2851	0.46%	0.5	0.285%
0.020	1.027	0.318	0.252	18.88	-0.1913	0.70%	2.0	0.291%
0.030	1.081	0.344	0.252	13.45	-0.1508	0.69%	0.5	0.281%
0.040	1.179	0.392	0.216	14.54	-0.1227	1.48%	0.5	0.661%
0.050	1.313	0.433	0.202	14.23	-0.1149	2.13%	0.5	0.866%
0.060	1.456	0.508	0.168	14.35	-0.0942	2.10%	0.5	0.898%
0.080	1.737	0.655	0.111	14.39	-0.0625	1.78%	0.5	0.821%
0.100	1.950	0.814	0.059	14.51	-0.0408	1.04%	0.5	0.663%
0.150	2.255	1.040	0.004	13.40	-0.0244	0.38%	2.0	0.170%
0.200	2.347	1.175	-0.021	12.06	-0.0193	1.56%	0.5	0.858%
0.300	2.314	1.322	-0.053	19.85	0.0016	1.66%	4.0	0.943%
0.400	2.213	1.375	-0.064	23.47	0.0154	1.80%	0.5	0.653%
0.500	2.145	1.378	-0.066	22.25	0.0179	1.29%	0.5	0.425%
0.600	2.088	1.369	-0.066	18.91	0.0152	0.98%	0.5	0.385%
0.800	1.994	1.341	-0.064	16.54	0.0166	0.42%	3.0	0.230%
1.000	1.925	1.303	-0.059	16.03	0.0166	0.46%	35.0	0.239%
1.500	1.814	1.211	-0.043	16.27	0.0125	0.33%	0.5	0.162%
2.000	1.749	1.147	-0.030	15.16	0.0065	0.40%	40.0	0.134%
3.000	1.657	1.052	-0.006	11.62	-0.0089	0.78%	1.0	0.355%
4.000	1.579	1.005	0.007	10.97	-0.0144	0.69%	1.0	0.405%
5.000	1.513	0.978	0.015	13.38	-0.0213	1.67%	0.5	0.742%
6.000	1.461	0.966	0.019	13.70	-0.0235	2.12%	0.5	0.812%
8.000	1.380	0.938	0.030	13.39	-0.0333	2.13%	0.5	1.040%
10.000	1.321	0.919	0.039	13.42	-0.0414	2.15%	1.0	1.040%
15.000	1.244	0.842	0.072	13.87	-0.0710	3.00%	3.0	1.737%

RADMODL
MODELING MANUAL

ANNEX 5

POTASSIUM MEDIUM, POTASSIUM RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.010	0.224	0.422	12.99	-0.4354	0.47%	3.0	0.220%
0.020	1.023	0.248	0.365	12.39	-0.2533	0.45%	7.0	0.270%
0.030	1.069	0.351	0.244	12.59	-0.1388	0.70%	2.0	0.323%
0.040	1.157	0.362	0.238	14.60	-0.1453	1.15%	2.0	0.490%
0.050	1.289	0.400	0.218	14.85	-0.1282	1.48%	0.5	0.706%
0.060	1.451	0.466	0.185	14.80	-0.1055	1.93%	0.5	0.782%
0.080	1.987	0.491	0.193	13.35	-0.1052	3.84%	0.5	1.997%
0.100	2.527	0.634	0.133	13.00	-0.0899	3.74%	0.5	1.871%
0.150	3.411	0.935	0.033	13.43	-0.0406	1.49%	35.0	1.021%
0.200	3.529	1.139	-0.014	12.77	-0.0218	1.21%	10.0	0.727%
0.300	3.188	1.309	-0.048	9.23	-0.0099	1.08%	0.5	0.393%
0.400	2.840	1.389	-0.067	20.01	0.0139	0.77%	0.5	0.336%
0.500	2.627	1.397	-0.070	17.55	0.0148	0.92%	0.5	0.282%
0.600	2.456	1.397	-0.072	16.30	0.0173	0.88%	2.0	0.322%
0.800	2.264	1.352	-0.066	16.77	0.0175	1.11%	0.5	0.306%
1.000	2.128	1.313	-0.061	15.50	0.0170	0.64%	0.5	0.276%
1.500	1.939	1.222	-0.046	14.93	0.0143	0.86%	0.5	0.296%
2.000	1.835	1.147	-0.030	16.46	0.0074	0.79%	0.5	0.243%
3.000	1.685	1.057	-0.008	12.35	-0.0057	0.88%	1.0	0.337%
4.000	1.589	0.983	0.015	11.87	-0.0235	1.30%	1.0	0.713%
5.000	1.501	0.956	0.024	12.99	-0.0361	0.86%	10.0	0.452%
6.000	1.432	0.945	0.028	12.78	-0.0350	1.24%	1.0	0.562%
8.000	1.334	0.934	0.033	12.11	-0.0332	1.61%	0.5	0.715%
10.000	1.283	0.890	0.050	13.89	-0.0525	1.73%	4.0	1.093%
15.000	1.175	0.934	0.040	14.39	-0.0436	2.08%	1.0	0.985%

RADMODL
MODELING MANUAL

ANNEX 5

POTASSIUM MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.012	0.130	0.620	11.39	-0.6162	0.43%	2.0	0.219%
0.020	1.024	0.289	0.289	12.38	-0.1453	0.41%	6.0	0.269%
0.030	1.067	0.384	0.215	12.44	-0.1141	0.71%	0.5	0.326%
0.040	1.151	0.382	0.222	13.92	-0.1229	1.26%	0.5	0.554%
0.050	1.269	0.408	0.217	14.20	-0.1274	1.77%	0.5	0.778%
0.060	1.392	0.483	0.178	14.36	-0.0988	1.82%	0.5	0.803%
0.080	1.644	0.609	0.129	14.32	-0.0742	2.23%	0.5	1.020%
0.100	1.853	0.757	0.077	14.33	-0.0502	2.55%	0.5	1.021%
0.150	2.146	1.005	0.010	13.70	-0.0216	0.96%	4.0	0.617%
0.200	2.235	1.166	-0.022	11.91	-0.0143	0.67%	1.0	0.438%
0.300	2.253	1.282	-0.043	10.15	-0.0111	1.68%	0.5	0.591%
0.400	2.199	1.343	-0.058	25.46	0.0094	1.31%	0.5	0.656%
0.500	2.122	1.361	-0.063	20.95	0.0137	1.19%	0.5	0.485%
0.600	2.070	1.353	-0.063	18.25	0.0123	0.74%	0.5	0.402%
0.800	1.979	1.328	-0.061	16.89	0.0137	0.71%	0.5	0.313%
1.000	1.914	1.294	-0.057	15.83	0.0146	0.54%	40.0	0.245%
1.500	1.804	1.214	-0.044	15.26	0.0131	0.45%	35.0	0.203%
2.000	1.744	1.144	-0.029	16.51	0.0061	0.34%	1.0	0.157%
3.000	1.658	1.047	-0.004	11.27	-0.0108	1.31%	1.0	0.488%
4.000	1.579	1.002	0.009	11.56	-0.0183	0.78%	0.5	0.492%
5.000	1.508	0.986	0.013	13.41	-0.0200	1.44%	1.0	0.683%
6.000	1.463	0.958	0.023	13.42	-0.0288	1.99%	0.5	0.865%
8.000	1.382	0.931	0.034	13.47	-0.0389	2.00%	0.5	0.978%
10.000	1.316	0.927	0.038	13.53	-0.0427	2.35%	0.5	1.085%
15.000	1.218	0.920	0.047	13.48	-0.0518	2.56%	1.0	1.163%

RADMODL
MODELING MANUAL

ANNEX 5

CALCIUM MEDIUM, CALCIUM RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.007	0.585	0.034	9.72	0.1113	0.60%	0.5	0.296%
0.020	1.017	0.370	0.247	11.26	-0.1771	0.44%	2.0	0.257%
0.030	1.056	0.363	0.237	12.80	-0.1459	0.53%	35.0	0.356%
0.040	1.127	0.380	0.222	13.84	-0.1211	0.84%	0.5	0.458%
0.050	1.240	0.389	0.225	14.22	-0.1325	1.52%	0.5	0.601%
0.060	1.382	0.450	0.190	14.77	-0.1058	2.01%	0.5	0.802%
0.080	1.741	0.573	0.136	15.85	-0.0738	1.90%	2.0	0.750%
0.100	2.203	0.685	0.099	15.97	-0.0680	1.43%	2.0	0.670%
0.150	3.245	0.871	0.051	13.42	-0.0502	2.20%	0.5	1.297%
0.200	3.471	1.072	0.002	12.89	-0.0317	1.53%	3.0	0.998%
0.300	3.172	1.273	-0.042	10.25	-0.0103	0.79%	5.0	0.415%
0.400	2.848	1.356	-0.061	27.24	0.0185	0.84%	4.0	0.469%
0.500	2.615	1.380	-0.067	17.03	0.0123	0.78%	2.0	0.381%
0.600	2.477	1.364	-0.065	21.16	0.0171	0.79%	0.5	0.282%
0.800	2.258	1.346	-0.065	16.21	0.0164	0.34%	2.0	0.207%
1.000	2.129	1.304	-0.059	16.33	0.0164	0.75%	0.5	0.251%
1.500	1.936	1.222	-0.046	15.60	0.0151	0.76%	0.5	0.289%
2.000	1.834	1.144	-0.029	17.20	0.0068	0.78%	0.5	0.279%
3.000	1.687	1.050	-0.005	11.95	-0.0099	0.76%	1.0	0.346%
4.000	1.589	0.978	0.017	12.17	-0.0250	1.30%	1.0	0.683%
5.000	1.498	0.963	0.021	14.58	-0.0317	1.45%	1.0	0.830%
6.000	1.429	0.944	0.029	12.99	-0.0361	0.97%	20.0	0.615%
8.000	1.330	0.932	0.035	12.38	-0.0364	1.77%	0.5	0.854%
10.000	1.274	0.903	0.047	13.91	-0.0513	1.84%	4.0	1.136%
15.000	1.167	0.957	0.034	14.47	-0.0375	2.26%	0.5	0.966%

RADMODL
MODELING MANUAL

ANNEX 5

CALCIUM MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.010	0.177	0.470	15.29	-0.4373	0.48%	4.0	0.260%
0.020	1.016	0.441	0.180	10.89	-0.0845	0.39%	1.0	0.262%
0.030	1.057	0.372	0.226	11.52	-0.1182	0.64%	3.0	0.277%
0.040	1.129	0.364	0.234	14.07	-0.1357	0.66%	3.0	0.344%
0.050	1.226	0.405	0.213	14.14	-0.1172	1.55%	0.5	0.669%
0.060	1.335	0.456	0.192	14.25	-0.1107	2.01%	0.5	0.871%
0.080	1.564	0.574	0.142	14.35	-0.0801	2.38%	0.5	1.070%
0.100	1.760	0.708	0.093	14.30	-0.0580	2.82%	0.5	1.112%
0.150	2.062	0.949	0.024	13.69	-0.0280	1.90%	0.5	0.795%
0.200	2.175	1.118	-0.012	12.58	-0.0188	1.88%	0.5	0.799%
0.300	2.204	1.257	-0.039	10.26	-0.0113	1.04%	0.5	0.521%
0.400	2.167	1.305	-0.049	9.80	-0.0059	1.30%	0.5	0.612%
0.500	2.101	1.344	-0.060	24.54	0.0172	1.04%	0.5	0.542%
0.600	2.058	1.333	-0.059	23.64	0.0150	1.03%	3.0	0.523%
0.800	1.963	1.322	-0.060	18.99	0.0166	1.17%	0.5	0.369%
1.000	1.904	1.289	-0.056	17.12	0.0159	0.77%	0.5	0.307%
1.500	1.796	1.210	-0.043	15.77	0.0128	0.33%	8.0	0.167%
2.000	1.737	1.148	-0.030	17.57	0.0079	0.45%	0.5	0.224%
3.000	1.640	1.070	-0.011	13.24	-0.0067	0.66%	40.0	0.317%
4.000	1.574	1.009	0.007	12.05	-0.0167	1.03%	0.5	0.579%
5.000	1.508	0.983	0.015	13.21	-0.0231	1.12%	0.5	0.665%
6.000	1.459	0.962	0.023	13.19	-0.0303	2.17%	0.5	0.918%
8.000	1.376	0.943	0.031	13.52	-0.0363	2.31%	0.5	1.091%
10.000	1.313	0.934	0.037	13.60	-0.0424	2.51%	0.5	1.147%
15.000	1.219	0.916	0.050	13.91	-0.0551	2.48%	1.0	1.277%

RADMODL
MODELING MANUAL

ANNEX 5

IRON MEDIUM, IRON RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.004	1.561	-0.554	5.60	0.3524	0.40%	1.0	0.129%
0.020	1.010	0.258	0.319	18.22	-0.2950	0.49%	3.0	0.247%
0.030	1.027	0.318	0.252	18.88	-0.1913	0.70%	2.0	0.291%
0.040	1.058	0.331	0.248	13.93	-0.1315	0.38%	35.0	0.249%
0.050	1.105	0.344	0.243	14.40	-0.1356	1.09%	0.5	0.383%
0.060	1.167	0.372	0.229	14.70	-0.1365	1.18%	0.5	0.530%
0.080	1.340	0.442	0.191	15.11	-0.1085	1.66%	0.5	0.685%
0.100	1.600	0.484	0.178	15.00	-0.1050	1.40%	3.0	0.880%
0.150	2.426	0.572	0.161	12.70	-0.1086	5.11%	0.5	2.318%
0.200	2.887	0.788	0.080	13.12	-0.0720	5.51%	0.5	2.306%
0.300	3.035	1.034	0.010	12.47	-0.0359	2.86%	0.5	1.456%
0.400	2.823	1.164	-0.020	11.68	-0.0210	1.90%	0.5	0.962%
0.500	2.626	1.225	-0.034	10.32	-0.0132	1.28%	0.5	0.685%
0.600	2.486	1.241	-0.038	10.26	-0.0113	1.01%	20.0	0.612%
0.800	2.277	1.241	-0.039	8.31	-0.0126	0.63%	40.0	0.404%
1.000	2.130	1.256	-0.049	18.40	0.0121	0.73%	4.0	0.343%
1.500	1.938	1.193	-0.039	15.35	0.0096	0.62%	1.0	0.280%
2.000	1.827	1.135	-0.026	25.39	0.0074	0.71%	1.0	0.238%
3.000	1.684	1.035	0.002	12.45	-0.0184	0.94%	1.0	0.587%
4.000	1.565	0.996	0.014	13.95	-0.0296	2.03%	0.5	0.976%
5.000	1.476	0.969	0.024	14.14	-0.0384	1.66%	4.0	0.981%
6.000	1.394	0.977	0.023	14.33	-0.0380	1.83%	1.0	0.919%
8.000	1.299	0.958	0.033	14.00	-0.0446	2.38%	0.5	1.123%
10.000	1.235	0.958	0.037	14.27	-0.0483	2.76%	1.0	1.262%
15.000	1.148	0.955	0.047	14.63	-0.0535	2.71%	1.0	1.268%

RADMODL
MODELING MANUAL

ANNEX 5

IRON MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.004	1.561	-0.554	5.60	0.3524	0.40%	1.0	0.129%
0.020	1.012	0.130	0.620	11.39	-0.6162	0.43%	2.0	0.219%
0.030	1.028	0.374	0.190	29.34	-0.3170	0.65%	3.0	0.281%
0.040	1.058	0.336	0.248	11.65	-0.1188	0.50%	7.0	0.238%
0.050	1.099	0.366	0.232	14.01	-0.1354	0.65%	3.0	0.343%
0.060	1.148	0.405	0.208	14.17	-0.1142	1.53%	0.5	0.577%
0.080	1.267	0.470	0.180	14.48	-0.0974	2.32%	0.5	0.892%
0.100	1.389	0.557	0.144	14.11	-0.0791	2.58%	0.5	1.040%
0.150	1.660	0.743	0.079	14.12	-0.0476	2.93%	0.5	1.143%
0.200	1.839	0.911	0.034	13.23	-0.0334	2.60%	0.5	1.169%
0.300	1.973	1.095	-0.009	11.86	-0.0183	2.34%	0.5	0.955%
0.400	1.992	1.187	-0.027	10.72	-0.0140	1.84%	0.5	0.777%
0.500	1.957	1.261	-0.046	24.77	0.0084	2.23%	0.5	0.837%
0.600	1.932	1.274	-0.049	22.82	0.0097	1.79%	0.5	0.674%
0.800	1.884	1.270	-0.050	20.30	0.0120	1.27%	0.5	0.513%
1.000	1.841	1.250	-0.048	19.49	0.0140	1.16%	0.5	0.400%
1.500	1.750	1.197	-0.040	15.90	0.0110	1.05%	0.5	0.318%
2.000	1.703	1.143	-0.028	20.42	0.0070	0.88%	0.5	0.309%
3.000	1.627	1.059	-0.005	11.99	-0.0132	0.85%	0.5	0.507%
4.000	1.553	1.026	0.005	12.93	-0.0191	1.93%	0.5	0.791%
5.000	1.483	1.009	0.012	13.12	-0.0258	2.24%	0.5	0.939%
6.000	1.442	0.980	0.023	13.37	-0.0355	2.16%	0.5	1.120%
8.000	1.354	0.974	0.029	13.65	-0.0424	3.36%	0.5	1.370%
10.000	1.297	0.949	0.042	13.97	-0.0561	3.23%	0.5	1.500%
15.000	1.199	0.957	0.049	14.37	-0.0594	3.38%	0.5	1.553%

RADMODL
MODELING MANUAL

ANNEX 5

COPPER MEDIUM, COPPER RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.001	2.044	-0.310	11.15	0.2519	0.46%	3.0	0.175%
0.020	1.006	0.230	0.442	12.61	-0.5099	0.49%	10.0	0.234%
0.030	1.017	0.370	0.247	11.26	-0.1771	0.44%	2.0	0.257%
0.040	1.038	0.392	0.197	25.45	-0.2886	0.58%	0.5	0.283%
0.050	1.071	0.353	0.243	12.89	-0.1407	0.39%	0.5	0.163%
0.060	1.121	0.340	0.250	14.53	-0.1501	1.02%	0.5	0.446%
0.080	1.246	0.395	0.217	14.39	-0.1226	2.08%	0.5	0.792%
0.100	1.381	0.539	0.133	19.42	-0.0874	2.07%	2.0	0.680%
0.150	2.120	0.472	0.208	13.51	-0.1372	5.43%	0.5	2.600%
0.200	2.603	0.671	0.120	13.45	-0.0928	6.52%	0.5	2.781%
0.300	2.926	0.921	0.039	12.80	-0.0495	4.82%	0.5	2.001%
0.400	2.795	1.070	0.002	12.19	-0.0331	3.45%	0.5	1.529%
0.500	2.612	1.158	-0.020	11.56	-0.0190	2.55%	0.5	1.093%
0.600	2.479	1.191	-0.028	10.74	-0.0147	2.09%	0.5	0.878%
0.800	2.270	1.210	-0.033	8.79	-0.0131	1.16%	0.5	0.587%
1.000	2.129	1.211	-0.036	7.13	-0.0090	1.03%	0.5	0.444%
1.500	1.952	1.149	-0.025	8.18	-0.0085	0.56%	2.0	0.300%
2.000	1.835	1.113	-0.019	9.49	-0.0052	0.81%	1.0	0.328%
3.000	1.673	1.041	0.001	12.27	-0.0174	1.97%	0.5	0.834%
4.000	1.542	1.016	0.010	14.08	-0.0286	2.41%	1.0	1.046%
5.000	1.451	0.993	0.019	14.15	-0.0372	1.96%	1.0	1.015%
6.000	1.381	0.984	0.023	14.30	-0.0395	2.29%	0.5	1.076%
8.000	1.285	0.959	0.036	14.05	-0.0494	2.35%	1.0	1.217%
10.000	1.226	0.958	0.041	14.33	-0.0536	2.70%	1.0	1.258%
15.000	1.142	0.944	0.057	14.81	-0.0634	2.39%	1.0	1.209%

RADMODL
MODELING MANUAL

ANNEX 5

COPPER MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.001	2.044	-0.310	11.15	0.2519	0.46%	3.0	0.175%
0.020	1.009	0.103	0.764	10.78	-1.0613	0.48%	7.0	0.243%
0.030	1.020	0.359	0.205	12.00	-0.0510	0.37%	8.0	0.247%
0.040	1.042	0.330	0.239	14.45	-0.0962	0.38%	4.0	0.215%
0.050	1.071	0.353	0.243	12.89	-0.1407	0.39%	0.5	0.163%
0.060	1.109	0.364	0.237	13.54	-0.1349	0.92%	0.5	0.410%
0.080	1.189	0.446	0.192	13.97	-0.1094	2.08%	0.5	0.748%
0.100	1.287	0.507	0.165	13.89	-0.0924	2.37%	0.5	0.921%
0.150	1.518	0.675	0.100	13.99	-0.0555	3.10%	0.5	1.109%
0.200	1.695	0.835	0.052	13.62	-0.0364	3.10%	0.5	1.163%
0.300	1.865	1.023	0.005	12.51	-0.0197	2.69%	0.5	1.004%
0.400	1.908	1.135	-0.018	11.46	-0.0137	2.16%	0.5	0.862%
0.500	1.899	1.215	-0.038	16.22	0.0026	2.42%	0.5	0.986%
0.600	1.882	1.235	-0.042	23.77	0.0062	2.44%	0.5	0.834%
0.800	1.854	1.239	-0.044	17.25	0.0057	1.35%	0.5	0.700%
1.000	1.813	1.226	-0.043	21.74	0.0120	1.23%	0.5	0.469%
1.500	1.733	1.185	-0.037	18.36	0.0106	0.84%	0.5	0.302%
2.000	1.694	1.128	-0.024	24.48	0.0026	1.10%	0.5	0.408%
3.000	1.617	1.059	-0.004	12.21	-0.0146	1.22%	0.5	0.608%
4.000	1.546	1.022	0.009	12.92	-0.0258	2.16%	0.5	0.976%
5.000	1.479	1.008	0.015	13.26	-0.0310	2.39%	0.5	1.105%
6.000	1.428	0.995	0.021	13.23	-0.0371	2.80%	0.5	1.201%
8.000	1.353	0.960	0.038	13.50	-0.0547	3.32%	0.5	1.576%
10.000	1.289	0.962	0.042	13.91	-0.0577	3.62%	0.5	1.627%
15.000	1.191	0.969	0.052	14.48	-0.0640	3.95%	1.0	1.757%

RADMODL
MODELING MANUAL

ANNEX 5

MOLYBDENUM MEDIUM, MOLYBDENUM RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.009	0.381	0.200	14.36	-0.0830	0.10%	10.0	0.027%
0.020	1.227	2.045	0.020	18.14	-0.0082	6.90%	3.0	3.828%
0.030	1.514	1.100	0.106	28.01	-0.1191	4.40%	8.0	2.352%
0.040	1.489	0.320	0.107	23.22	-0.0448	0.50%	10.0	0.226%
0.050	1.383	0.052	-0.154	8.30	0.1218	0.40%	40.0	0.263%
0.060	1.327	0.023	0.799	14.91	-0.1910	0.40%	2.0	0.158%
0.080	1.300	0.081	0.573	14.04	-0.2282	1.60%	0.5	0.559%
0.100	1.194	0.253	0.328	13.79	-0.1685	0.90%	0.5	0.424%
0.150	1.447	0.321	0.287	14.10	-0.1596	1.60%	0.5	0.747%
0.200	2.280	0.307	0.318	14.03	-0.1986	3.80%	0.5	1.677%
0.300	2.386	0.559	0.159	14.06	-0.0975	2.30%	0.5	1.158%
0.400	2.678	0.714	0.106	13.91	-0.0868	2.80%	0.5	1.533%
0.500	2.696	0.830	0.067	13.90	-0.0645	2.70%	0.5	1.316%
0.600	2.652	0.892	0.047	13.76	-0.0533	2.10%	0.5	1.132%
0.800	2.504	0.966	0.025	13.66	-0.0397	1.50%	5.0	0.825%
1.000	2.369	1.001	0.014	13.55	-0.0314	1.80%	5.0	0.724%
1.500	1.941	1.093	-0.011	13.47	-0.0147	0.90%	5.0	0.323%
2.000	1.850	1.048	0.002	13.07	-0.0244	1.40%	5.0	0.726%
3.000	1.720	0.956	0.034	13.21	-0.0571	3.10%	0.5	1.751%
4.000	1.600	0.906	0.054	13.52	-0.0749	4.50%	0.5	2.240%
5.000	1.570	0.833	0.084	13.78	-0.1024	4.80%	0.5	2.687%
6.000	1.514	0.811	0.096	14.00	-0.1130	4.90%	1.0	2.775%
8.000	1.480	0.792	0.111	14.29	-0.1246	5.10%	1.0	2.767%
10.000	1.413	0.878	0.087	14.35	-0.1013	5.00%	1.0	2.494%
15.000	1.406	1.018	0.063	14.28	-0.0848	3.80%	1.0	2.024%

RADMODL
MODELING MANUAL

ANNEX 5

MOLYBDENUM MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.009	0.366	0.223	12.62	-0.1086	0.0 %	10.0	0.018%
0.020	2.556	2.027	0.023	13.30	-0.0123	9.70%	3.0	4.622%
0.030	3.642	1.092	0.109	32.14	-0.2177	6.60%	0.5	3.404%
0.040	3.941	0.322	0.088	23.37	-0.0321	0.90%	10.0	0.446%
0.050	3.109	0.038	-0.317	11.96	0.0558	2.20%	1.0	0.949%
0.060	2.408	0.004	1.103	17.52	-0.1479	1.30%	1.0	0.417%
0.080	1.661	0.033	0.767	14.40	-0.2560	1.80%	0.5	0.760%
0.100	1.158	0.300	0.290	13.75	-0.1554	1.10%	0.5	0.445%
0.150	1.241	0.490	0.174	14.42	-0.0901	0.80%	0.5	0.408%
0.200	1.474	0.514	0.173	14.29	-0.0993	2.10%	0.5	0.843%
0.300	1.589	0.733	0.080	14.49	-0.0428	0.90%	5.0	0.391%
0.400	1.711	0.891	0.038	14.18	-0.0333	1.00%	5.0	0.476%
0.500	1.773	0.978	0.016	14.33	-0.0238	1.20%	5.0	0.433%
0.600	1.796	1.024	0.004	13.94	-0.0183	0.90%	5.0	0.384%
0.800	1.804	1.073	-0.008	14.02	-0.0129	0.90%	5.0	0.385%
1.000	1.784	1.092	-0.013	13.43	-0.0103	0.90%	3.0	0.394%
1.500	1.624	1.161	-0.030	7.13	0.0009	1.30%	0.5	0.459%
2.000	1.601	1.127	-0.021	12.62	-0.0054	0.70%	5.0	0.292%
3.000	1.557	1.065	0.0	12.84	-0.0283	1.90%	1.0	0.953%
4.000	1.505	1.023	0.016	13.36	-0.0428	2.70%	0.5	1.335%
5.000	1.519	0.942	0.046	13.59	-0.0702	3.40%	0.5	1.957%
6.000	1.497	0.921	0.057	13.82	-0.0796	4.00%	1.0	2.155%
8.000	1.531	0.878	0.080	14.15	-0.0985	4.40%	1.0	2.381%
10.000	1.502	0.965	0.059	14.21	-0.0784	3.90%	1.0	2.024%
15.000	1.573	1.118	0.035	14.16	-0.0599	3.30%	1.0	1.603%

RADMODL
MODELING MANUAL

ANNEX 5

TIN MEDIUM, TIN RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.005	0.420	0.170	18.40	-0.0827	0.10%	5.0	0.024%
0.020	1.011	0.363	0.217	13.09	-0.0857	0.10%	20.0	0.025%
0.030	1.770	1.862	0.042	11.05	-0.0312	11.20%	3.0	4.908%
0.040	1.660	1.261	0.088	13.32	-0.0262	6.00%	15.0	3.455%
0.050	1.639	0.492	0.280	16.68	-0.2376	2.20%	20.0	0.954%
0.060	1.568	0.257	-0.078	21.17	0.0538	0.60%	0.5	0.277%
0.080	1.393	0.034	0.733	14.24	-0.2271	0.50%	1.0	0.245%
0.100	1.337	0.069	0.659	13.41	-0.3590	1.30%	2.0	0.709%
0.150	1.438	0.181	0.428	13.86	-0.2354	1.70%	0.5	0.843%
0.200	1.624	0.283	0.326	13.92	-0.1909	2.50%	0.5	1.085%
0.300	1.917	0.456	0.205	13.82	-0.1165	2.10%	0.5	1.022%
0.400	2.260	0.590	0.152	13.87	-0.1081	3.00%	0.5	1.520%
0.500	2.364	0.706	0.107	13.87	-0.0848	3.30%	0.5	1.488%
0.600	2.396	0.775	0.082	13.73	-0.0710	2.90%	0.5	1.377%
0.800	2.348	0.865	0.053	13.63	-0.0547	2.10%	0.5	1.137%
1.000	2.259	0.914	0.038	13.50	-0.0462	1.80%	0.5	0.988%
1.500	1.917	1.035	0.004	13.66	-0.0240	1.00%	5.0	0.518%
2.000	1.849	0.993	0.019	13.12	-0.0385	1.90%	0.5	1.124%
3.000	1.713	0.924	0.047	13.27	-0.0708	4.70%	0.5	2.278%
4.000	1.585	0.891	0.063	13.64	-0.0860	6.30%	0.5	2.764%
5.000	1.558	0.825	0.092	13.89	-0.1131	6.50%	0.5	3.156%
6.000	1.513	0.796	0.108	14.10	-0.1277	5.90%	0.5	3.189%
8.000	1.477	0.810	0.112	14.34	-0.1294	6.00%	1.0	3.114%
10.000	1.418	0.914	0.085	14.29	-0.1043	5.60%	1.0	2.818%
15.000	1.413	1.082	0.059	14.09	-0.0884	4.70%	1.0	2.323%

RADMODL
MODELING MANUAL

ANNEX 5

TIN MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.005	0.432	0.160	26.10	-0.1522	0.0 %	2.0	0.021%
0.020	1.011	0.389	0.192	14.26	-0.0695	0.10%	6.0	0.026%
0.030	2.897	1.873	0.040	10.77	-0.0311	11.30%	3.0	4.998%
0.040	3.574	1.221	0.097	26.32	-0.1252	8.80%	3.0	4.316%
0.050	3.487	0.491	0.280	16.80	-0.2372	2.30%	0.5	1.207%
0.060	2.945	0.234	-0.028	5.00	-0.0557	0.60%	40.0	0.363%
0.080	1.808	0.017	0.811	15.45	-0.1526	1.10%	1.0	0.364%
0.100	1.396	0.056	0.688	13.79	-0.3221	1.70%	2.0	0.774%
0.150	1.219	0.326	0.279	13.95	-0.1554	1.40%	0.5	0.599%
0.200	1.261	0.500	0.171	14.62	-0.0918	1.10%	0.5	0.484%
0.300	1.405	0.647	0.106	14.23	-0.0501	0.80%	5.0	0.391%
0.400	1.531	0.788	0.065	14.14	-0.0424	0.90%	5.0	0.475%
0.500	1.610	0.871	0.043	14.06	-0.0355	1.00%	5.0	0.476%
0.600	1.645	0.935	0.024	14.02	-0.0249	0.90%	5.0	0.427%
0.800	1.683	0.999	0.008	14.09	-0.0183	1.00%	5.0	0.393%
1.000	1.685	1.029	0.001	13.43	-0.0162	0.90%	5.0	0.362%
1.500	1.570	1.122	-0.021	14.30	-0.0045	0.90%	0.5	0.346%
2.000	1.556	1.108	-0.016	13.10	-0.0087	0.80%	1.0	0.352%
3.000	1.523	1.058	0.004	12.99	-0.0331	2.20%	0.5	1.149%
4.000	1.470	1.035	0.016	13.43	-0.0449	3.40%	0.5	1.516%
5.000	1.490	0.957	0.046	13.69	-0.0729	4.30%	0.5	2.163%
6.000	1.479	0.933	0.059	13.92	-0.0842	4.50%	0.5	2.328%
8.000	1.525	0.913	0.076	14.16	-0.0983	4.70%	1.0	2.538%
10.000	1.504	1.033	0.048	14.18	-0.0710	4.10%	1.0	2.083%
15.000	1.592	1.207	0.026	13.91	-0.0566	3.60%	1.0	1.671%

RADMODL
MODELING MANUAL

ANNEX 5

LANTHANUM MEDIUM, LANTHANUM RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.003	0.464	0.161	11.39	-0.0760	0.0 %	2.0	0.025%
0.020	1.007	0.390	0.194	13.63	-0.0649	0.10%	0.5	0.029%
0.030	1.021	0.349	0.221	14.76	-0.0813	0.10%	10.0	0.034%
0.040	1.891	1.773	0.052	10.42	-0.0383	12.10%	3.0	5.206%
0.050	1.820	1.285	0.095	21.62	-0.1009	9.10%	3.0	4.835%
0.060	1.693	0.781	0.181	16.56	-0.1494	2.30%	1.0	1.224%
0.080	1.602	0.212	-0.056	14.11	0.0650	0.30%	1.0	0.156%
0.100	1.453	0.043	0.640	14.28	-0.1659	0.60%	1.0	0.245%
0.150	1.429	0.109	0.549	13.75	-0.2886	1.80%	0.5	0.796%
0.200	1.518	0.212	0.394	13.84	-0.2265	2.30%	0.5	0.999%
0.300	1.809	0.349	0.271	13.54	-0.1550	2.50%	0.5	1.151%
0.400	2.080	0.487	0.199	13.86	-0.1328	3.60%	0.5	1.555%
0.500	2.102	0.617	0.139	13.88	-0.0990	3.00%	0.5	1.414%
0.600	2.185	0.687	0.111	13.71	-0.0842	2.90%	0.5	1.419%
0.800	2.211	0.786	0.076	13.61	-0.0650	2.70%	0.5	1.283%
1.000	2.173	0.841	0.059	13.53	-0.0569	2.20%	0.5	1.175%
1.500	2.007	0.923	0.038	13.54	-0.0498	2.80%	0.5	1.224%
2.000	1.987	0.886	0.054	13.32	-0.0668	4.80%	0.5	2.089%
3.000	1.910	0.803	0.092	13.49	-0.1107	7.60%	0.5	3.350%
4.000	1.795	0.768	0.111	13.85	-0.1284	8.80%	0.5	3.717%
5.000	1.855	0.700	0.145	14.11	-0.1596	8.40%	0.5	3.922%
6.000	1.823	0.710	0.145	14.27	-0.1574	8.00%	0.5	3.769%
8.000	1.906	0.777	0.129	14.28	-0.1449	7.20%	0.5	3.568%
10.000	1.887	0.930	0.087	14.06	-0.1104	6.90%	0.5	3.236%
15.000	1.987	1.151	0.050	13.77	-0.0849	4.90%	0.5	2.611%

RADMODL
MODELING MANUAL

ANNEX 5

LANTHANUM MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.003	0.501	0.128	11.60	-0.0387	0.10%	6.0	0.028%
0.020	1.007	0.414	0.172	17.10	-0.0603	0.10%	0.5	0.028%
0.030	1.022	0.322	0.244	13.95	-0.0909	0.10%	35.0	0.029%
0.040	2.921	1.788	0.049	10.98	-0.0358	12.30%	3.0	5.336%
0.050	3.127	1.311	0.089	20.24	-0.0771	9.10%	3.0	5.153%
0.060	2.825	0.774	0.184	16.36	-0.1517	2.80%	1.0	1.540%
0.080	2.048	0.212	-0.124	16.38	0.0663	0.70%	1.0	0.319%
0.100	1.470	0.039	0.661	14.46	-0.1664	0.70%	1.0	0.270%
0.150	1.194	0.236	0.361	13.74	-0.2061	1.40%	0.5	0.587%
0.200	1.194	0.450	0.195	14.20	-0.1044	1.10%	0.5	0.441%
0.300	1.308	0.580	0.131	13.84	-0.0623	0.60%	5.0	0.385%
0.400	1.416	0.713	0.087	14.12	-0.0505	0.80%	5.0	0.459%
0.500	1.488	0.803	0.060	14.10	-0.0399	0.90%	5.0	0.464%
0.600	1.534	0.865	0.041	13.81	-0.0304	0.90%	5.0	0.445%
0.800	1.588	0.934	0.023	13.66	-0.0234	0.90%	5.0	0.394%
1.000	1.602	0.974	0.014	13.24	-0.0222	0.70%	25.0	0.412%
1.500	1.538	1.072	-0.009	13.64	-0.0108	0.60%	1.0	0.277%
2.000	1.553	1.044	0.002	13.08	-0.0225	0.90%	4.0	0.628%
3.000	1.543	1.009	0.019	13.39	-0.0447	3.40%	0.5	1.518%
4.000	1.523	0.970	0.037	13.74	-0.0609	4.10%	0.5	1.821%
5.000	1.611	0.888	0.070	13.96	-0.0893	4.80%	0.5	2.332%
6.000	1.650	0.884	0.076	14.19	-0.0919	4.50%	0.5	2.307%
8.000	1.847	0.929	0.073	14.18	-0.0906	4.00%	0.5	2.245%
10.000	1.918	1.097	0.035	14.06	-0.0582	2.90%	0.5	1.639%
15.000	2.180	1.316	0.008	13.68	-0.0396	1.90%	1.0	1.063%

RADMODL
MODELING MANUAL

ANNEX 5

GADOLINIUM MEDIUM, GADOLINIUM RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.002	0.539	0.111	11.48	-0.0337	0.10%	0.5	0.032%
0.020	1.005	0.393	0.191	10.33	-0.0581	0.10%	4.0	0.025%
0.030	1.015	0.325	0.239	14.39	-0.0881	0.10%	2.0	0.031%
0.040	1.031	0.310	0.258	14.22	-0.1014	0.10%	2.0	0.026%
0.050	1.053	0.323	0.243	14.30	-0.0957	0.10%	2.0	0.061%
0.060	1.777	1.500	0.063	29.33	-0.1035	10.20%	40.0	5.175%
0.080	1.734	0.587	0.245	16.07	-0.2151	2.10%	35.0	1.262%
0.100	1.643	0.237	-0.007	18.36	0.0556	0.30%	0.5	0.166%
0.150	1.467	0.060	0.678	14.02	-0.3125	1.20%	0.5	0.558%
0.200	1.485	0.144	0.486	13.76	-0.2671	2.10%	0.5	0.942%
0.300	1.657	0.287	0.316	13.38	-0.1787	2.40%	0.5	1.089%
0.400	1.879	0.411	0.240	13.78	-0.1558	3.10%	0.5	1.413%
0.500	2.022	0.511	0.187	13.85	-0.1264	3.40%	0.5	1.551%
0.600	1.976	0.614	0.137	13.66	-0.0950	2.70%	0.5	1.340%
0.800	2.062	0.711	0.100	13.60	-0.0757	2.60%	0.5	1.317%
1.000	2.067	0.772	0.080	13.51	-0.0669	2.40%	0.5	1.293%
1.500	1.903	0.891	0.046	13.68	-0.0522	2.90%	0.5	1.244%
2.000	1.884	0.865	0.060	13.37	-0.0694	5.10%	0.5	2.174%
3.000	1.785	0.801	0.093	13.53	-0.1111	7.90%	0.5	3.415%
4.000	1.650	0.788	0.104	13.87	-0.1217	9.40%	0.5	3.696%
5.000	1.667	0.727	0.135	14.15	-0.1502	8.90%	0.5	3.901%
6.000	1.631	0.740	0.135	14.30	-0.1487	8.40%	0.5	3.754%
8.000	1.648	0.814	0.119	14.28	-0.1368	7.50%	0.5	3.548%
10.000	1.586	0.976	0.077	14.14	-0.1007	7.00%	0.5	3.072%
15.000	1.581	1.190	0.046	13.74	-0.0810	5.00%	0.5	2.512%

RADMODL
MODELING MANUAL

ANNEX 5

GADOLINIUM MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.003	0.261	0.299	21.25	-0.2771	0.10%	1.0	0.034%
0.020	1.005	0.393	0.195	12.95	-0.0802	0.10%	15.0	0.028%
0.030	1.015	0.326	0.241	13.87	-0.0885	0.10%	35.0	0.022%
0.040	1.031	0.312	0.256	14.14	-0.0997	0.10%	8.0	0.032%
0.050	1.051	0.324	0.248	14.02	-0.1050	0.10%	10.0	0.065%
0.060	2.512	1.510	0.062	28.83	-0.1054	10.40%	20.0	5.657%
0.080	2.104	0.593	0.243	15.93	-0.2151	2.40%	35.0	1.390%
0.100	1.617	0.241	-0.007	19.33	0.0608	0.30%	0.5	0.173%
0.150	1.198	0.149	0.473	13.83	-0.2602	1.00%	0.5	0.498%
0.200	1.159	0.389	0.229	14.18	-0.1218	1.10%	0.5	0.442%
0.300	1.233	0.544	0.143	13.81	-0.0659	0.50%	0.5	0.335%
0.400	1.321	0.669	0.099	14.23	-0.0534	0.70%	35.0	0.413%
0.500	1.394	0.744	0.076	14.15	-0.0447	0.70%	5.0	0.443%
0.600	1.442	0.800	0.058	13.75	-0.0359	0.80%	5.0	0.461%
0.800	1.506	0.872	0.038	13.69	-0.0279	0.90%	5.0	0.431%
1.000	1.527	0.929	0.023	13.52	-0.0222	0.90%	5.0	0.414%
1.500	1.495	1.023	0.003	14.01	-0.0176	0.60%	35.0	0.279%
2.000	1.496	1.042	0.001	13.15	-0.0192	1.50%	0.5	0.657%
3.000	1.488	1.014	0.018	13.26	-0.0438	3.60%	0.5	1.536%
4.000	1.466	0.987	0.033	13.74	-0.0572	4.20%	0.5	1.804%
5.000	1.533	0.915	0.063	13.98	-0.0835	5.40%	0.5	2.377%
6.000	1.563	0.915	0.069	14.16	-0.0873	5.20%	0.5	2.378%
8.000	1.726	0.966	0.066	14.13	-0.0861	5.00%	0.5	2.398%
10.000	1.793	1.127	0.033	13.96	-0.0587	3.40%	0.5	1.736%
15.000	2.000	1.358	0.005	13.71	-0.0370	2.70%	1.0	1.253%

RADMODL
MODELING MANUAL

ANNEX 5

TUNGSTEN MEDIUM, TUNGSTEN RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.002	0.293	0.254	28.31	-0.3727	0.10%	2.0	0.034%
0.020	1.003	0.468	0.137	25.30	-0.0820	0.10%	3.0	0.028%
0.030	1.009	0.357	0.220	13.52	-0.0868	0.10%	7.0	0.029%
0.040	1.019	0.320	0.251	13.89	-0.1026	0.10%	0.5	0.029%
0.050	1.034	0.296	0.263	14.01	-0.0992	0.10%	2.0	0.050%
0.060	1.054	0.284	0.277	13.97	-0.1120	0.30%	0.5	0.103%
0.080	1.984	1.385	0.089	12.82	-0.0580	10.30%	3.0	4.997%
0.100	1.790	0.836	0.168	16.34	-0.1388	2.80%	1.0	1.488%
0.150	1.594	0.107	0.313	24.26	-0.0182	0.90%	2.0	0.399%
0.200	1.521	0.074	0.631	13.95	-0.3015	1.20%	2.0	0.621%
0.300	1.559	0.203	0.396	13.31	-0.2181	2.30%	0.5	1.027%
0.400	1.678	0.326	0.294	13.71	-0.1849	2.90%	0.5	1.289%
0.500	1.793	0.418	0.235	13.74	-0.1529	3.20%	0.5	1.426%
0.600	1.715	0.537	0.166	13.58	-0.1058	2.20%	0.5	1.134%
0.800	1.834	0.627	0.128	13.58	-0.0851	2.50%	0.5	1.228%
1.000	1.872	0.692	0.105	13.53	-0.0762	2.50%	0.5	1.292%
1.500	1.784	0.841	0.059	13.85	-0.0560	2.60%	0.5	1.180%
2.000	1.764	0.842	0.065	13.44	-0.0686	5.40%	0.5	2.169%
3.000	1.659	0.813	0.087	13.54	-0.1032	8.80%	0.5	3.424%
4.000	1.542	0.800	0.100	13.85	-0.1176	9.90%	0.5	3.744%
5.000	1.527	0.756	0.125	14.14	-0.1422	10.20%	0.5	4.125%
6.000	1.485	0.758	0.131	14.29	-0.1478	9.70%	0.5	4.062%
8.000	1.482	0.803	0.128	14.31	-0.1487	8.90%	0.5	4.023%
10.000	1.432	0.957	0.088	14.21	-0.1128	8.60%	0.5	3.548%
15.000	1.432	1.160	0.059	13.89	-0.0949	7.10%	0.5	3.222%

RADMODL
MODELING MANUAL

ANNEX 5

TUNGSTEN MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.002	0.317	0.228	33.67	-0.4556	0.10%	2.0	0.032%
0.020	1.003	0.468	0.137	25.30	-0.0820	0.10%	3.0	0.028%
0.030	1.009	0.388	0.187	19.12	-0.0843	0.10%	1.0	0.031%
0.040	1.019	0.320	0.251	13.89	-0.1026	0.10%	1.0	0.038%
0.050	1.033	0.299	0.264	13.96	-0.1066	0.10%	7.0	0.053%
0.060	1.048	0.314	0.257	14.20	-0.1100	0.10%	35.0	0.088%
0.080	2.238	1.442	0.079	17.80	-0.0858	10.90%	25.0	6.249%
0.100	1.764	0.867	0.160	15.88	-0.1366	2.90%	4.0	1.753%
0.150	1.253	0.145	0.353	15.12	-0.0845	0.40%	0.5	0.152%
0.200	1.155	0.248	0.347	13.68	-0.1966	0.90%	0.5	0.466%
0.300	1.170	0.487	0.168	13.62	-0.0812	0.60%	0.5	0.326%
0.400	1.234	0.601	0.123	14.14	-0.0647	0.60%	25.0	0.378%
0.500	1.293	0.672	0.098	14.13	-0.0532	0.60%	25.0	0.405%
0.600	1.338	0.722	0.080	13.69	-0.0438	0.70%	5.0	0.415%
0.800	1.402	0.797	0.057	13.71	-0.0334	0.70%	25.0	0.410%
1.000	1.436	0.853	0.042	13.34	-0.0285	0.80%	5.0	0.426%
1.500	1.421	0.977	0.013	14.30	-0.0205	0.50%	4.0	0.258%
2.000	1.428	1.012	0.007	13.40	-0.0200	1.30%	0.5	0.665%
3.000	1.406	1.023	0.014	13.42	-0.0385	3.30%	0.5	1.351%
4.000	1.363	1.037	0.018	13.72	-0.0437	4.20%	0.5	1.555%
5.000	1.393	0.964	0.049	13.94	-0.0723	5.40%	0.5	2.246%
6.000	1.397	0.963	0.056	14.34	-0.0769	5.50%	0.5	2.371%
8.000	1.465	0.990	0.063	14.15	-0.0848	5.80%	0.5	2.583%
10.000	1.475	1.151	0.031	14.10	-0.0561	4.50%	0.5	1.890%
15.000	1.589	1.335	0.016	13.60	-0.0494	3.40%	0.5	1.708%

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RADMODL
MODELING MANUAL

ANNEX 5

LEAD MEDIUM, LEAD RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	0.0	0.0	0.0	0.0	0.0	0.0 %	0.0	0.0 %
0.020	0.0	0.0	0.0	0.0	0.0	0.0 %	0.0	0.0 %
0.030	1.007	0.309	0.264	13.16	-0.1229	0.10%	2.0	0.023%
0.040	1.014	0.304	0.262	13.53	-0.0970	0.10%	35.0	0.026%
0.050	1.024	0.294	0.267	14.35	-0.1097	0.10%	0.5	0.033%
0.060	1.036	0.300	0.272	13.88	-0.1245	0.10%	2.0	0.058%
0.080	1.076	0.277	0.297	13.69	-0.1425	0.30%	2.0	0.140%
0.100	1.934	1.336	0.096	12.88	-0.0695	9.40%	3.0	4.893%
0.150	1.728	0.304	0.298	27.59	-0.0003	2.70%	0.5	1.087%
0.200	1.589	0.078	0.489	17.42	-0.1064	0.80%	1.0	0.315%
0.300	1.530	0.144	0.476	13.28	-0.2522	2.00%	0.5	0.959%
0.400	1.594	0.262	0.347	13.60	-0.2151	2.90%	0.5	1.225%
0.500	1.674	0.352	0.276	13.67	-0.1762	3.10%	0.5	1.343%
0.600	1.555	0.496	0.181	13.55	-0.1093	2.00%	0.5	0.976%
0.800	1.685	0.570	0.149	13.53	-0.0930	2.20%	0.5	1.127%
1.000	1.741	0.635	0.124	13.51	-0.0829	2.50%	0.5	1.235%
1.500	1.719	0.784	0.076	13.99	-0.0636	3.20%	0.5	1.311%
2.000	1.730	0.784	0.084	13.50	-0.0798	6.20%	0.5	2.379%
3.000	1.642	0.764	0.104	13.62	-0.1140	9.50%	0.5	3.604%
4.000	1.524	0.764	0.112	13.91	-0.1241	10.30%	0.5	3.789%
5.000	1.521	0.714	0.141	14.20	-0.1537	10.50%	0.5	4.202%
6.000	1.475	0.737	0.138	14.36	-0.1503	10.50%	0.5	4.142%
8.000	1.480	0.791	0.132	14.35	-0.1495	9.70%	0.5	4.150%
10.000	1.428	0.963	0.086	14.23	-0.1084	9.60%	0.5	3.630%
15.000	1.437	1.152	0.062	13.87	-0.0968	8.10%	0.5	3.454%

RADMODL
MODELING MANUAL

ANNEX 5

LEAD MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	0.0	0.0	0.0	0.0	0.0	0.0 %	0.0	0.0 %
0.020	0.0	0.0	0.0	0.0	0.0	0.0 %	0.0	0.0 %
0.030	1.007	0.322	0.246	13.67	-0.1030	0.0 %	0.5	0.020%
0.040	1.014	0.317	0.245	14.95	-0.0867	0.10%	0.5	0.035%
0.050	1.023	0.312	0.252	14.17	-0.1005	0.10%	0.5	0.044%
0.060	1.033	0.320	0.260	13.89	-0.1223	0.10%	4.0	0.058%
0.080	1.058	0.362	0.233	13.91	-0.1127	0.20%	0.5	0.115%
0.100	1.930	1.499	0.061	29.65	-0.1162	10.10%	40.0	4.366%
0.150	1.402	0.352	0.269	17.09	-0.0247	1.10%	0.5	0.581%
0.200	1.201	0.158	0.426	14.12	-0.1873	0.30%	10.0	0.202%
0.300	1.148	0.422	0.203	13.49	-0.1013	0.80%	0.5	0.364%
0.400	1.187	0.562	0.137	14.19	-0.0706	0.60%	0.5	0.351%
0.500	1.233	0.634	0.109	14.20	-0.0556	0.60%	0.5	0.380%
0.600	1.269	0.685	0.089	13.78	-0.0440	0.60%	1.0	0.360%
0.800	1.329	0.759	0.065	13.69	-0.0317	0.80%	1.0	0.394%
1.000	1.367	0.811	0.051	13.67	-0.0283	0.80%	1.0	0.416%
1.500	1.369	0.942	0.020	14.65	-0.0207	0.90%	1.0	0.336%
2.000	1.384	0.980	0.014	13.51	-0.0216	1.70%	0.5	0.675%
3.000	1.367	1.006	0.017	13.33	-0.0377	3.40%	0.5	1.304%
4.000	1.337	1.009	0.024	14.15	-0.0455	3.70%	0.5	1.464%
5.000	1.360	0.957	0.049	14.04	-0.0683	5.40%	0.5	2.117%
6.000	1.363	0.965	0.054	14.21	-0.0716	5.70%	0.5	2.211%
8.000	1.441	0.994	0.061	14.18	-0.0800	5.80%	0.5	2.450%
10.000	1.464	1.148	0.032	14.08	-0.0554	4.10%	0.5	1.733%
15.000	1.573	1.337	0.016	13.54	-0.0463	3.50%	0.5	1.755%

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ANNEX 5

URANIUM MEDIUM, URANIUM RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	0.0	0.0	0.0	0.0	0.0	0.0 %	0.0	0.0 %
0.020	0.0	0.0	0.0	0.0	0.0	0.0 %	0.0	0.0 %
0.030	1.005	0.336	0.224	25.06	-0.2039	0.0 %	8.0	0.021%
0.040	1.010	0.301	0.257	14.81	-0.0871	0.10%	2.0	0.032%
0.050	1.016	0.323	0.235	15.31	-0.0834	0.10%	1.0	0.040%
0.060	1.025	0.287	0.282	14.53	-0.1333	0.10%	2.0	0.035%
0.080	1.051	0.269	0.303	13.80	-0.1469	0.20%	0.5	0.125%
0.100	1.083	0.275	0.301	13.80	-0.1524	0.30%	0.5	0.172%
0.150	1.832	0.976	0.134	16.75	-0.1034	3.70%	1.0	1.872%
0.200	1.759	0.334	0.147	13.39	-0.0426	0.20%	0.5	0.095%
0.300	1.587	0.089	0.563	13.59	-0.2424	1.10%	2.0	0.508%
0.400	1.571	0.179	0.441	13.56	-0.2670	2.50%	0.5	1.152%
0.500	1.592	0.272	0.339	13.60	-0.2137	2.90%	0.5	1.298%
0.600	1.464	0.420	0.220	13.49	-0.1309	2.10%	0.5	0.981%
0.800	1.571	0.493	0.183	13.47	-0.1102	2.30%	0.5	1.104%
1.000	1.591	0.574	0.146	13.46	-0.0912	2.10%	0.5	1.114%
1.500	1.643	0.702	0.104	14.01	-0.0780	3.30%	0.5	1.417%
2.000	1.677	0.715	0.107	13.60	-0.0909	6.70%	0.5	2.502%
3.000	1.612	0.707	0.123	13.68	-0.1233	10.00%	0.5	3.600%
4.000	1.518	0.704	0.132	14.03	-0.1340	10.50%	0.5	3.770%
5.000	1.514	0.674	0.153	14.30	-0.1542	11.50%	0.5	4.230%
6.000	1.487	0.680	0.158	14.45	-0.1618	10.80%	0.5	4.147%
8.000	1.492	0.762	0.139	14.43	-0.1499	10.80%	0.5	4.226%
10.000	1.461	0.911	0.100	14.26	-0.1188	9.80%	0.5	3.690%
15.000	1.468	1.114	0.070	13.88	-0.1022	8.60%	0.5	3.562%

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ANNEX 5

URANIUM MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	0.0	0.0	0.0	0.0	0.0	0.0 %	0.0	0.0 %
0.020	0.0	0.0	0.0	0.0	0.0	0.0 %	0.0	0.0 %
0.030	1.005	0.336	0.224	25.06	-0.2039	0.0 %	8.0	0.021%
0.040	1.010	0.296	0.272	14.23	-0.1199	0.10%	2.0	0.028%
0.050	1.016	0.313	0.248	13.81	-0.0893	0.10%	10.0	0.029%
0.060	1.022	0.336	0.244	14.48	-0.1157	0.10%	2.0	0.036%
0.080	1.039	0.357	0.236	13.87	-0.1154	0.20%	0.5	0.093%
0.100	1.057	0.390	0.217	13.78	-0.1096	0.20%	3.0	0.125%
0.150	1.598	1.030	0.122	16.02	-0.0996	4.00%	1.0	2.002%
0.200	1.324	0.366	0.167	13.28	-0.0655	0.20%	3.0	0.108%
0.300	1.160	0.284	0.304	13.28	-0.1643	0.80%	0.5	0.419%
0.400	1.157	0.490	0.171	13.96	-0.0911	0.90%	0.5	0.417%
0.500	1.185	0.577	0.131	14.05	-0.0682	0.70%	0.5	0.389%
0.600	1.207	0.643	0.101	13.80	-0.0473	0.60%	1.0	0.332%
0.800	1.261	0.705	0.080	13.89	-0.0362	0.70%	1.0	0.353%
1.000	1.298	0.754	0.066	13.69	-0.0325	0.70%	1.0	0.404%
1.500	1.320	0.873	0.038	14.78	-0.0282	0.60%	10.0	0.345%
2.000	1.338	0.923	0.028	13.56	-0.0274	1.60%	0.5	0.691%
3.000	1.326	0.968	0.024	13.45	-0.0372	3.20%	0.5	1.172%
4.000	1.299	0.984	0.027	13.84	-0.0418	3.50%	0.5	1.280%
5.000	1.327	0.932	0.052	14.08	-0.0638	5.10%	0.5	1.903%
6.000	1.339	0.935	0.058	14.53	-0.0676	5.10%	0.5	1.982%
8.000	1.422	0.973	0.063	14.26	-0.0761	5.30%	0.5	2.190%
10.000	1.451	1.133	0.032	14.31	-0.0502	3.70%	0.5	1.486%
15.000	1.557	1.328	0.015	13.75	-0.0405	3.60%	0.5	1.573%

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ANNEX 5

WATER MEDIUM, WATER RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.188	0.464	0.172	14.00	-0.0829	1.37%	0.5	0.508%
0.020	1.449	0.532	0.152	14.61	-0.0764	1.91%	0.5	0.730%
0.030	2.411	0.741	0.084	14.62	-0.0452	2.29%	0.5	1.065%
0.040	3.587	1.114	-0.018	12.48	0.0013	0.68%	0.5	0.248%
0.050	4.554	1.457	-0.084	13.69	0.0341	1.47%	35.0	0.977%
0.060	5.018	1.735	-0.127	13.70	0.0676	2.37%	35.0	1.564%
0.080	5.030	2.054	-0.167	13.84	0.0763	3.00%	35.0	1.982%
0.100	4.627	2.207	-0.184	13.27	0.0799	2.98%	10.0	1.885%
0.150	3.888	2.206	-0.180	14.27	0.0738	2.37%	0.5	1.478%
0.200	3.462	2.132	-0.173	14.51	0.0750	2.36%	0.5	1.335%
0.300	2.897	2.008	-0.162	14.18	0.0641	2.40%	35.0	1.412%
0.400	2.646	1.874	-0.148	14.16	0.0591	2.41%	35.0	1.377%
0.500	2.499	1.749	-0.132	14.36	0.0517	2.00%	1.0	1.195%
0.600	2.383	1.662	-0.121	14.19	0.0482	1.97%	35.0	1.224%
0.800	2.223	1.524	-0.101	14.31	0.0403	1.97%	1.0	1.078%
1.000	2.106	1.436	-0.088	14.19	0.0367	1.68%	0.5	0.970%
1.500	1.948	1.265	-0.057	14.98	0.0245	1.51%	0.5	0.616%
2.000	1.843	1.169	-0.038	14.22	0.0157	1.61%	0.5	0.551%
3.000	1.716	1.050	-0.011	13.63	0.0027	0.97%	0.5	0.314%
4.000	1.633	0.979	0.007	14.23	-0.0060	0.65%	0.5	0.252%
5.000	1.571	0.928	0.022	13.20	-0.0157	0.62%	4.0	0.336%
6.000	1.521	0.893	0.033	11.92	-0.0208	1.87%	1.0	0.636%
8.000	1.432	0.873	0.038	11.56	-0.0204	0.59%	3.0	0.355%
10.000	1.378	0.849	0.045	14.34	-0.0280	0.98%	0.5	0.574%
15.000	1.280	0.829	0.052	14.85	-0.0367	1.23%	3.0	0.688%

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ANNEX 5

WATER MEDIUM, AIR RESPONSE

E (MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.182	0.463	0.175	14.23	-0.0908	1.69%	0.5	0.634%
0.020	1.427	0.549	0.143	14.86	-0.0707	2.31%	0.5	0.780%
0.030	2.335	0.736	0.087	13.28	-0.0419	2.34%	0.5	1.180%
0.040	3.477	1.117	-0.019	11.67	0.0026	0.89%	0.5	0.298%
0.050	4.461	1.457	-0.084	13.62	0.0341	1.26%	10.0	0.850%
0.060	4.983	1.730	-0.126	13.64	0.0561	2.22%	10.0	1.563%
0.080	5.059	2.059	-0.168	13.67	0.0770	2.94%	35.0	1.946%
0.100	4.663	2.221	-0.186	13.33	0.0826	3.02%	10.0	1.925%
0.150	3.897	2.242	-0.185	14.19	0.0777	2.55%	15.0	1.584%
0.200	3.478	2.154	-0.176	14.50	0.0774	2.50%	0.5	1.492%
0.300	2.920	2.022	-0.164	14.21	0.0655	2.46%	1.0	1.471%
0.400	2.660	1.882	-0.149	14.24	0.0595	2.17%	35.0	1.372%
0.500	2.500	1.766	-0.135	14.33	0.0546	2.46%	1.0	1.380%
0.600	2.377	1.679	-0.124	14.23	0.0503	2.02%	1.0	1.265%
0.800	2.212	1.544	-0.105	14.36	0.0437	1.97%	0.5	1.186%
1.000	2.103	1.441	-0.089	14.22	0.0378	1.55%	0.5	0.895%
1.500	1.939	1.269	-0.058	14.52	0.0246	1.91%	0.5	0.757%
2.000	1.839	1.173	-0.039	14.07	0.0161	1.45%	0.5	0.522%
3.000	1.710	1.056	-0.013	11.82	0.0047	0.70%	0.5	0.239%
4.000	1.621	0.989	0.004	13.45	-0.0041	0.55%	1.0	0.211%
5.000	1.554	0.939	0.018	13.55	-0.0122	0.51%	30.0	0.333%
6.000	1.507	0.903	0.029	16.13	-0.0272	0.85%	25.0	0.475%
8.000	1.422	0.879	0.035	13.36	-0.0191	0.89%	0.5	0.445%
10.000	1.362	0.859	0.042	13.37	-0.0247	0.90%	0.5	0.453%
15.000	1.267	0.843	0.047	15.08	-0.0336	1.02%	1.0	0.604%

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ANNEX 5

CONCRETE MEDIUM, CONCRETE RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.028	0.429	0.174	27.56	-0.2976	0.58%	4.0	0.282%
0.020	1.067	0.396	0.204	13.32	-0.0960	0.74%	0.5	0.414%
0.030	1.220	0.403	0.212	14.44	-0.1160	1.01%	0.5	0.558%
0.040	1.472	0.489	0.172	14.92	-0.0943	1.94%	0.5	0.766%
0.050	1.826	0.602	0.127	15.51	-0.0687	1.30%	2.0	0.638%
0.060	2.249	0.723	0.087	16.62	-0.0622	1.30%	2.0	0.563%
0.080	3.263	0.885	0.045	14.03	-0.0402	1.15%	10.0	0.700%
0.100	3.867	1.101	-0.009	13.91	-0.0161	0.80%	2.0	0.367%
0.150	4.066	1.413	-0.072	13.89	0.0174	2.67%	0.5	1.007%
0.200	3.682	1.552	-0.095	13.73	0.0285	2.96%	0.5	1.182%
0.300	3.090	1.617	-0.106	14.23	0.0331	2.21%	0.5	1.085%
0.400	2.774	1.593	-0.104	14.36	0.0323	2.22%	0.5	1.000%
0.500	2.572	1.552	-0.099	14.76	0.0315	1.61%	0.5	0.799%
0.600	2.433	1.507	-0.093	14.78	0.0296	1.99%	0.5	0.833%
0.800	2.243	1.429	-0.082	14.85	0.0270	1.79%	0.5	0.687%
1.000	2.124	1.359	-0.071	15.31	0.0243	1.48%	0.5	0.563%
1.500	1.934	1.249	-0.053	14.53	0.0201	1.18%	0.5	0.497%
2.000	1.834	1.161	-0.035	13.88	0.0117	0.75%	2.0	0.332%
3.000	1.701	1.051	-0.009	10.11	-0.0021	0.42%	0.5	0.180%
4.000	1.613	0.981	0.010	12.99	-0.0133	0.64%	4.0	0.331%
5.000	1.551	0.919	0.030	11.99	-0.0263	2.82%	0.5	0.979%
6.000	1.475	0.930	0.024	15.87	-0.0273	0.80%	10.0	0.475%
8.000	1.383	0.909	0.031	12.43	-0.0218	1.21%	1.0	0.573%
10.000	1.320	0.902	0.033	14.83	-0.0258	1.49%	1.0	0.710%
15.000	1.229	0.866	0.048	15.03	-0.0426	1.25%	10.0	0.806%

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ANNEX 5

CONCRETE MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.029	0.364	0.240	14.12	-0.1704	0.46%	25.0	0.236%
0.020	1.067	0.389	0.214	12.68	-0.1126	0.72%	0.5	0.359%
0.030	1.212	0.421	0.201	14.12	-0.1079	1.56%	0.5	0.610%
0.040	1.455	0.493	0.171	14.53	-0.0925	2.01%	0.5	0.831%
0.050	1.737	0.628	0.115	15.82	-0.0600	0.97%	2.0	0.499%
0.060	2.125	0.664	0.118	11.90	-0.0615	2.90%	0.5	1.389%
0.080	2.557	0.895	0.042	14.37	-0.0413	1.86%	0.5	0.958%
0.100	2.766	1.069	0.001	12.64	-0.0251	1.14%	35.0	0.623%
0.150	2.812	1.319	-0.050	8.75	-0.0040	0.41%	5.0	0.269%
0.200	2.716	1.430	-0.070	18.52	0.0108	0.50%	0.5	0.164%
0.300	2.522	1.492	-0.082	16.59	0.0161	0.49%	40.0	0.246%
0.400	2.372	1.494	-0.085	15.96	0.0194	0.40%	25.0	0.195%
0.500	2.271	1.466	-0.082	16.25	0.0195	0.28%	15.0	0.163%
0.600	2.192	1.434	-0.078	17.02	0.0199	0.55%	1.0	0.242%
0.800	2.066	1.386	-0.073	15.07	0.0202	0.68%	35.0	0.296%
1.000	1.982	1.332	-0.065	15.38	0.0193	0.46%	35.0	0.189%
1.500	1.848	1.227	-0.047	16.41	0.0160	0.64%	0.5	0.317%
2.000	1.775	1.154	-0.033	14.35	0.0100	0.64%	40.0	0.194%
3.000	1.671	1.054	-0.010	10.47	-0.0008	0.31%	3.0	0.152%
4.000	1.597	0.988	0.008	12.53	-0.0115	0.81%	1.0	0.433%
5.000	1.531	0.945	0.022	10.26	-0.0199	0.59%	40.0	0.335%
6.000	1.478	0.940	0.021	13.11	-0.0163	1.30%	0.5	0.560%
8.000	1.395	0.917	0.028	13.45	-0.0213	1.42%	0.5	0.604%
10.000	1.334	0.901	0.035	12.56	-0.0267	1.48%	0.5	0.623%
15.000	1.260	0.823	0.065	14.28	-0.0581	1.96%	3.0	1.151%

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ANNEX 5

AIR MEDIUM, AIR RESPONSE

E(MEV)	B	C	A	XK	D	MAX.D	XMAX	S.D
0.015	1.170	0.459	0.175	13.73	-0.0862	1.45%	0.5	0.512%
0.020	1.407	0.512	0.161	14.40	-0.0819	2.15%	0.5	0.830%
0.030	2.292	0.693	0.102	13.34	-0.0484	2.48%	0.5	1.240%
0.040	3.390	1.052	-0.004	19.76	-0.0068	0.95%	0.5	0.383%
0.050	4.322	1.383	-0.071	13.51	0.0270	1.19%	4.0	0.782%
0.060	4.837	1.653	-0.115	13.66	0.0511	2.37%	0.5	1.422%
0.080	4.929	1.983	-0.159	13.74	0.0730	2.73%	10.0	1.909%
0.100	4.580	2.146	-0.178	12.83	0.0759	2.69%	1.0	1.733%
0.150	3.894	2.148	-0.173	14.46	0.0698	2.51%	35.0	1.506%
0.200	3.345	2.147	-0.176	14.08	0.0719	2.51%	35.0	1.540%
0.300	2.887	1.990	-0.160	14.13	0.0633	2.29%	25.0	1.450%
0.400	2.635	1.860	-0.146	14.24	0.0583	2.17%	35.0	1.377%
0.500	2.496	1.736	-0.130	14.32	0.0505	2.30%	1.0	1.267%
0.600	2.371	1.656	-0.120	14.27	0.0472	1.80%	25.0	1.198%
0.800	2.207	1.532	-0.103	14.12	0.0425	1.92%	0.5	1.131%
1.000	2.102	1.428	-0.086	14.35	0.0344	1.63%	0.5	0.858%
1.500	1.939	1.265	-0.057	14.24	0.0232	1.22%	0.5	0.610%
2.000	1.835	1.173	-0.039	14.07	0.0161	1.31%	0.5	0.534%
3.000	1.712	1.051	-0.011	13.67	0.0024	0.81%	0.5	0.254%
4.000	1.627	0.983	0.006	13.51	-0.0051	0.44%	5.0	0.257%
5.000	1.558	0.943	0.017	13.82	-0.0117	0.76%	1.0	0.371%
6.000	1.505	0.915	0.025	16.37	-0.0231	0.99%	1.0	0.513%
8.000	1.418	0.891	0.032	12.06	-0.0167	1.12%	0.5	0.418%
10.000	1.358	0.875	0.037	14.01	-0.0226	1.16%	0.5	0.547%
15.000	1.267	0.844	0.048	14.55	-0.0344	1.08%	4.0	0.651%

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Appendix D

Subroutines and COMMONs

The various subroutines and their functions in program QADSR are listed in Table D1. The common blocks in each routine and their contents are listed in Table D2.

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Table D1: Routines in Program QADSR

Routine	Function
MAIN	Main program. Sets detector coordinates. Also calculates uncollided gamma flux and dose rate with and without buildup
QADHEADR	Writes headings to start program, headings for top of each page and headings for end of job
BLKDAT	Assigns number to certain parameters
INPUTGP	Reads input, sets source divisions, buildup material and attenuation coefficients in standard geometries
GEOMIN	Calls appropriate geometry set-up routine, calculates surface and region parameters
BOXGEO	Sets up geometry for standard box
CYLGEO	Sets up geometry for standard cylinder and annular cylinder
SPHGEO	Sets up geometry for standard sphere
GENGEO	Sets up geometry for general case
SOURCE	Calculates source strength associated with each source point
BUFACT	Provides buildup factor
READBF	Reads G-P buildup parameters

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SETP	Performs energy interpolation on G-P buildup parameters
LITEBF	Checks calculated G-P buildup factors
BUILD	Performs actual G-P buildup factor calculation
XSECQD	Provides gamma attenuation coefficients for non-standard materials
READX	Reads detector coordinates in general geometry problems
TITLE	Prints page titles
LENGTH	Calculates distance through a region along the source point-detector point ray
SHIFT	Performs circular shift of a vector in an array
KERNELGP	Calculates attenuation factors
PRINT	Prints results
FUNRD	Free form input routine
TERPU, TTRACE, IHUNT	Part of interpolation/extrapolation system TERP

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Table D2: Common Blocks and Their Distribution
in Program QADSR

Routine	Common	Variables
MAIN	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT
	BLOCAA	NTRYZN(50,200)
	BLOCKB	ID(10), NBMID(12,5), EG(30)
	BLOCKC	RSO(300), PHISO(300), ZSO(300), FL(300), FN(300), FM(300), GAMEN(30), CONV(30), ZSAV,XSAV
	GEOM	TSHLD, Z, DD, W, HL, H1, R0, RMIN, DISPD, TCLAD, MATL(10)
	BLDABC	PARAM(30,5)
	BLDDEF	BFSET(25,5)
	BLDMAT	MATGP,ICGP
	STDATA	NAME(100), ENRG(28), XSECO(28,100), XSECEA(28), C(4,6,9), EMINBB(8), NAMB(8), XSECNT(100), DCONST
QADHEADR	--	

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BLKDAT	TAPE	INT, IOUT, IEDT, INT1, INT2, IAGG, ITRAN, INTER
	PAREM	XB(3), WB(3), IR, WP(3), XP(3), RIN, ROUT, PINF, DIST, IR, IDBG, IRPRIM, NASC, LSURF, NBO, LRI, LRO, KLOOP, LOOP, ITYPE, N0A
	BLDMAT	MATGP,ICGP
	STDATA	NAME(100), ENRG(28), XSECO(28,100), XSECEA(28), C(4,6,9), EMINBB(8), NAMB(8), XSECNT(100), DCONST
	ORGI	DIST0, MARK, NMED, NBLZ, BLZOLD
INPUTGP	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT
	BLOCKB	ID(10), NBMID(12,5), EG(30)
	BLOCKC	RSO(300), PHISO(300), ZSO(300), FL(300), FN(300), FM(300), GAMEN(30), CONV(30), ZSAV,XSAV
	BLOCKD	ASO, XISO(2,3)
	BLOCKE	XSEC(20,30), BILD0(30), BILD1(30), BILD2(30), BILD3(30), NBLD
	BLOCKG	COMP(20,30), EPSLN, FUDGE

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	GEOM	TSHLD, Z, DD, W, HL, H1, R0, RMIN, DISPD, TCLAD, MATL(10)
	BLOCKY	VOL, FACTV, FACTC, FACTS, UNITSC
	T	THICK(9)
	FUN	SBUFF1, IPAR, RPAR
	BLDABC	PARAM(30,5)
	BLDDEF	BFSET(25,5)
	BLDMAT	MATGP,ICGP
	STDATA	NAME(100), ENRG(28), XSECO(28,100), XSECEA(28), C(4,6,9), EMINBB(8), NAMB(8), XSECNT(100), DCONST
	QADATA	EBAR(30), MATZ(20)
GEOMIN	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT
BOXGEO	GEOM	TSHLD, Z, DD, W, HL, H1, R0, RMIN, DISPD, TCLAD, MATL(10)
	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT

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CYLGEO	BLOCKF	ABD(10,200), BBD(3,200)
	GEOM	TSHLD, Z, DD, W, HL, H1, R0, RMIN, DISPD, TCLAD, MATL(10)
	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT
SPHGEO	BLOCKF	ABD(10,200), BBD(3,200)
	GEOM	TSHLD, Z, DD, W, HL, H1, R0, RMIN, DISPD, TCLAD, MATL(10)
	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT
GENGEO	BLOCKF	ABD(10,200), BBD(3,200)
	GEOM	TSHLD, Z, DD, W, HL, H1, R0, RMIN, DISPD, TCLAD, MATL(10)
	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT
SOURCE	BLOCKF	ABD(10,200), BBD(3,200)
	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200),

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BUFACT	BLOCKC	NEQBD(200), NASET(5), LITE1, ISPRT RSO(300), PHISO(300), ZSO(300), FL(300), FN(300), FM(300), GAMEN(30), CONV(30), ZSAV,XSAV
	BLOCKD	ASO, XISO(2,3)
	BLOCKY	VOL, FACTV, FACTC, FACTS, UNITSC
	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT
	BLOCKB	ID(10), NB MID(12,5), EG(30)
	BLOCKC	RSO(300), PHISO(300), ZSO(300), FL(300), FN(300), FM(300), GAMEN(30), CONV(30), ZSAV,XSAV
	BLOCKE	XSEC(20,30), BILD0(30), BILD1(30), BILD2(30), BILD3(30), NBLD
	GEOM	TSHLD, Z, DD, W, HL, H1, R0, RMIN, DISPD, TCLAD, MATL(10)
	T	THICK(9)
	BLDABC	PARAM(30,5)
	BLDDEF	BFSET(25,5)
	BLDMAT	MATGP,ICGP

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	STDATA	NAME(100), ENRG(28), XSECO(28,100), XSECEA(28), C(4,6,9), EMINBB(8), NAMB(8), XSECNT(100), DCONST
READBF	--	
SETP	--	
LITEBF	--	
BUILD	BLDABC	PARAM(30,5)
XSECQD	BLOCKA	NSET(35), IU, NCMPZN(200), LBD(15,200), NBNDZN(200), NEQBD(200), NASET(5), LITE1, ISPRT
	BLOCKB	ID(10), NB MID(12,5), EG(30)
	BLOCKE	XSEC(20,30), BILD0(30), BILD1(30), BILD2(30), BILD3(30), NBLD
	BLOCKG	COMP(20,30), EPSLN, FUDGE
	QADATA	EBAR(30), MATZ(20)
	FUN	SBUFF1, IPAR, RPAR
	BLDABC	PARAM(30,5)
	BLDDEF	BFSET(25,5)
	BLDMAT	MATGP,ICGP
	STDATA	NAME(100), ENRG(28), XSECO(28,100), XSECEA(28),

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C(4,6,9), EMINBB(8), NAMB(8),
XSECNT(100), DCONST

READX

--

TITLE

Prints page titles

LENGTH

BLOCKA

NSET(35), IU, NCMPZN(200),
LBD(15,200), NBNDZN(200),
NEQBD(200), NASET(5), LITE1,
ISPRT

BLOCAA

NTRYZN(50,200)

BLOCKE

XSEC(20,30), BILD0(30), BILD1(30),
BILD2(30), BILD3(30), NBLD

BLOCKF

ABD(10,200), BBD(3,200)

BLOCKG

COMP(20,30), EPSLN, FUDGE

SHIFT

BLOCAA

NTRYZN(50,200)

KERNELGP

BLOCKA

NSET(35), IU, NCMPZN(200),
LBD(15,200), NBNDZN(200),
NEQBD(200), NASET(5), LITE1,
ISPRT

BLOCKE

XSEC(20,30), BILD0(30), BILD1(30),
BILD2(30), BILD3(30), NBLD

GEOM

TSHLD, Z, DD, W, HL, H1,
R0, RMIN, DISPD, TCLAD,
MATL(10)

PRINT

BLOCKA

NSET(35), IU, NCMPZN(200),
LBD(15,200), NBNDZN(200),

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		NEQBD(200), NASET(5), LITE1, ISPRT
	BLOCKC	RSO(300), PHISO(300), ZSO(300), FL(300), FN(300), FM(300), GAMEN(30), CONV(30), ZSAV,XSAV
	GEOM	TSHLD, Z, DD, W, HL, H1, R0, RMIN, DISPD, TCLAD, MATL(10)
	BLOCKY	VOL, FACTV, FACTC, FACTS, UNITSC
FUNRD	INTRNL	REXP, FRACT, XNUMB,PART2, XIEC, PART1, IE, IP, IS, IPF, IWF, IXF, IEF, ISL1F, IDF, ISLF, IER, ITF, IIF, IEND, ISFLAG, IAPF
	FUN	SBUFF1, IPAR, RPAR
TERPU	--	
TTRACE	--	
IHUNT	--	

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6. PARABINT MODULE

6.1 Description of PARABINT Code

PARABINT was written in Fortran (R) and compiled with Microsoft 5.1 version of Fortran Compiler. The following is a listing of the filenames used to build the executable file PARABINT.EXE:

PARABINT.FOR

6.2 Compiler Options Used to Make PARABINT.EXE

FL /FPi87 /G2 /AH /c *.FOR /FePARABINT *.OBJ /link

6.3 Source Code Listing

The source code listing is contained in Volume 2, Source Code Listing, Volume PARABINT.

6.4 Documentation of PARABINT

See Annex 6

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PARABINT

I. INTRODUCTION

PARABINT is a program to integrate a set of data. The program approximates the data with a series of parabolas, using consecutive sets of three data points to define each parabola. The area between two consecutive points under the parabola can be determined analytically. For N points ($N > 3$) there will be $N-3$ areas for which the calculation is performed twice. Since the program was developed to integrate dose rates over time, for which a conservative result is usually required, the larger of the two values is chosen. The sum of the areas calculated represents the desired integral.

II. METHODOLOGY

The general equation of a parabola can be written as

$$(x+a)^2 - 2p(y+b) = 0 \quad (1)$$

or, expanding,

$$x^2 + 2ax + a^2 - 2py - 2pb = 0 \quad (2)$$

Let there be three points (x_1, y_1) , (x_2, y_2) , (x_3, y_3) . Substituting these into equation (2) we get

$$x_1^2 + 2ax_1 + a^2 - 2py_1 - 2pb = 0 \quad (3a)$$

$$x_2^2 + 2ax_2 + a^2 - 2py_2 - 2pb = 0 \quad (3b)$$

$$x_3^2 + 2ax_3 + a^2 - 2py_3 - 2pb = 0 \quad (3c)$$

To solve for p , subtract eq. (3b) from eq. (3a) and eq. (3c) from eq. (3b).

$$x_1^2 - x_2^2 + 2a(x_1 - x_2) - 2p(y_1 - y_2) = 0 \quad (4a)$$

and

$$x_2^2 - x_3^2 + 2a(x_2 - x_3) - 2p(y_2 - y_3) = 0 \quad (4b)$$

Let $x_{12} = (x_1 - x_2)$, $x_{23} = (x_2 - x_3)$, $y_{12} = (y_1 - y_2)$ and $y_{23} = (y_2 - y_3)$. Multiplying eq. (4a) by x_{23} and eq. (4b) by x_{12} and subtracting (4b) from (4a) yields

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$$(x_1^2 - x_2^2)x_{23} - (x_2^2 - x_3^2)x_{12} - 2p(y_{12}x_{23} - y_{23}x_{12}) = 0 \quad (5)$$

Performing the indicated multiplications, collecting terms, replacing $(x_3 - x_1)$ with x_{31} and solving for p results in

$$p = (x_{12}x_{23} + x_{22}x_{31} + x_{32}x_{12})/2(y_{12}x_{23} - y_{23}x_{12}) \quad (6)$$

Similarly, solving eq. (3b) and (3c) for a (remembering that p is already known) results in

$$a = (2py_{23} - x_2^2 + x_3^2)/2x_{23} \quad (7)$$

and solving (3a) for b gives

$$b = [(x_1 + a)^2 - 2py_{12}]/2p \quad (8)$$

Solving eq. (1) for y leads to the form

$$y = \frac{(x+a)^2}{2p} - b \quad (9)$$

Integrating this equation from x_1 to x_2 results in

$$\int_{x_1}^{x_2} y \, dx = \left[\frac{(x_2+a)^3 - (x_1+a)^3}{6p} \right] + b(x_1 - x_2) \quad (10)$$

This is the equation which is evaluated by the program.

III. SPECIFIC PROGRAM DESCRIPTION

PARABINT reads a set of x , y pairs from an input file. The end of the input is signaled by a negative value for x ; the corresponding value for y is irrelevant, but a value must be given. A maximum of 43 pairs are permitted. The program compares consecutive x values; if duplicates are found, the program ends with an error message.

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Next, the program calculates the parameters for a parabola, using the data for points 1, 2 and 3 on the list. Note that, if the first two y values are equal the area under the curve is a rectangle and the area is so calculated; if the second area is also a rectangle ($y_2=y_3$), no parabola is calculated. The area under the curve between points 1 and 2 is calculated according to eq. (10) if applicable and entered into a running sum. The area between points 2 and 3 is then calculated, and the count advanced to calculate the parabola defined by points 2, 3 and 4. The area between points 2 and 3 calculated from the second parabola is compared with that calculated from the first; the larger one is added to the running sum. This process is repeated until the end of the input list.

IV. INPUT REQUIREMENTS

The input for a PARABINT run is calculated from the results of the preceding QADSR run. No user input is required.

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Appendix A

Table A1: Routines in Program PARABINT

Routine	Function
MAIN	Main program performs all required functions
INTHEADR	Provides heading for output identification, starting and ending date and time.

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7. DOSE MODULE

7.1 Description of DOSE Module Code

The code developed for the DOSE module was developed using Clipper (R). The executable code is contained in the pre-processor module RAD.EXE. All of the compile command and make files are the same as for the pre-processor.

The DOSE module imports output from QADSR and PARABINT into a tabular format for the user to view. The outputs from PARABINT are modified by the user supplied input fractions resulting in the spreadsheet like table output. All calculations are contained in the subroutine SPREADSHEET in the RADPOST.PRG source files. This source file is one of the components that make-up the RAD.EXE module.

7.2 Compiler Options Used to Make DOSE.EXE

See Section 10.2.

7.3 Source Code Listing and Header Files for DOSE

See Section 10.3.

7.4 Additional References for DOSE

See RADMOL User's Manual

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8. GRAPHICS POST-PROCESSOR

8.1 Description of Post-Processor Code

The Post-Processor Code consists of one executable file RADSIM.EXE. This file graphically displays the gamma dose rates for each detector with the geometry specified in the FLOW_IT.TXT file. RADSIM was written using Microsoft C Language on the IBM Computer. The following is a listing of the filenames used to build the executable file RADSIM.EXE:

RADDEFS.H - Definition Header File
RADTYPE.H - Types Header File
RADPROT.H - Prototype Header File
RADGLOB.H - Global Variables Header File
RADSND.C - Sound Generation Code
RADGRAP.C - Graph Updating Code
RADSIM.C - User Interface Code
RAD3D.C - 3D Graph Code

8.2 Compiler Options Used to Make RADSIM.EXE

.OBJ.EXE:

LINK \$*.OBJ;

RADSIM.OBJ: RADSIM.C
CL /c /AH /F A9FF RADSIM.C

RAD3D.OBJ: RAD3D.C
CL /c /AH /F A9FF RAD3D.C

RADSND.OBJ: RADSND.C
CL /c /AH /F A9FF RADSND.C

RADGRAP.OBJ: RADGRAP.C
CL /c /AH /F A9FF RADGRAP.C

RADSIM.EXE: RADSIM.OBJ RAD3D.OBJ RADSND.OBJ RADGRAP.OBJ

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**LINK /CO /STACK:43519
RADSIM.OBJ+RAD3D.OBJ+RADSND.OBJ+
RADGRAP.OBJ,RADSIM,,c:\lib\libce.lib,,**

8.3 Source Code Listing and Header Files for RADSIM

See RADMOL Source Code Listing Volume RADSIM

8.4 Additional References for RADSIM

See RADMOL User's Manual

8.5 Input Files Required

8.5.1 FLOW.TXT & Modify Display Data

When Modify Display Data (Option 2) is selected from the Setup Menu of the RADMOL program, FLOW.TXT is created by RAD.EXE. FLOW.TXT contains the geometry for the display. Modify Display Data allows the programmer to edit by modifying the location, size, shape, color, labeling text, etc. of each displayable object.

The password for Modify Display Data (Option 2) is ISSI.

8.5.1.1 SHAPE

All the coordinates for the displayed items are laid out on a scale of 0 to 640 horizontally and 0 to 320 vertically. Coordinates for the top, left, bottom, and right vertices of rectangles and circles are listed here. In case of a circle, the coordinates may be specified such that the circle is actually an ellipse. Polygons require that the number of vertices and the x and y coordinates for each vertex be specified. Top, left, bottom, and right are optional.

8.5.1.2 COLOR

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Color for the walls, color for the labeling text, and color for the interior of each object are specified on a scale of 0 to 15 as follows:

0	Black	8	Gray
1	Blue	9	Bright Blue
2	Green	10	Bright Green
3	Cyan	11	Bright Cyan
4	Red	12	Bright Red
5	Magenta	13	Bright Magenta
6	Brown	14	Yellow
7	White	15	Bright White

8.5.1.3 LABELS

Text location for labels is given by row and column coordinates. Text rows are specified on a scale of 0 to 43 (top to bottom) and text columns are specified on a scale of 0 to 80 (left to right).

8.5.1.4 ELEVATION

Elevation is listed for each object as -20 or -40, and determines the display where it will appear.

8.5.1.5 COMPARTMENTS

Objects capable of containing detectors are assigned compartment (volume) numbers in the data file. All other objects must have a compartment number of zero.

8.5.2 CHANGE SETUP INFORMATION

Change setup information allows the user to specify defaults for the system. After pressing the number <3>, or moving the highlighted block with the arrow keys and pressing <ENTER>, the system will ask for a password (See Figure 9.2). If the user's response is correct, the system will move to the setup information screen (See Figure 8.2). If the response is not correct, the Setup Menu screen will reappear.

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8.5.2.1 SETUP SCREEN

The Change Setup screen provides a vertical field display for the user to move with the arrows (up or down) or <ENTER> (down only) to change qualifiers in setup information (See Figure 8.5.2).

8.5.2.1.1 ENTER PASSWORD

The password for change setup is "EGS." (See Figure 8.5.2.1.1)

8.5.2.1.2 POST-PROCESSOR TITLE

Allows the user to specify the title for the Post-Processor Display.

8.5.2.1.3 POWER LEVEL DENOMINATOR

The default denominator used in the Power Level calculations for the Dose Model. For more information on Power Level Denominator, see Section 9.1 of RADMODL User's Manual.

8.5.2.1.4 FAILED FUEL DENOMINATOR

The default denominator used in the Failed Fuel calculations for the Dose Model. The failed fuel fraction is that damaged portion of the reactor core that contributes this fraction of the total power output (for more information, see Section 9.1 of the RADMODL User's Manual.)

8.5.2.1.5 INPUT DATAFILE

The datafile used by the post-processor for displaying the volume information.

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8.5.2.1.6 SOUND FOR POST-PROCESSOR

Allows the user to default the post-processor sound on or off. This option can be overridden by the user during execution of the post-processor (see Section 10.2.2 of the RADMOL User's Manual).

8.5.2.1.7 NEW ISOTOPES LIST PROGRAM

The name of the STPISOTP executable application program.

8.5.2.1.8 NEW FLOW MODEL

The name of the STP executable application program.

8.5.2.1.9 NEW DOSE RATE

The name of the QADSR executable application program.

8.5.2.1.10 NEW INTEGRATION

The name of the executable application program.

8.5.2.1.11 DEFAULT DIRECTORY

Allows the user to specify the default directory for the system. This directory is where all the programs reside.

8.5.2.2 EXITING SETUP SCREEN

To exit the Change Setup screen, press <ESCAPE> and the screen will return to the Setup Menu.

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Figure 8.5.2. Setup Information

```
*****Setup Information*****
*
*      Post Processor Title : Savannah River Radiation Model
*
*      Power Level Denominator :      1250
*
*      Failed Fuel Denominator :      100
*
*      Input Datafile : POST.DAT
*
*      Sound for Post Processor : Y      (Y/N)
*
*      New Isotopes List Program : STPISOTP
*
*      New Flow Model : STP
*
*      New Dose Rate Calculation : QAD
*
*      New Integration : PARABINT
*
*      Default Directory : C:\WALT\
*
*****
      Change Setup Information for Radiation Model
```


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Figure 8.5.2.1.1. Password to Change Setup Information

```
-- Radiation Integration Ver. 1.0 --
    Developed by:
      EGS Corporation and
      Infinite Software Solutions, Inc.
      408 Cedar Bluff Road, Suite 230
      Knoxville, Tennessee 37923

*****Enter Password:*****
*
*
*
*****
|4. Reindex Datafiles      |
+-----+
```

Currently Selected Model is TEST MODEL

(c) copyright 1992, EGS Corporation and Infinite Software Solutions, Inc.
Change Setup Information for Radiation Model

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9.0 PRE-PROCESSOR PROGRAM RAD.EXE

9.1 General Description of the Pre-Processor Program

RAD.EXE is the interface program and linker between the separate modules in the **RADMODL** Model.

RAD.EXE is executed by typing **RADMODL** at the DOS prompt. **RADMODL.BAT** is the batch file which calls the **RAD.EXE** application. **RAD.EXE** interfaces with the user and prepares the input files for the model.

This application was written in **CLIPPER (R)** which is a database environment compiler for IBM PCs. The following is a listing of the filenames used to build the executable file **RAD.EXE**:

ENVIRON.PRG	- Setup Environment Information
ERRSAVE.PRG	- Error Handling Routines
SETSTACK.PRG	- Stack Handling Routines
FIX.PRG	- File Strip Routine (for carriage returns and line feeds)
INSTALL.PRG	- Install Routine for RADMODL
RAD.PRG	- Menu Interface System
RADPOST.PRG	- Post-Processor Preparation Routines
RADMAN.PRG	- File Management Routines
RADFILE.PRG	- File Search Routines

9.2 Compiler Options Used To Make RAD.EXE

.prg.obj:

CLIPPER \$* /W /N /A

ERRSAVE.OBJ: ERRSAVE.PRG

.prg.obj:

CLIPPER \$* /W /N

ENVIRON.OBJ: ENVIRON.PRG

SETSTACK.OBJ: SETSTACK.PRG

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.prg.obj:
CLIPPER \$* /W /N

RADMAN.OBJ: RADMAN.PRG
.prg.obj:
CLIPPER \$* /W

RADFILE.OBJ: RADFILE.PRG

.prg.obj:
CLIPPER \$* /W

RADPOST.OBJ: RADPOST.PRG

.prg.obj:
CLIPPER \$* /W

RAD.OBJ RAD.PRG

**RAD.EXE : RAD.OBJ RADPOST.OBJ RADFILE.OBJ RADMAN.OBJ
ENVIRON.OBJ ERRSAVE.OBJ SETSTACK.OBJ DEFAULT.OBJ
RTLINK FILE RAD, RADPOST, RADFILE, RADMAN, ENVIRON, ERRSAVE,
SETSTACK, DEFAULT**

9.3 SOURCE CODE LISTING AND HEADER FILES FOR RAD

See RADMODL Source Code Listing Volume RAD

9.4 ADDITIONAL REFERENCES FOR RAD

See RADMODL User's Manual

9.5 RADMODL FILES REQUIRED

To run RADMODL, the following files are required:

PROGRAM FILES

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RADMODL.EXE	The main interface program for RADMODL.
RADSIM.EXE	Actual executable code for the Graphics Post-Processor.
STP.EXE	STP executable file
RADMODL.BAT	Batch file to initiate RAD
PARABINT.EXE	Executable code for PARABINT
PRINTER.EXE	Printer output routine
RAD.EXE	Executable code for RADMODL
QADSR.EXE	Executable file for QAD

DATA FILES

SETUP.MEM	The default setup file for RADMODL Model.
SETUP.DAT	Contains System Setup Information and Title Information.
FLOW_IT.DBF	The geometry database file for the Post-Processor.
FLOW.TXT	An ASCII text file which contains the geometry for the Graphics Post-Processor.
FORT10	Datafiles for STP
FORT11	Datafiles for STP
VOL*.INP	Volume Input Files for QADSR
ISO.MEM	Default Memory file for STPISOTP
FLOW .TXT	An Ascii textfile which contains the geometry for the Graphics Post-Processor.
OUTY	Spectra output from STP
QAD.MEM	Default memory file for QAD

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QAD.OUT	Default QAD output file
ISOTOPES.DBF	Isotopes Database List
HELP.DBF	Help Database for RADMODL
STP.MEM	Default Memory file for STP
RAD.MEM	Default RADMODL memory file
GAMEN	Energy group file created for STPISOTP
ISONAME	Isotope file created for STPISOTP
GAMEN.DEF	Default Energy group file
ISONAME.DEF	Default Isotopes file
UNIT1.DEF	Default Unit 1 file for STP
FILE.06	Datafile for STP runs
DRALIST.DAT	Datafile for STP runs
PAR.MEM	Default PARABINT Memory file
UNIT11.DEF	Default Unit 11 for STP
MODEL.NTX	Index for RADMODL Model Selection
VOL*.D*	Input files for PARABINT by volume and detector
UNIT11	Unit 11 input file created by RADMODL for STP
UNIT21.DEF	Default Unit 21 for STP
HELP.NTX	Index for Help Database
VOLUMES.NTX	Index for Volumes Database

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ENERGY.DBF	Energy Groups Database
INFILE.DEF	Default Infile information for QAD runs
VOLUMES.DBF	Volumes Database
VOL*.INT	Integral files from QAD for volume
SETUP.MEM	Default setup information for RADMODL
VOL*.D*	Output files from PARABINT for each detector within each volume
DOSE.DBF	Dose Database for RADMODL
FLOW_IT.NTX	Index file for Geometry Database
POST.DAT	Post-Processor Input file
SETUP.DAT	Contains Setup Information and Title Information for the Post-Processor
FLOW_IT.DBF	The Geometry Database file for the Post-Processor
DESC?.TXT	Contains the Narrative for a selected model
PARDOSE.DBF	Database file for PARABINT Runs
MODEL.DBF	Model Database file
*.FON	Font files for Graphics Post-Processor
TMP_FILE.DBF	Temporary Database File
UNIT1	Unit 1 created by RADMODL
PAR.OUT	Default PARABINT output file
OUTY	Spectra output from STP

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QAD.OUT	Default QAD output file
STP.OUT	Default STP output file
GAMEN	Energy group file created for STPISOTP
ISONAME	Isotope file created for STPISOTP
UNIT11	Unit 11 input file created by RADMODL for STP
INTEGRAL	Output file from QAD runs
VOL*.INT	Integral files from QAD for volume
ERR.TXT	Error output file for RADMODL
VOL*.D*	Output files from PARABINT for each detector within each
DOSE.DBF	Dose Database for RADMODL
POST.DAT	Post-Processor Input file
SETUP.DAT	Contains Setup Information and Title Information for the Post-Processor
UNIT21	Unit 21 input file created by RADMODL for STP
DESC?.TXT	Contains the Narrative for a selected model
PARDOSE.DBF	Database file for PARABINT Runs
TMP_FILE.DBF	Temporary Database File
ISO.OUT	Default output file for STP Isotopes

Any of the .DBF files may be edited and viewed with Dbase or any Dbase readable software application. This is not a necessary feature, but may be of interest to some users.

**DATE
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10 / 7 / 93

END