VARSKIN MOD2 and SADDE MOD2: Computer Codes for Assessing Skin Dose from Skin Contamination

Manuscript Completed: November 1992
Date Published: December 1992

Prepared by
J. S. Durham

J. M. Bell, NRC Technical Monitor

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Regulatory Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN L1543

This document is
PUBLICLY RELEASABLE
Benny Steel

Authorizing Official
Date: 1-23-07

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *Se*

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

The computer code VARSKIN has been modified to calculate dose to skin from three-dimensional sources, sources separated from the skin by layers of protective clothing, and gamma dose from certain radionuclides. A correction for backscatter has also been incorporated for certain geometries. This document describes the new code, VARSKIN Mod 2, including installation and operation instructions, provides detailed descriptions of the models used, and suggests methods for avoiding misuse of the code. The input data file for VARSKIN Mod 2 has been modified to reflect current physical data, to include the contribution to dose from internal

conversion and Auger electrons, and to reflect a correction for low-energy electrons.

In addition, the computer code SADDE: Scaled Absorbed Dose Distribution Evaluator has been modified to allow the generation of scaled absorbed dose distributions for mixtures of radionuclides and internal conversion and Auger electrons. This new code, SADDE Mod 2, is also described in this document. Instructions for installation and operation of the code and detailed descriptions of the models used in the code are provided.

CONTENTS

ABSTRACT	iii
ACKNOWLEDGMENTS	ix
1 Introduction	1
2 The VARSKIN Mod 2 Computer Code Package	3
2.1 Installation	3
2.2 Running VARSKIN Mod 2	4
2.2.1 Geometry Options Screen	5
2.2.2 Distributed Sources Screen	7
2.2.3 Radionuclide Selection and Source Strength Screen	7
2.2.4 Geometry Description Screen	9
2.2.5 Volume-Averaging Screen	13
2.2.6 Hot Particle Gamma Dose Model	14
2.2.7 Dose Calculations	16
2.2.8 Offset Particle Model	17
2.2.9 Output Screen	18
2.2.10 Output File	19
2.3 Running SADDE Mod 2	19
2.4 Description of the Executable and Data Files	23
3 Technical Basis for VARSKIN Mod 2	25
3.1 Beta Dose	25
3.2 Backscatter	28
3.3 Protective Clothing and Air Gap Models	32
3.4 Volume-Averaged Dose Model	34
3.5 Offset Particle Model	35
3.6 Hot Particle Gamma Dose Model	35
3.7 Internal Conversion and Auger Electrons	37
3.8 Positron-Emitting Radionuclides	37
4 Technical Basis for SADDE Mod 2	39
4.1 Beta Spectra	39
4.2 Auger and Internal Conversion Electrons	43
5 Special Topics for Accurate Use of VARSKIN Mod 2	45
5.1 Infinite Sources	45
5.2 Volume-Averaged Doses for Point Sources	46
5.3 Maximum Dose to 1 cm ² from Multiple Hot Particles	46
5.4 Short-Lived Radionuclides	47

Contents

6	References	49
---	------------------	----

APPENDIX A - BETA-DECAY RADIONUCLIDE DATABASE

APPENDIX B - INDEPENDENT VERIFICATION OF VARSKIN MOD 2 DOSE CALCULATIONS

APPENDIX C - TEXT OF VARSKIN MOD 2 CODE

APPENDIX D - TEXT OF THE USER INTERFACE MODULES

APPENDIX E - TEXT OF SADDE MOD 2 CODE

FIGURES

2.1	Introductory screen	4
2.2	Geometry options screen	5
2.3	Three-dimensional source models	5
2.4	Distributed source screen	7
2.5	Radionuclide selection and source strength screen	8
2.6	Geometry description screen for disk geometry	10
2.7	Schematic of the protective clothing and air gap models	12
2.8	Volume averaging screen	13
2.9	Schematic drawing of the volume averaged dose model	14
2.10	Hot particle gamma dose screen	15
2.11	Final user interface screen	16
2.12	Final user interface screen	17
2.13	Offset particle model	17
2.14	Output screen	19

3.1 Schematic representation of a dose calculation for a three-dimensional disk source	26
3.2 Backscatter correction factor at a skin depth of 7 mg/cm ²	29
3.3 Backscatter model as a function of X ₉₀ /thickness based on Cross's backscatter model	30
3.4 Schematic drawing of a generic dosed calculation performed by VARSKIN Mod 2 for the three-dimensional disk geometry	33

TABLES

1 Types and abundances of a combination of radionuclides comprising a 65-day aged fuel particle based on the distribution published by Bray et al. (1987)	9
2 Typical thicknesses and densities of protective clothing covering materials	12
3 Examples of input decks for SADDE Mod 2	22
4 Dose factors	31

ACKNOWLEDGMENTS

The author would like to acknowledge the following people outside the Pacific Northwest Laboratory, the developer of this software, who helped test VARSKIN Mod 2:

C. Ross Hirning, Ontario Hydro
J. P. Burion and D. Delacroix, C. E. Saclay
Bradley Parfitt, GPU Nuclear
Rick Traub, EG&G Mound Applied Technologies
Christian Wernli, Paul Scherrer Institut
Douglas Stretch, Union Electric
Dale S. Cunningham, Westinghouse Hanford
Corporation
Paul D. Rittman, Westinghouse Hanford
Corporation
Dick Olsher, Los Alamos National Laboratory
John Lepo, Pennsylvania Power and Light

The author would also like to acknowledge the efforts of W. Dan Reece, Texas A&M University, for the development of the user interface and the backscatter model; Gamal Akabani for compiling the input data for SADDE Mod 2; Walter E. Wilson for calculating the percentile-distance ratios and scaled absorbed dose distributions for low-energy primary electrons; and Robert D. Stewart for performing EGS4 calculations to verify VARSKIN Mod 2 results.

Finally, the author would like to thank Ila Stephens, group secretary; Marianna Cross, word processor; and Jim Weber, technical editor, for the production of this document.

FORWORD

The original VARSKIN code has been used for several years as a tool for helping in the assessment of personnel doses from skin contamination, including so-called "hot particles." Although useful in skin contamination dose assessments, VARSKIN tended to provide overly conservative dose results for hot particles because of its inability to account for source self-shielding and source geometry effects. Also, the code was unable to accommodate those situations where sources are not directly on the skin (e.g., on clothing or hair) and are shielded by clothing or protective equipment. With beta-gamma emitting sources shielded by clothing or protective equipment, the gamma dose assumes more importance but could not be calculated with VARSKIN.

As a result of these recognized shortcomings, a new code has been developed to allow more accurate skin dose assessments with improved flexibility in a more "user-friendly" format. The new code has been extensively peer-reviewed and validated.

Although the new code was developed for use by NRC personnel for performing skin dose calculations needed in carrying out their regulatory duties, it is hoped that, like the original VARSKIN code, it will prove useful to other members of the radiation protection community.

NUREG/CR-5873 is not a substitute for NRC regulations, and compliance is not required. The approaches and/or methods described in this NUREG are provided for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein.

Donald A. Cool, Chief
Radiation Protection and
Health Effects Branch
Division of Regulatory Applications
Office of Nuclear Regulatory Research

1 Introduction

The original VARSKIN computer code (Traub et al. 1987) was intended for calculation of skin dose from contamination directly on the skin. The contamination was assumed to be an infinitely thin layer of radioactive material distributed over an area or at a single point on the skin. Soon after the release of VARSKIN, a "new" type of skin contaminant was encountered in the industry. This contaminant consists of discrete microscopic radioactive particles, called "hot" particles. These particles differ radically from uniform skin contamination in that the particles have a thickness associated with them and many of the exposures result from particles on the outside of protective clothing. Since no other option for calculating skin dose from hot particles was readily available, skin dose calculations from hot particles were performed using VARSKIN.

Calculating skin doses from hot particles using VARSKIN has three primary drawbacks. First, VARSKIN models the contaminant as having no thickness; thus, source self-shielding is not taken into account in the calculation. For many hot particles consisting of the weak beta-emitting radionuclide ^{60}Co , VARSKIN greatly overestimates calculated skin doses, including particles that are thicker than about $1\text{ }\mu\text{m}$. Second, VARSKIN does not model protective clothing that is sometimes between the source and skin, again leading to an overestimate of skin dose from beta-emitting fuel particles. Finally, it has been shown that the gamma component of a mixed beta/gamma-emitting hot particle becomes increasingly important as the skin depth and, most importantly, the thickness of protective clothing increase. Since VARSKIN does not model protective clothing, the gamma dose is not generally significant and no gamma dose model was included. Thus, an upgrade of VARSKIN was needed to provide accurate skin dose calculations.

The upgraded computer code VARSKIN Mod 2 contains all of the features of the original VARSKIN with numerous significant additions. Additional features in VARSKIN Mod 2 include modeling of three-dimensional sources (thick disks, spheres, and slabs), modeling of materials placed between the source and skin (including air gaps), modeling of hot particle gamma doses in certain cases, and methods to model multiple hot particles and volume-averaged doses. VARSKIN Mod 2 also uses a correction for backscatter for one- and two-dimensional sources in certain cases. In addition, the VARSKIN Mod 2 package incorporates a user interface that greatly simplifies data entry for calculating skin dose in addition to providing on-line guidance in the form of help screens.

VARSKIN Mod 2 includes models for particle self-shielding and attenuation by protective clothing and air gaps. Also included in the upgraded code are volume averaging and offset particle models. The volume-averaging model allows the user to calculate the dose averaged over a volume defined by two different skin depths instead of the dose at one given depth. The offset particle model, which allows dose to be calculated for a particle that is not centered over the dose area of interest, is useful for calculating dose from multiple hot particles. Finally, the operation of

Introduction

VARSKIN Mod 2 is facilitated by a user interface with on-line help and the capability to use composite source terms that allow a user to calculate the total dose from a mixture of beta-emitters in the same amount of time required for one radionuclide.

The upgraded code is based on the same Berger kernel used in VARSKIN (Berger 1971), but the integration is more complex. Instead of integrating over two source dimensions as in VARSKIN, VARSKIN Mod 2 integrates over three source dimensions. The added dimension necessarily requires significantly more execution time.

The input data file for VARSKIN Mod 2, BETADATA.DAT, has undergone significant revision. Note that previous versions of BETADATA.DAT (supplied with VARSKIN) will not allow VARSKIN Mod 2 to calculate doses. The old file should be removed from the system or stored separately from VARSKIN Mod 2 files. The new BETADATA.DAT file has been modified to reflect more recent physical data for the average energy, maximum energy, and yield based on data generated by the computer code RADLST (Burrows 1988). Additional information on RADLST is given in Appendix B. Further modifications include adding data for gamma dose calculations and including contributions from internal conversion and Auger electrons.

Also included with the VARSKIN Mod 2 package is an upgraded (Mod 2) version of SADDE: Scaled Absorbed Dose Distribution Evaluator (Reece et al. 1989). The original version of SADDE calculated the scaled absorbed dose distribution functions that were input to VARSKIN. The upgraded version, SADDE Mod 2, contains all of the capabilities of the original version, with the additional feature of allowing the user to develop scaled absorbed dose distributions for mixtures of up to 30 radionuclides. To facilitate the use of SADDE Mod 2, input to the code for virtually every beta-emitting radionuclide is included in Appendix A. SADDE Mod 2 uses scaled absorbed dose distributions for monoenergetic electrons that have been extended down to energies of 50 eV. Finally, SADDE Mod 2 can be used to include doses from internal conversion and Auger electrons when they accompany beta emission.

Section 2.0 of this report describes the contents of the VARSKIN Mod 2 and SADDE Mod 2 code packages, including instructions for installing each package on a DOS-system personal computer and for running the package. Section 3.0 discusses the technical basis for VARSKIN Mod 2, the skin dose calculation portion of the package, including the calculational methodology. Section 4.0 presents the models and required input to SADDE Mod 2, the upgraded version of SADDE. Section 5.0 alerts users to possible misuse of the VARSKIN Mod 2 package and explains the correct method for modeling semi-infinite sources.

2 The VARSKIN Mod 2 Computer Code Package

This section describes the procedures for installing the VARSKIN Mod 2 and SADDE Mod 2 computer codes on a personal computer. It also describes the separate codes in the code package, some of which are executed via a single batch file and some of which must be executed separately. VARSKIN Mod 2 and SADDE Mod 2 may be obtained from Energy Science and Technology Software Center (ESTSC), P.O. Box 1020, Oak Ridge, TN 37831-1020, or the Radiation Shielding Information Center (RSIC), Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6367. The telephone number for ESTSC is (615) 576-2606 and for RSIC it is (615) 574-6176. A nominal fee may be required.

2.1 Installation

Both VARSKIN Mod 2 and SADDE Mod 2 are designed for use on personal computers in a DOS environment. The codes are supplied on 3.5-in. or 5.25-in. diskettes. The source codes for the programs are also provided.

The most efficient operation of VARSKIN Mod 2 and SADDE Mod 2 is realized by installing them on a hard disk drive in a computer with a math coprocessor. The user should create a subdirectory dedicated to the VARSKIN Mod 2 code package, which includes both VARSKIN Mod 2 and SADDE Mod 2. To create a subdirectory use the following command at the prompt:

```
MKDIR VARSKIN
```

Next, switch to the VARSKIN subdirectory using the command

```
CD VARSKIN
```

To install the code package, put the diskette into the appropriate drive (usually the 'A' drive). If the computer on which the code is to be installed has a math coprocessor, use the command

```
a:CD math
```

to change to the subdirectory on the distribution diskette that contains the codes for computers with a math coprocessor. Then use the command

```
copy a:*.*
```

If the personal computer is not supplied with a math coprocessor, use the command

```
a: cd emul
```

to change to the subdirectory on the distribution diskette that contains VARSKIN Mod 2 for computers without a math coprocessor. Then, type the command

```
copy a:*.*
```

If the personal computer does not have a hard drive, VARSKIN Mod 2 can be run from a floppy disk, but the execution time will be significantly increased. A backup copy of the distribution diskette should be made before attempting to use either VARSKIN Mod 2 or SADDE Mod 2. Follow the above instructions for the hard disk installation but substitute the drive letter of the target diskette for the hard drive designation.

A third subdirectory, entitled SOURCE, contains all of the FORTRAN and C source codes for the executable files. These files are not required to execute either VARSKIN Mod 2 or SADDE Mod 2, and are included to allow a user to make changes or review the programming of each of the two codes. The FORTRAN codes were compiled using Microsoft optimizing FORTRAN Compiler Version 5.1. The C modules were compiled using Microsoft C compiler Version 6.0.

2.2 Running VARSKIN Mod 2

To begin VARSKIN Mod 2, enter the following command at the prompt:

VARMOD2

A short title screen, shown in Figure 2.1, will appear. Hitting any key at this point will initiate the user interface module, which allows data entry in VARSKIN Mod 2. The statement "Reading Data - Please Wait" will appear for up to 20 seconds (depending on the speed of the computer) after pressing any key while the BETADATA.DAT file is read by the user interface.

Figure 2.1 Introductory screen

2.2.1 Geometry Options Screen

The geometry options screen, shown in Figure 2.2, lists the five available geometry options in VARSKIN Mod 2: Point, 2-D disk (identical to the previous version of VARSKIN), 3-D disk, Sphere, and 3-D Slab. Representative drawings of the three models are provided in Figure 2.3. A brief description of each model follows.

Figure 2.2 Geometry options screen

Figure 2.3 Three-dimensional source models

The spherical geometry model is perhaps the simplest to use because it requires knowledge of only one source dimension: the sphere diameter. The sphere model assumes that the source is surrounded by air and touches the skin or protective clothing only at the bottom-most point on the sphere surface. The air surrounding the sphere does not shield the source particles as efficiently as in the disk and slab models, and the average path length within a spherical source is at a minimum; therefore, doses calculated using the spherical model will be consistently higher than those calculated using the other models. Because hot particles seldom resemble spheres, this model is of more limited utility than the other two models.

The three-dimensional disk model requires knowledge of two dimensions: the disk diameter and the disk thickness. The disk model assumes that the source is surrounded by air but that the entire bottom of the disk is in contact with skin or protective clothing. This model requires the same amount of time to execute as the spherical model but offers a more practical application. Of the two disk source dimensions, the calculated dose is much more sensitive to changes in the disk thickness than in the disk diameter. For low-energy beta emitters, the difference in the calculated dose averaged over 1 cm^2 at a skin depth of $70 \text{ }\mu\text{m}$ for 2-mm- and 10-mm-diameter sources is only 11%, while for high-energy sources this difference is 16%, all other source parameters being equal.

The three-dimensional slab geometry model requires knowledge of three physical dimensions: the x-side length, the y-side length, and the thickness. The slab model requires 2 to 5 times more execution time than the three-dimensional disk and sphere models, and the accuracy of the calculation is significantly lower. The 3-D slab geometry model should only be used when skin dose from multiple, discrete particles is needed.

The following general rules should govern the choice of geometry package, progressing from most conservative to least conservative:

- If nothing is known about the particle size and shape, use the point source option (option 1).
- If the diameter is known but the thickness cannot be estimated, or if a distributed source is being modeled (i.e., with a known source strength per unit area), use the 2-D disk option (option 2).
- If the thickness and the diameter can be estimated but the shape is not known, use the 3-D disk option (option 3), because this geometry requires only two dimensions (thickness and radius) to describe the particle.
- If the particle is known to be spherical and is not imbedded in another material, use only the spherical geometry option (option 4).
- If the particle is known to be rectangular, use the 3-D disk geometry (option 5). The thickness of the particle should be maintained, and the area of the contact surface should be equivalent. This option requires less time to run than the 3-D slab model and is more accurate.

Note the statement in Figure 2.2, "PRESS <F1> FOR HELP...." The user interface to VARSKIN Mod 2 contains help screens for most of the input parameters. The help screen will, in general, repeat what is stated in this document for the parameter of interest.

2.2.2 Distributed Sources Screen

Once the geometry has been selected, the distributed source screen (Figure 2.4) appears. A distributed source is characterized in units of activity per unit area or volume. The source can also be characterized in terms of total activity. If the total activity of the source is known, answer this question by typing "N". However, if the source is known in terms of $\mu\text{Ci}/\text{cm}^2$ or $\mu\text{Ci}/\text{cm}^3$, answer this question by typing "Y". The distributed source feature is useful for large-area contaminations.

Figure 2.4 Distributed source screen

2.2.3 Radionuclide Selection and Source Strength Screen

Next, the list of available radionuclides will be displayed on the screen as shown in Figure 2.5. The arrow keys are used to move around the screen and highlight the desired radionuclide. When the desired radionuclide is highlighted, press <Return>. At this point, a window will open that requests the source strength either in μCi , $\mu\text{Ci}/\text{cm}^2$, or $\mu\text{Ci}/\text{cm}^3$, depending on the response to the question on the distributed source screen. Enter the source strength in the appropriate units at this point. When the source strength is entered, the list of available radionuclides appears again and another radionuclide can be selected. VARSKIN Mod 2 can be used to calculate the dose from up to five radionuclides in a single execution.

Figure 2.5 Radionuclide selection and source strength screen

Note that one of the "radionuclides" in the list is entitled "Fuel." This entry serves as an example of the type of composite source that can be prepared using SADDE Mod 2. This source is a composite of 16 weighted radionuclides that comprise a 65-day-old fuel particle (Bray et al. 1987). The fuel particle includes each of the radionuclides listed in Table 1, yet requires the same execution time as for a single radionuclide. Choosing "Fuel" as the radionuclide will provide an estimate of skin dose from an aged fuel particle. Only the beta dose is calculated when "Fuel" is chosen as the source since the list of radionuclides in Table 2.1 does not include gamma emitters.

Table 1 Types and abundances of a combination of radionuclides comprising a 65-day aged fuel particle based on the distribution published by Bray et al. (1987)

Radionuclide	E ₀ (MeV)	Fraction of Total Activity
⁸⁹ Sr	1.491	0.0905
⁹⁰ Sr	0.546	0.0085
⁹⁰ Y	2.284	0.0085
⁹¹ Y	1.543	0.1278
⁹⁵ Zr	0.123	0.1097
⁹⁵ Nb	1.160	0.1640
¹⁰³ Ru	0.723	0.0650
¹⁰⁶ Rh	3.541	0.0458
¹⁰⁶ Ru	0.039	0.0458
¹⁴⁰ Ba	1.005	0.0112
¹⁴⁰ La	2.164	0.0192
¹⁴¹ Ce	0.580	0.0639
¹⁴³ Pr	0.935	0.0075
¹⁴⁴ Ce	0.318	0.1331
¹⁴⁴ Pr	2.996	0.1331
¹⁴⁷ Pm	0.225	0.0288
TOTAL		1.000

2.2.4 Geometry Description Screen

The geometry description screen, shown for a three-dimensional disk source in Figure 2.6, contains a description of the geometry that is to be modeled. The input parameters include the dimensions of the source, the irradiation time in minutes, the density of the source if necessary, the relative error (see discussion below), the thickness of any air gap, and the thickness and density of any protective clothing. Source dimensions are entered in micrometers; all densities are in grams per cubic centimeter; and the air gap and protective clothing thicknesses are in millimeters. The user can enter the values simply by using the arrow keys to highlight the desired entry. If a value for a given variable is to be changed, the original value for that parameter must be erased by striking <Delete> once before entering the new variable. If the delete key is not used, then the new value will be appended to the existing value, possibly resulting in erroneous data entry.

```

3-D DISK GEOMETRY

Enter the 3-D disk diameter in micrometer      : 1000.000
Enter the disk thickness in micrometer         : 20
Enter the time of exposure in minutes         : 60
Enter the Source Material Density (g/cm^3)     : 2.6
Enter the Relative error                     : .001
Enter a value for the skin depth in mg/cm^2    : 7
Enter the air gap between the source and the skin in mm : 0
Enter the thickness of the material between the source and the skin (protective clothing ) in mm : .125
Enter the density of covering material in g/cc : 1

<ESC=FINISHED> <F1=HELP>....
    
```

Figure 2.6 Geometry description screen for disk geometry

The two-dimensional disk geometry package has a unique feature. The user has the option of entering either the source radius or the source area in cm^2 . This feature simplifies data entry for two-dimensional sources where the area and the total microcurie inventory are known.

A sensitivity analysis of many of the geometry input parameters for VARSKIN Mod 2 has been published (Durham et al. 1991). The results of the analysis show that the most sensitive source dimension for calculating dose is the source thickness, and that the dose will vary greatly for small variations in the value of this parameter. Similarly, the source density is an equally sensitive parameter. It is essential that these parameters be known accurately or that a conservative estimate of their values be made. The following guidelines will help in choosing appropriate values for source dimensions and density:

1. Diameter (2-D and 3-D disks); X-side and Y-side lengths (3-D Slab)

The dose calculation for most radionuclides is relatively insensitive with respect to these dimensions for sizes below 1-2 mm. A conservative dose estimate can be made by choosing a larger rather than a smaller value for this dimension.

2. Thickness (3-D disk, 3-D Slab, and Sphere Diameter)

The dose calculation for all radionuclides is very sensitive to this dimension, especially for low-energy beta-emitting radionuclides. A conservative dose estimate can be made by minimizing the value of this dimension.

3. Source Density (3-D geometries)

Choose a source density that is consistent with the radionuclide within the source. For hot particle contaminations, a typical density for stellite (^{60}Co) is 8.3 g/cm^3 and for fuel is 14 g/cm^3 .

Additional guidance and several examples of the sensitivity of these calculations can be found in the literature (Durham et al. 1991). The above guidance is also available in the form of a help screen, which may be viewed by highlighting the appropriate variable and pressing <F1>.

The next variable to input is the relative error, which must be between zero and one. This value controls the convergence of the numerical integration. (Additional information on the integration is provided in Section 4.) The recommended value of the relative error is 0.001, which corresponds to a convergence level of 0.1%. A larger value may result in decreased execution time, but with reduced precision. Similarly, a smaller value may provide greater precision but can require a larger execution time.

The next input is the skin depth in mg/cm^2 . The default value is 7 mg/cm^2 , the depth recommended by the NRC for skin dose calculations.

The presence of protective clothing and air gaps can be chosen separately or together. A representative drawing of the two models is shown in Figure 2.7, which depicts the three-dimensional disk geometry, although the two models are available for any of the source geometries. The required input for the protective clothing model is the thickness (in mm) of the clothing and its corresponding density in grams per cubic centimeter. Note that both parameters are needed to account for the $1/r^2$ dependence of the Berger point kernel (geometric attenuation) and for the energy loss due to attenuation in the material (material attenuation). For the air gap model, only the thickness of the air gap is required for input. VARSKIN Mod 2 uses a default value of 0.001293 g/cm^3 for air density.

Air gap and protective clothing physical characteristics can significantly affect the calculated skin dose. While the air gap has little effect on material attenuation, its effect on geometric attenuation can be dramatic. Protective clothing affects both the geometric and material attenuation. Some suggested thickness and density values are given in Table 2. VARSKIN Mod 2 allows only one cover material and one air gap to be modeled. However, composite cover materials can be modeled using the following procedure.

Figure 2.7 Schematic of the protective clothing and air gap models

Table 2 Typical thicknesses and densities of protective clothing covering materials

Material	Thickness (mm)	Density (g/cm ³)
Lab Coat (plastic)	0.1	0.036
Cotton Glove Liner	0.3	0.3
Surgeon's Glove	0.5	0.9
Outer Glove (thick)	0.45	1.1
Ribbed Outer Glove	0.55	0.9
Plastic Bootie	0.2	0.6
Rubber Shoe Cover	1.2	1.0
Coveralls	0.7	0.4

Both the density (g/cm³) and thickness (mm) of each covering material must be known. To obtain the thickness (mm) of the composite material, sum the thicknesses (mm) of the covering materials. To obtain the density of the composite material, multiply the density of each material by its thickness (cm) to obtain the density thickness (g/cm²) of each covering material; then, sum the density thicknesses of the covering materials and divide this number by the total thickness of the composite material. The result is the density of the composite material in grams per cubic centimeter. Be sure to enter the thickness of the composite material in mm.

The thickness of an air gap will greatly influence the calculated dose rate. A conservative estimate of the dose will be obtained if the air gap is ignored or

minimized. When the exposure geometry has been entered, the user is instructed to press <Escape> to accept the entered values.

2.2.5 Volume-Averaging Screen

The next screen, shown in Figure 2.8, will ask if the user wishes to perform volume averaging. The volume-averaging model allows the user to calculate the dose averaged between any two depths in the skin. Initially, the code calculates the dose at 20 depths between a skin depth of zero and the maximum penetration depth of the beta particles, as shown in Figure 2.9. Thus, the volume-averaging model requires up to 20 times the execution time of that for a single depth. Once the code has completed the initial calculations, the user is prompted to enter the skin depths corresponding to the top and bottom of the volume, and the volume-averaged dose is calculated almost instantaneously. The user can then enter two new skin depths or press <Enter> to complete the dose calculation.

Figure 2.8 Volume averaging screen

Figure 2.9 Schematic drawing of the volume averaged dose model

2.2.6 Hot Particle Gamma Dose Model

VARSKIN Mod 2 includes a "hot particle gamma dose" calculation routine that assumes that the source is small enough to be considered a point source and that any covering material is similar to tissue or water. The gamma dose model is based on a model published by Lantz and Lambert (1990) and is described in more detail in Section 3.6. The code will perform the gamma calculation only if the following four criteria are satisfied:

1. The radionuclide has a gamma component.
2. The diameter of the disk or sphere source, or any dimension of the slab source, is smaller than 1 mm (1000 μm).
3. Any air gap is smaller than 5 cm.
4. The dose averaging area is 1 cm^2 .

Hot particle gamma doses are calculated as if the source were a point source, and the model includes effects due to the incomplete establishment of electronic equilibrium. Electronic equilibrium is established at different depths, depending on the average energy of the gamma photon (or photons) emitted by the particle. At shallow depths (before electronic equilibrium is established), the gamma dose is lower than the dose would be if electronic equilibrium had been fully established. The gamma dose calculation executes in less than 2 seconds. A screen, shown in Figure 2.10, asks the user if the gamma dose is to be calculated for each of the radionuclides that have a gamma component.

Figure 2.10 Hot particle gamma dose screen

In general, the calculated gamma skin dose will be negligible compared to the beta dose, usually by three orders of magnitude. A significant exception to this concerns ^{60}Co . The relatively low energy beta particles from this radionuclide can be easily shielded by protective clothing, with little attenuation of the gamma dose. For this case, the gamma dose will account for 100% of the calculated skin dose. Measurements verifying this phenomenon have been published by Durham and Lantz (1991).

VARSKIN Mod 2 is primarily a beta dose calculation tool. The hot particle gamma dose model is intended for use in estimating the gamma dose, averaged over 1 cm^2 of skin, from a hot particle. It is not intended for use with distributed contamination. Calculations of gamma dose for distributed sources can be performed using a code designed to calculate gamma dose. An example of such a gamma dose code is ISOSHL, available from the Radiation Shielding Information Center, Oak Ridge, TN. (ISOSHL is only an example; no recommendation for the use of ISOSHL is implied.)

The instruction concerning calculation of the gamma dose completes the user interface portion of VARSKIN Mod 2. The input data are written to the ASCII file OUTPUT.DAT, as shown in Figure 2.11. If the user wishes to make any changes to the input data, a provision is made for this option before beginning the dose calculation portion of VARSKIN Mod 2. However, the user must re-enter all of the source radionuclides if changes to the input data are required.

Figure 2.11 Final user interface screen

The data file OUTPUT.DAT also serves to store default values used when the user interface is executed for a new calculation. In this manner, VARSKIN Mod 2 "remembers" the data from the previous calculation, with the exception of the names of the source radionuclides.

2.2.7 Dose Calculations

When the user interface, INTEXE, has been executed, the screen border changes to red (when a coprocessor is used) and the dose calculation module of VARSKIN Mod 2 is initiated. As shown in Figure 2.12, the user is asked if the output file is to be saved, and the name of the output file is provided. If it is desired that the output file be saved, enter "Y"; otherwise enter "N". The default entry for saving the output file is "N". If "Y" is entered, the user will be asked to enter a descriptive title for the current calculation. The descriptive title can have a length of up to 20 characters. If no title is desired, press <Enter> at the prompt. Once the answer has been entered, the beta dose calculations commence.

The time required for the beta dose calculations can vary from a few seconds to several minutes, depending on the geometry. In general, the point and 2-D disk models require the least amount of time, followed by the 3-D disk, the sphere, and slab geometry, which generally requires the most execution time. Other factors that influence the execution time are the average beta energy and the existence of protective clothing. Usually, the execution time decreases with increasing beta energy, since the dose is much more uniform over the area of irradiation. The execution time also decreases with increasing thicknesses of protective clothing, again because the dose is more uniform at greater distances from the source. Finally, the time required to calculate beta doses is machine-dependent.

Figure 2.12 Final user interface screen

2.2.8 Offset Particle Model

Another option is available in VARSKIN Mod 2 for the three-dimensional slab geometry. The offset particle model allows skin dose to be calculated for a particle that is not centered over the dose area of interest and is useful for calculating dose from multiple hot particles. This model is available only for the three-dimensional slab geometry, and the offset particle must have equal x- and y-side lengths. The offset model is pictured in Figure 2.13. As seen in the figure, the offset is the horizontal distance between the center of the offset particle and the center of the dose-averaging area. The value of the offset is the only additional input value that is required for the model, and the calculation is completed in roughly the same amount of time as a centered particle. The three-dimensional slab geometry should only be used if use of the offset particle model is desired.

Figure 2.13 Offset particle model

The offset particle model can be used to calculate the dose from multiple hot particles. One of the particles is chosen to be the centered particle, and the dose to the dose-averaging area is calculated. The offset for each of the remaining particles is then determined, and the dose to the dose-averaging area is calculated for each particle. The user can then add the contributions from each particle to obtain the total skin dose to the dose-averaging area.

Next, VARSKIN Mod 2 performs the beta dose calculations. Following completion of the calculations, the user is asked if the output data file is to be saved. The name of the output file is automatically chosen by the code. If the output file is not to be saved, the user must obtain the results directly from the screen. The output file name is chosen by VARSKIN Mod 2; the user may change the output file name manually at the completion of the code. VARSKIN Mod 2 can name up to 27 different output files; if a user attempts to save more than 27 output files, VARSKIN Mod 2 will issue an error message and the user must delete or rename some of the output files.

2.2.9 Output Screen

When the dose calculations are completed, the results are displayed on the screen, as shown in Figure 2.14 for the input data in Figure 2.6. The output screen includes the input variables chosen and the results of the calculations. The first result displayed tells the user whether the irradiated area is larger or smaller than the area over which the calculation is averaged and shows the beta dose for the area of irradiation. If the irradiated area is smaller than the averaging area, the radius of the irradiated area and the dose averaged over that area is provided to the user.

The next two results present the beta dose and beta dose rate averaged over the dose area. Note that the dose area defaults to 1 cm² for the first calculation. The last two results that are printed to the screen are the gamma dose and dose rate averaged over 1 cm². If a given radionuclide has no gamma component, the gamma dose is omitted. If a given radionuclide has a gamma component, the total dose (gamma plus beta) is displayed.

One final option exists for VARSKIN Mod 2. If the user wishes to repeat the calculations for the same radionuclide(s) and geometry but for a different skin area (the initial value of the skin area is 1 cm²), the new value is entered at the prompt, "Enter new area over which to average dose." If <Return> or a non-positive number is entered, the code will terminate, the output file will be saved (if desired), the red border around the screen will be erased (math coprocessing version only), and the program will exit to the operating system.

Figure 2.14 Output screen

VARSKIN Mod 2 can calculate doses from up to five radionuclides simultaneously. If more than one radionuclide is selected, the output screen and the output file, if requested, will display the sum of the beta doses and the sum of the gamma doses from all of the selected radionuclides. The sum of the total doses (gamma plus beta) from all of the selected radionuclides will also be displayed if any of the selected radionuclides contain a gamma component. The results are not shown in Figure 2.14.

2.2.10 Output File

If the user desires to save the data in an output file, a file is created by VARSKIN Mod 2 with a filename that conforms to the following procedure. VARSKIN Mod 2 attempts to open a file with the name VMOD2.OUT. If that file exists, VARSKIN Mod 2 attempts to open a file VMOD2A.OUT, followed by VMOD2B.OUT, etc. If all files including VMOD2Z.OUT already exist, VARSKIN Mod 2 will issue an error message and execution will be terminated.

The output file contains virtually the same information as displayed on the output screen. For all geometry options except for the three-dimensional slab, the output file will also contain the dose profile as a function of the radius of the circular skin irradiation area. This information is not provided when using the slab geometry since radial symmetry does not exist for a slab source.

2.3 Running SADDE Mod 2

At the DOS prompt, start SADDE Mod 2 by typing
SADMOD2.

The user will be asked to answer a series of questions, after which the new scaled absorbed dose distribution will be calculated. SADDE Mod 2 automatically accesses BETADATA.DAT and adds the new data, including the name of the radionuclide.

In order to accomplish this task, however, BETADATA.DAT must be present in the same directory as SADDE Mod 2. If BETADATA.DAT is not present, the data generated by SADDE will be lost and the user must restart SADDE Mod 2.

Because the SADDE input is not printed in the output files and all computer users are prone to errors, the creation of an input file is highly recommended. The input file simply contains the answers to the questions asked by SADDE. The input file can be created using EDIT or EDLIN, text editors included in the DOS package, or a word processing program, as long as the input file is in ASCII format. The input file must contain the following information in the specified order:

1. The name of the radionuclide or mixture - This name must be no longer than six characters and must be different than any previous source name.
2. Enter "Y" if multiple radionuclides are to be included in the distribution. If not, enter "N".

If the response to step 2 is "N", proceed to step 4.

3. Enter the number of radionuclides to be included in the distribution. This number must be less than 30.
4. Enter the number of decay modes for the parent radionuclide.
5. Enter the atomic number of the transition product (daughter) nucleus (parent atomic number plus 1).
6. Enter the atomic mass of the decaying (parent) radionuclide.

If the response to step 2 is "N", proceed to step 8.

7. Enter the relative weighting of the radionuclide. The sum of the weighting factors will usually equal to 1.
8. Enter the endpoint energy of the decay path in MeV.
9. Enter the probability (yield) of that decay path.
10. Enter the degree of forbiddenness for that decay path.
11. Repeat the information in steps 8 through 10 for each decay path.
12. Enter the number of Auger and/or internal conversion electrons emitted by this radionuclide. This number must be less than 30.
13. Enter the energy of the Auger or internal conversion electron.

14. Enter the yield of the Auger or internal conversion electron.
15. Repeat steps 13 and 14 for each Auger or internal conversion electron identified in step 12.
16. If multiple radionuclides are to be included, repeat steps 4 through 15 for each radionuclide.

Input data for parts 8, 9, and 10 are tabulated in Appendix A. Input data for steps 13 and 14 can be obtained from several references, including Kocher (1981). Examples of several input files are provided in Table 3. If the input file is named INPUT, for example, after changing directories or drives as discussed above, run the code by typing "SADMOD2 < INPUT". Note that if an input file is not used, the preceding list of input parameters must be supplied by the user in the order shown.

After completing the distribution calculations, SADDE MOD 2 automatically writes the results to the ASCII file BETADATA.DAT for use with VARSKIN Mod 2. If BETADATA.DAT is not present in the local subdirectory, SADDE Mod 2 will issue an error message and the code must be restarted. If BETADATA.DAT contains data for 100 radionuclides, then the user must edit BETADATA.DAT using either EDIT, EDLIN, or another word processor to remove any unwanted data entries. Note that a user can create a replacement BETADATA.DAT by creating an ASCII text file that contains the line

ENDOFI

SADDE Mod 2 will add the new distributions to this file, providing a customized BETADATA.DAT file.

Information needed for calculations using the gamma dose model in VARSKIN Mod 2 is not calculated by SADDE Mod 2. Therefore, SADDE Mod 2 simply enters values of 0.0 for both the average gamma energy and the specific gamma ray constant. See Sections 2.2.6 and 3.6 for more information concerning the gamma dose calculation. Section 3.6 also describes the methodology that can be used to add gamma dose information to BETADATA.DAT.

Table 3 Examples of input decks for SADDE Mod 2

<u>Input Deck for ⁴⁹Ca</u>	<u>Input Deck for ⁹⁰Y</u>	<u>Input Deck for ⁴⁹Ca, ¹⁴¹Ce, and ⁹⁰Y</u>
Ca-49	Y-90	Mix1
n	n	y
6.	1	3
21.	40.	6
49.	90.	21.
.525	2.2792	49.
0.0021	.99984	.333
0	1	.525
.77	0	0.0021
0.0066		0
0		.77
1.1913	<u>Input Deck for ⁹⁰Sr/⁹⁰Y</u>	0.0066
0.07	SrY-90	0
0	y	1.1913
1.7467	2	0.07
0.0018	1	0
0	39.	1.7467
2.1789	90.	0.0018
0.915	.500	0
0	1.	2.1789
2.8915	0.546	0.915
0.0041	1.000	0
0	1	2.8915
0	0	0.0041
0	1	0
	40.	0
<u>Input Deck for ¹⁴¹Ce</u>	90.	0
Ce-141	.500	2
n	1	59.
2	2.2792	141.
59.	.99984	.333
141.	1	0.5813
0.5813	0	0.2980
0.2980		0
0		0.4359
0.4359		0.702
0.702		0
0		2
2		0.1035
0.1035		0.188
0.188		0.1386
0.1386		0.0259
0.0259		1
		40.
		90.
		.333
		2.2792
		.99984
		1
		0

2.4 Description of the Executable and Data Files

During installation, a number of executable files will be copied from the distribution diskette to the target drive (hard disk or floppy diskette). The following discussion will give a brief overview of these various executable files and their function. VARSKIN Mod 2 will be discussed first, followed by SADDE Mod 2.

When the name of the batch file VARMOD2 is entered, a series of files is sequentially executed. The first file, BORDERB, simply draws a blue border around the text area of the screen and is included for aesthetic purposes only. The programs that draw borders around the text area of the screen will not affect a monochrome screen, and no border is drawn unless a math coprocessor is used. Next, the user interface (written in the programming language C) is executed through the executable file INT.

Before the FORTRAN portion of VARSKIN Mod 2 is executed, BORDERR changes the color of the area bordering the text region of the screen to red, providing the math coprocessor package is used. This color change signifies that the user interface has been exited and the dose calculation portion of the program has been initiated. The calculational portion of the program has been given the name VARINT and is described in detail in Section 3. When the execution of VARINT is complete, the utility program BORDERBL erases the colored border that outlines the text portion of the screen and VARSKIN Mod 2 is complete. Note: BORDERB, BORDERR, and BORDERBL can only be used with a math coprocessor. If the files under the subdirectory EMUL are installed, the border will remain black throughout the calculations.

Three other files are also required to run the VARSKIN Mod 2 package: BETADATA.DAT, OUTPUT.DAT, and HELP.TXT. The BETADATA.DAT file contains the necessary input for the source radionuclides available for VARINT. The OUTPUT.DAT file contains the data on the geometry package to be chosen by the user. When execution of the user interface portion of VARSKIN Mod 2 is completed, OUTPUT.DAT is saved on the disk. This file contains the input data needed by VARINT for execution. OUTPUT.DAT has another function, as well. When INTEXE is executed, the default values are obtained from the latest version of OUTPUT.DAT. Thus, VARSKIN Mod 2 "remembers" the previous calculation. The HELP.TXT file contains the text portion of the help screens and can be edited to reflect the needs of the user. This file is used by the interface program INTEXE.

SADDE Mod 2 consists of a single executable file, SADMOD2.EXE. The data file BETADATA.DAT must reside in the same directory as SADMOD2.EXE, or the data file cannot be modified. If the two files are not in the same directory, an error message will be generated by SADDE Mod 2.

3 Technical Basis for VARSKIN Mod 2

This section discusses the theory underlying the dose calculation portion of VARSKIN Mod 2, including the modeling of beta dose, backscatter, protective clothing and air gaps, volume-averaged doses, offset particles, and hot particle gamma doses. A brief discussion of doses from internal conversion electrons is also provided. The formulas and features described in this section are incorporated into the FORTRAN program VARINT.

3.1 Beta Dose

The computer code VARSKIN Mod 1 calculates skin dose rate from beta-emitters by performing a numerical integration of the Berger point kernel (Berger 1971). This kernel is mathematically written as

$$B(r) = k E_{\beta} Y F_{\beta}(r_1/X_{90}) / (4 \pi \rho r^2 X_{90}) \quad (3.1)$$

where

- r = a variable representing the distance between a source point and a dose point
- k = a unit conversion constant
- E_{β} = the average beta energy for the radionuclide
- Y = the beta yield per disintegration
- $F_{\beta}(r_1/X_{90})$ = the scaled absorbed dose distribution as a function of the modified path length and the X_{90} distance
- r_1 = the modified path length between the source point and dose point
- ρ = the density of the irradiated medium (assumed to be unity for tissue).

The X_{90} distance is defined as the radius of a sphere in which 90% of the beta energy is deposited from a point source in an infinite medium. A computer code, SADDE Mod 2, that calculates $F_{\beta}(r_1/X_{90})$ for various radionuclides is described in Section 4.

In VARSKIN, the integration was performed over the area of the two-dimensional disk source. If the position at the skin depth from the center of the irradiated area is denoted as d , then

$$\vec{r} = \vec{d} + \vec{r}' \quad (3.2)$$

and

$$\dot{D}(d) = \int_0^{2\pi} \int_0^R S_A B(r', d) r' dr' d\theta \quad (3.3)$$

where R is the radius of the source disk, $d = \vec{d} \cdot \hat{i}$, and S_A is source term (assumed to be constant with respect to time and space for VARSKIN Mod 2 areal calculations).

For the purposes of illustration, the following discussion describes a dose calculation for the three-dimensional disk geometry shown in Figure 3.1. The integration is performed by choosing 26 dose points (points at which the dose rate is to be calculated), beginning at the source centerline and proceeding radially outward from the centerline at the skin depth level. Since the source is symmetric, dose points represent concentric isodose circles that describe the radial dose rate profile at a given depth in skin. For each dose point, an integration is performed over the area of the disk-shaped source by choosing eight concentric circles located at radially equidistant positions on the source. One of these circles defined by a radial dose point is chosen, subdivided into eight source points at equiangular locations (angular source points), and the dose rate at the dose point from each of these eight source points is calculated. The contribution to the dose from the first four points is then compared to the contribution to the last four points; if the relative difference between the two contributions is less than a user-selected tolerance (denoted as the relative error), then convergence of the integral for the circle is considered to be achieved and this procedure is repeated at the next radial position. If the relative difference between the two contributions is greater than the relative error, each of the two contributions is again subdivided into eight source points and the above procedure is repeated for each of the two sets. This process, known as the Newton-Cotes eight-panel quadrature routine, provides a fast and accurate method of numerically integrating complex functions such as the Berger kernel.

Figure 3.1 Schematic representation of a dose calculation for a three-dimensional disk source. Note that the z value for the source is constant to reduce clutter.

Once a dose rate value from each radial dose point is determined, the first four radial values are summed and compared to the sum of the last four radial values. These two groups of radial points are checked for convergence, and the above procedure is followed until convergence is reached for all radial points in the source. The dose rate at the next dose point is then calculated until values are obtained at all 26 dose points. If the dose rate profile defined by these 26 points as a function of target radius d' is denoted $D(d')$, then the dose rate averaged over an area in the skin is calculated using the equation

$$D_{\text{avg}} = \frac{2 \pi \int_0^R D(d') d' dd'}{\pi R^2} \quad (3.4)$$

The 26 dose points are chosen such that more points are chosen where the dose profile is changing the most. In general, this occurs at the edge of the source. The distribution of dose points is chosen automatically within VARSKIN Mod 2 and is listed in the output file.

VARSKIN Mod 2 uses the same Newton-Cotes eight-panel quadrature routines as VARSKIN with the addition of a third integration that accounts for the thickness of the source T . The eight-panel quadrature routine was chosen to optimize computer time and calculational accuracy. Thus, the dose integral is written

$$\dot{D}(d') = \int_0^{2\pi} \int_0^R \int_0^T S_v B(r', d, \theta, z) r' dz dr' d\theta \quad (3.5)$$

where S_v is the volumetric source strength. A similar equation can be written for spherical and slab geometries. Those equations are:

$$\dot{D}(d) = S_v \int_0^\pi \int_0^{2\pi} \int_0^R B(r'/d', \theta, \phi) r' \sin\theta dr' d\theta d\phi \quad (3.6)$$

in spherical geometry, and

$$\dot{D}(d) = S_v \int_{-x_{\text{max}}}^{x_{\text{max}}} \int_{-y_{\text{max}}}^{y_{\text{max}}} \int_0^{\text{thickness}} B(d', x, y, z) dz dy dx \quad (3.7)$$

in slab geometry.

When modelling a three-dimensional source, two types of attenuation must be addressed: attenuation due to the presence of the source material and attenuation due to geometry (i.e., $1/r^2$ attenuation). The VARSKIN Mod 2 code determines the attenuation within the source material by calculating the path lengths within the source, outside the source but above the skin, in the cover material (if any), and in the skin. Each of the path lengths is then modified by multiplying the path length by the ratio of the density of the material to the density of water.

3.2 Backscatter

VARSKIN Mod 2 incorporates a limited backscatter correction. When Berger developed the point kernel used in VARSKIN Mod 2, he used data that was measured in an infinite water medium. Therefore, the scaled absorbed dose distributions used by VARSKIN Mod 2 include backscatter from the surrounding medium. For infinitely thin sources (i.e., point sources or two-dimensional disk sources) that are bounded on one side by air (the side not in contact with the skin), the calculated doses overestimate the actual skin dose because they include the contribution from particles that were scattered from the medium behind the source toward the skin.

The absence of backscatter occurs only in the case of infinitely thin sources. For sources with a finite thickness, the greatest contribution to skin dose is from beta particles emitted from the portion of the source that is nearest to the skin. Because the remaining source material lies above this portion, backscatter from the remaining source material must be included. Since most hot particles have a density higher than that of water (such as fuel or stellite), the backscatter component is probably underestimated from the portion of the source that is nearest to the skin. This underestimate is compensated, within the accuracy of the calculations, by the overestimate of backscatter from the portions of the source that are farthest from the skin. Thus, for three-dimensional sources, a backscatter correction is not included in the code.

Backscatter calculations and their results for plane, isotropic sources at a skin density thickness of 7 mg/cm^2 have been published by Cross et al. (1990). Figure 3.2 illustrates the backscatter factor as a function of E_{max} for a plane source and a point detector. Because of reciprocity, the same backscatter factor is applicable for a point source and a plane detector. Other data published by Cross et al. suggest that the backscatter factor for a plane source and a plane detector is within 10% of the data in Figure 3.2. The backscatter factor incorporated within VARSKIN Mod 2 is an extension of the Cross data.

Since the data from Cross only applies to point sources irradiating a 1 cm^2 area or a 1 cm^2 source irradiating a point, the backscatter correction is used sparingly. Backscatter corrections are performed only when the following conditions exist: 1) the source is either a point or an infinitely-thin plane, and 2) the area over which the dose is averaged is 1 cm^2 . For other conditions, no backscatter correction is made.

Figure 3.2 Backscatter correction factor at a skin depth of 7 mg/cm² (Cross et al. 1990)

The backscatter factor incorporated into VARSKIN Mod 2 was derived in the following manner. The abscissa of Figure 3.2, $E_{\max}$, was converted to X_{90} using the data presented by Berger (1971). The X_{90} distance was then divided by 0.007 cm, the skin density thickness at which the Cross data was calculated, to obtain the backscatter factor shown in Figure 3.3. Implicit in the VARSKIN Mod 2 backscatter factor is the assumption that the shape of the curve in Figure 3.2 does not change with skin depth, but that the curve merely shifts to the left at depths less than 7 mg/cm² and shifts to the right at depths greater than 7 mg/cm².

A feature of the backscatter factor in VARSKIN Mod 2 is that backscatter is included with the protective clothing and air gap models and at different skin depths. Since the abscissa of Figure 3.3 is labeled " X_{90} /Thickness", an equivalent thickness that includes the skin depth, the thickness of protective clothing, and the air gap thickness must be calculated. The equivalent thickness is obtained by adding the density thicknesses of skin, protective clothing, and any air gap and dividing by 1 g/cm². The X_{90} distance is then divided by the equivalent thickness and the backscatter factor obtained from Figure 3.3.

Figure 3.3 Backscatter model as a function of X_{90} /thickness based on Cross's backscatter model (Cross et al. 1990)

The original VARSKIN document (Traub et al. 1987) included a table of dose factors for various radionuclides. In VARSKIN Mod 2, these values have changed significantly because the following have been added: a backscatter factor, new low-energy electron contributions to dose (see Chapter 4), upgraded radioactive decay data, dose from Auger and internal conversion electrons, and gamma dose. The updated dose factors are presented in Table 4. The dose factors in Table 4 were calculated using the computer code VARSKIN Mod 2 using a point source of strength $1 \mu\text{Ci}/\text{cm}^2$ at a depth of $7 \text{ mg}/\text{cm}^2$. The dose factors provide the dose rate in rad/h. The dose factors in Table 4 do reflect any contribution from gamma components of the radionuclide.

Many users who are familiar with the original VARSKIN code may wish to repeat their original calculations using VARSKIN Mod 2. Since the backscatter model is automatically incorporated into VARSKIN Mod 2, doses calculated with the two versions will differ. To perform original VARSKIN calculations using VARSKIN Mod 2, the user should choose the three-dimensional disk model with a source diameter of $1 \mu\text{m}$, a source thickness of $1 \mu\text{m}$, and a source density of $0.001 \text{ g}/\text{cm}^3$. By choosing a three-dimensional source geometry, the backscatter model will not be included and original VARSKIN calculations can be reproduced.

Table 4. Dose factors^(a)

Radionuclide	Factor	Radionuclide	Factor	Radionuclide	Factor
³ H	-0-	⁶³ Ni	-0-	¹²⁴ I	0.535
¹¹ C	6.35	⁶⁴ Cu	0.241	¹³¹ I	5.03
¹⁴ C	0.942	⁶⁵ Zn	0.0669	¹³² I	5.92
¹³ N	6.41	⁶⁸ Ga	5.57	¹³³ Xe	3.71
¹⁵ O	6.59	⁷⁶ As	6.37	¹³⁷ Cs	5.78
¹⁸ F	5.96	⁸² Br	4.65	¹⁴⁰ Ba	5.32
²² Na	5.02	⁷⁹ Kr	0.173	¹⁴⁰ La	5.89
²⁴ Na	6.20	⁸⁵ Kr	5.45	¹⁴¹ Ce	5.79
²⁸ Mg	4.94	⁸⁶ Rb	6.13	¹⁴⁴ Ce	3.22
²⁸ Al	6.68	⁸⁹ Sr	6.01	¹⁴⁴ Pr	6.52
³² P	6.24	⁹⁰ Sr	5.25	¹⁴⁷ Pm	2.15
³⁵ S	1.04	⁸⁷ Y	0.155	¹⁹⁸ Au	5.89
³⁶ Cl	5.45	⁸⁸ Y	0.274	²⁰³ Hg	4.60
³⁸ Cl	6.55	⁹⁰ Y	6.40	²¹⁰ Pb	0.061
⁴⁰ K	4.87	⁹¹ Y	6.01	²⁰⁴ Tl	5.43
⁴² K	6.54	⁹⁵ Zr	4.10	²⁰⁸ Tl	6.90
⁴⁵ Ca	2.85	⁹⁵ Nb	0.885	²¹² Pb	9.90
⁴⁷ Ca	5.61	⁹⁹ Mo	5.59	²¹⁴ Pb	8.73
⁴⁹ Ca	6.43	⁹⁹ Tc	3.15	²¹⁰ Bi	5.74
⁴⁷ Sc	4.77	¹⁰³ Ru	2.56	²¹² Bi	2.60
⁴⁹ Sc	6.34	¹⁰⁶ Ru	-0-	²¹⁴ Bi	5.98
⁵² Mn	0.898	¹¹¹ Ag	5.72	²²⁸ Ac	6.64
⁵⁹ Fe	3.99	¹²⁴ Sb	5.12	²³¹ Th	3.53
⁵⁶ Co	5.10	¹²⁵ Sb	2.49	^{234m} Pa	6.29
⁵⁸ Co	0.259	¹³² Te	2.65	²³⁴ Th	1.50
⁶⁰ Co	3.89				

(a) Dose rate (sum of beta and gamma) at 7 mg/cm² (in rad/h) for a contamination level of 1 μ Ci/cm².

3.3 Protective Clothing and Air Gap Models

The backscatter model is executed automatically when either the point source or two-dimensional disk source models are chosen. However, the backscatter model is only applied to a dose area of 1 cm². No additional information is required from the user.

Both protective clothing and air gaps can be modelled using VARSKIN Mod 2. The models use the concept of path length to determine the energy lost in either clothing or air. The "path length" is not the true path traversed by the beta particle; it is merely a mathematical convenience introduced to provide a measure of the energy lost in each layer.

The method used to determine path length within the source and within the cover material can be illustrated using Figure 3.4. For the pictured cylindrical or three-dimensional disk source, the known values in the figure are the source radius (*RMAX*), the horizontal distance from the centerline to the source point (*SRAD*), the source thickness (*STHICK*), the cover thickness (*CTHICK*), the skin depth (*SDEP*), the source and cover densities (ρ_s and ρ_c , respectively), the distance from the centerline to the dose point (*PS*), and the distance from the skin to the plane of the source point (*DRAD*). The quadrature routines choose values for the distance from the centerline to the source point (*SRAD*), the angle between *SRAD* and *PS* (*THETA*), and the height of the dose point (*DRAD*). The first quantity to be calculated is *r*, the physical distance from a source point to a dose point. To do this, the square of the projected distance, r_p^2 , is calculated using the law of cosines:

$$r_p^2 = PS^2 + SRAD^2 - 2 \cdot PS \cdot SRAD \cdot \cos(THETA) \quad (3.8)$$

The value of *r* can then be determined using the Pythagorean Theorem:

$$r = \sqrt{r_p^2 + DRAD^2} \quad (3.9)$$

The quantity *r* is used in the denominator of the expression in Equation (3.1) and represents the geometric attenuation between the dose point and the source point. This quantity is further analyzed to calculate the modified path length used to evaluate the scaled absorbed dose distribution as discussed below.

$$r_1 = (r_s \rho_s + r_c \rho_c + r_t \rho_t) / \rho_t \quad (3.13)$$

where ρ_t is the density of tissue (water).

For small-diameter sources, the path between the dose point and the source point may pass through the side of the source, that is, the path may exit the sources and pass through air before passing into skin. Thus, the quantity in Equation (3.7) must be further analyzed to determine the path length within the source and the path length outside the source but above the cover-material level. The actual path length within the source is multiplied by the source density, and the path length outside the source and above the cover material is multiplied by the density of the material outside the source, assumed to be air.

In spherical geometry, the actual distance from source point to dose point is given by Equation (3.8) after substituting $SRAD \cdot \sin \phi$ for $SRAD$. In slab geometry, the actual distance is given by the equation

$$r = [(x_{\text{source}} - x_{\text{dose}})^2 + (y_{\text{source}} - y_{\text{dose}})^2 + (z_{\text{source}} - z_{\text{dose}})^2]^{1/2} \quad (3.14)$$

Equations (3.9) through (3.13) then apply to both spherical and slab geometries.

3.4 Volume-Averaged Dose Model

The volume-averaged dose model, shown schematically in Figure 2.9, allows the calculation of doses averaged over volumes of skin. The volume is bounded by any two planes of irradiated skin, i.e., any two planes between zero skin depth and the skin depth that corresponds to the maximum penetration of beta particles emitted by the source. For sources in contact with the skin, the maximum penetration depth is equal to $1.8 \cdot X_{90}$. Doses averaged over 1 cm^2 are calculated at 20 skin depths between these two limits, and a cubic spline (a third-order piecewise polynomial curve fit) is fit to this depth-dose distribution. When the user enters the skin depths corresponding to the volume of interest, VARSKIN Mod 2 integrates the depth dose function over the region of interest to obtain the volume-averaged dose. Note that the doses calculated at the various skin depths are averaged over 1 cm^2 when VARSKIN Mod 2 is first invoked. The user can choose to calculate volume-averaged doses for different areas only after calculating volume-averaged doses for 1-cm^2 areas.

The volume-averaged dose model requires roughly 20 times the execution time as a single depth calculation to establish the depth dose function. Once this function is calculated, however, subsequent calculations require less than 1 second. Thus, doses

averaged over a number of different volumes can be obtained in roughly the same amount of time as the dose averaged over a single volume.

3.5 Offset Particle Model

The offset particle model, shown schematically in Figure 2.13, allows calculation of skin dose averaged over areas that are not directly below the contaminant. This model is intended to be used to calculate doses from multiple hot particles. In the interests of reasonable execution time and code complexity, the offset particle model is available only for the three-dimensional slab geometry.

The offset particle model requires only one input variable, the distance of the offset. When performing the calculations for the model, VARSKIN Mod 2 assumes that the offset is in the x direction. Since this requirement implies a symmetrical source, the x- and y-side lengths must be equal. If a user invokes the offset particle model with a source that does not have equal x- and y-side lengths, VARSKIN Mod 2 will request that the user re-enter the x- and y-side lengths. VARSKIN Mod 2 also provides the user with the x-side length that corresponds to a source of equivalent area should the user wish to maintain the area of the source.

For multiple particle irradiations, doses from each particle must be calculated separately, running VARSKIN Mod 2 for each particle. The offset particle model does not calculate the maximum dose to skin from several particles; the iterative process for determining the maximum dose to 1 cm^2 is outlined in Section 5.3.

3.6 Hot Particle Gamma Dose Model

Hot particle gamma doses calculated by VARSKIN Mod 2 use a simplified model that has limited application. The model was developed by Lantz and Lambert (1990). The gamma dose model assumes that the source is a point source and that any material between the source and skin is nearly tissue-equivalent. Therefore, the largest dimension of any source has been arbitrarily limited to a maximum of 1 mm. Also, the size of any air gap is limited to 5 cm. The gamma dose is calculated (provided that the radionuclide emits gamma radiation) only for a skin area of 1 cm^2 . The gamma dose model has been experimentally verified by Durham and Lantz (1991).

Two pieces of information are required to perform the gamma dose: the specific gamma-ray exposure constant and the average gamma energy. The specific gamma-ray constant is used to determine gamma doses when electronic equilibrium is fully established. The average gamma energy is used to determine the extent to which electronic equilibrium is established.

The specific gamma-ray exposure constant, in units of $\text{R-cm}^2\text{-Ci}^{-1}\text{-h}^{-1}$, was calculated for the radionuclides listed in BETADATA.DAT using data published by Unger and Trubey (1982). This reference also contains all of the information needed to calculate the specific gamma ray constants for other gamma-emitting radionuclides.

To calculate the specific gamma-ray exposure constant, the following equation should be used (Attix 1986):

$$\Gamma = 193.8 \left[\sum_{i=1}^n P_i E_i \left(\frac{\mu_{en}}{\rho} \right)_{E_i, \text{air}} \right] \quad (3.15)$$

where P_i is the probability of emission of a gamma ray having an energy E_i in MeV and $(\mu_{en}/\rho)_{E_i, \text{air}}$ is the mass energy absorption coefficient in air in units of m^2/kg for the gamma ray. Data for $(\mu_{en}/\rho)_{E_i, \text{air}}$ can be obtained from Attix (1986), and data for E_i and P_i can be found in Unger and Trubey (1982).

The average gamma energy in keV was calculated using the equation

$$E_{\text{avg}} = \frac{\sum_i P_i E_i}{\sum_i P_i} \quad (3.16)$$

The specific gamma-ray constant and the average gamma energy are included in BETADATA.DAT. Beta-dose data for radionuclides not included in BETADATA.DAT can be added using the computer code SADDE Mod 2, but data needed for calculating gamma dose cannot be added using this code. It is possible for a user to add gamma dose data to BETADATA.DAT by manually editing the last line for the radionuclide. After adding a radionuclide using SADDE Mod 2, the last line of the added data contains two zeros. The user can replace the first 0.0 with the correct value for the specific gamma-ray exposure constant and the second 0.0 with the value of the average energy. VARSKIN Mod 2 will then automatically calculate the gamma component of dose when the radionuclide is chosen.

Similarly, the data in BETADATA.DAT can be modified to calculate doses from radionuclides that are pure gamma emitters. This can be accomplished by copying the lines of data for any of the listed radionuclides using a suitable editor. The first line of data (after the radionuclide name, which should be changed to reflect the new radionuclide) contains the values of the average beta energy, the X_{90} distance, and the beta yield of the radionuclide. Substituting a value of "0.1" for the X_{90} distance will cause VARSKIN Mod 2 to bypass the beta dose calculation. The appropriate values for the specific gamma ray exposure constant and the average gamma energy, respectively, can be substituted for the two values in the last line of data. Note that the format of the data must be preserved.

3.7 Internal Conversion and Auger Electrons

The input file for VARSKIN Mod 2, BETADATA.DAT, includes the contribution to the scaled absorbed dose distribution function, F_{β} , from Auger and internal conversion electrons. BETADATA.DAT includes the contribution to F_{β} from all Auger and internal conversion electrons that have energies greater than 65 keV and emission yields, relative to the beta emission yield, of greater than 0.005. The energy cutoff was chosen since electrons with energies less than 65 keV do not contribute to dose at a depth of 7 mg/cm². The emission yield cutoff was chosen because the contribution to dose from electrons with relative yields below 0.005 is negligible. Due to the integration method used in VARSKIN Mod 2, it is not possible to calculate skin dose from radionuclides that emit Auger and internal conversion electrons without an accompanying beta spectrum.

Inclusion of Auger and internal conversion electrons with energies or yields below the cutoff value can be accomplished by using SADDE Mod 2. A description of the methodology used to include Auger and internal conversion electrons is included in Section 4.2.

3.8 Positron-Emitting Radionuclides

Radionuclides that emit positrons pose a problem when using VARSKIN Mod 2 and SADDE Mod 2, since all positrons are treated as negatrons. The energy distribution of positrons is higher than that of negatrons because of coulombic repulsion by the nucleus. Thus, positrons have a higher ratio of average energy to maximum energy than negatrons. Also, F_{β} is skewed toward higher positrons than negatrons.

Average energies calculated for positrons using SADDE Mod 2 were compared to published data for positrons (Kocher 1981). It was found that the difference in the average energy calculated using SADDE Mod 2 was consistently less than the published value by as much as 31%. Thus, the values of the average energy for positron-emitting radionuclides were adjusted to remain consistent with values of average energy generated using RADLST (Burrows 1988).

The adjustment to the average energy will not correct differences in the spatial energy distribution for positron-emitting radionuclides. Care must be exercised when performing calculations of skin dose from positrons using VARSKIN Mod 2. Errors in the spatial energy distribution, F_{β} range from 3% for low-Z radionuclides to 31% for high-Z radionuclides. However, errors in doses calculated for positrons will not be as large as the errors in F_{β} , especially if doses are averaged over 1 cm². The errors associated with skin dose calculations for positrons will be consistent with the errors associated with the calculation, especially if the average energy, as calculated using SADDE Mod 2, is adjusted to be consistent with published data.

4 Technical Basis for SADDE Mod 2

This chapter presents the technical approach used in SADDE Mod 2. Much of the information is reprinted from the original NUREG document that describes SADDE (Reece et al. 1989) with additions that reflect the modifications. Section 2.3 highlights the modifications incorporated into the upgraded code, and this chapter serves as a complete technical description of SADDE MOD 2.

4.1 Beta Spectra

From the basic definitions of specific absorbed fraction for monoenergetic electrons given by Berger (1971), the absorbed dose rate is defined as follows:

$$R(x, E_0) = A n k E_0 \phi(x, E_0) \quad (4.1)$$

where $R(x, E_0)$ = the absorbed dose rate

x = the distance from the point source

A = the source activity

n = the number of electrons emitted at energy E_0 per unit
of source activity

k = a unit conversion factor

E_0 = the initial energy of the electron

$\Phi(x, E_0)$ = the specific absorbed fraction of the energy.

For a spectrum of energies such as would be emitted from a source undergoing beta decay, the absorbed dose rate $R_\beta(x)$ would be:

$$R_\beta(x) = A Y_\beta k \int_0^{E_{\max}} E S(E) \phi(x, E) dE \quad (4.2)$$

where $E_{\max}$ is the endpoint energy of the beta spectrum, Y_β is the number of beta particles emitted per disintegration (the yield), and $S(E)$ is the energy spectrum of the beta particles in particles/MeV.

For convenience, Equation (4.2) can be cast into the same form as Equation (4.1):

$$R_\beta(x) = A Y_\beta k E_{av} \phi_\beta(x) \quad (4.3)$$

where E_{av} , the mean energy of the spectrum, is defined as

$$E_{av} = \frac{\int_0^{E_{max}} E S(E) dE}{\int_0^{E_{max}} S(E) dE} \quad (4.4)$$

and

$$\phi_p(x) = \int_0^{E_{max}} (E/E_{av}) S(E) \phi(x,E) dE \quad (4.5)$$

The first step in determining the scaled absorbed dose distributions for a given isotope is calculating the emitted beta spectra. This is accomplished by a code called BETA, developed at Kansas State University by Richard Faw and Gale Simons, which (with minor modifications) is installed as a subroutine in the SADDE MOD 2 code. The BETA code is used with the permission of Faw and Simons. The following information is needed to calculate the beta spectrum from the decay of a radionuclide or mixture:

- the name of the radionuclide or mixture - This name must be no longer than six characters and must be different than any previous radionuclide name.
- an indication if multiple radionuclides are to be used when calculating the distribution
- if multiple radionuclides are to be included in the distribution, the number of those radionuclides - This number must be less than 30.
- the number of decay modes for the parent radionuclide
- the atomic number of the transition product (daughter) nucleus
- the atomic mass of the decaying (parent) radionuclide
- if multiple radionuclides are to be included in the distribution, the relative weight of each radionuclide - The sum of the weighting factors will usually be equal to 1.
- the endpoint (maximum) energy of the particular decay path

- the probability of the particular decay path (the yield)
- the degree of forbiddenness for the particular decay.

If multiple radionuclides are to be included in the distribution, the last seven items must be repeated for each radionuclide.

Using this input data, the routine BETA calculates a normalized beta spectrum, $n(E)$, such that

$$\int_0^{E_{\max}} n(E) dE = Y_{\beta} \quad (4.6)$$

The calculated spectrum is divided into 150 energy bins and then interpolated to 1500 values using a spline interpolation routine. These interpolated values are stored in an array called COMP (see Appendix E for a listing of the FORTRAN programs). The average energy of the composite spectrum is calculated using the following algorithm:

$$EAV = \int_0^{E_{\max}} COMP(E) E dE \quad (4.7)$$

where $E_{\max}$ is the maximum endpoint energy for the composite spectrum.

The subroutine SADD uses the average energy and COMP to calculate the scaled absorbed dose function, $\Phi_{\beta}(x)$. The SADD routine determines the maximum beta range and sets the range step size to 1/150 of this maximum range. The scaled absorbed dose function for the beta spectrum is calculated for each distance step by integrating through energy in steps of 1/150th of the maximum energy using the following equation:

$$\Phi_{\beta} = \frac{1}{E_{av}} \int_0^{E_{\max}} E n(E) \phi(x, E) dE \quad (4.8)$$

where $\Phi(x, E)$ is the scaled absorbed dose function for monoenergetic electrons.

The function $\Phi(x, E)$ is determined within the SADD routine by a routine named SPENS, an algorithm for interpolating Spencer's data (1959) for scaled absorbed dose distribution as a function of distance and electron energy through energy and

distance. When SADD picks an energy (E) and a distance (x), $\Phi(x,E)$ is calculated by the following algorithm:

$$\Phi(x,E) = F(\xi,E)/4 \pi \rho x^2 X_{90}(E) \quad (4.9)$$

where ξ is $x/X_{90}(E)$ and ρ is the density of the absorbing medium.

$F(\xi,E)$ is a tabulated function of ξ and E that is interpolated to calculate the function value. Output of the routine SADD is the function $\Phi_\beta(x)$, the array PHI in the FORTRAN program, which has 150 values.

The X_{90} distance is calculated using the array PHI and EAV. This is accomplished by summing up the values of dE/dx over distance and arriving at the total energy in the beta spectrum:

$$\frac{dE}{dx} = 4 \pi \rho x^2 E_{av} \Phi_\beta(x) \quad (4.10)$$

Therefore,

$$E_{Tot} = \sum_i \Delta x_i 4 \pi \rho x_i^2 E_{av} \Phi_\beta(x) \quad (4.11)$$

Once the total energy in the spectrum is found, a second sum is computed as follows:

$$FRAC = \sum_i \Delta x_i 4 \pi \rho x_i^2 E_{av} \Phi_\beta(x) / E_{Tot} \quad (4.12)$$

FRAC is evaluated for successively larger values of x until FRAC is 0.9, then the current x value becomes the X_{90} value and is stored as the FORTRAN variable X90.

The routine FBETA calculates the function $F_\beta(\xi)$. The routine uses X90 and PHI to perform the following calculation:

$$F_\beta(\xi) = 4 \pi \rho x^2 X_{90} \Phi_\beta(x) \quad (4.13)$$

The values of x are divided by X_{90} and then $F_\beta(x)$ is tabulated against the x values. The resulting values of $F_\beta(\rho)$ are stored in the array F. The final routine FIT uses

linear interpolation to extract the 30 specific values of $F_{\beta}(\rho)$ needed by VARSKIN and writes these values to the output file.

Values of the functions $F(\xi, E)$ and $X_{90}(E)$ in Equation (4.9) have been extended to energies as low as 0.05 keV in SADDE Mod 2. Work performed by Wilson and Reece (1991) extends the values of these functions to 0.05 keV. Wilson's results compared favorably with Berger's improved point kernels (1973) at 25 keV, the lowest energy for which Berger's functions were provided. The low energy corrections in SADDE Mod 2 should have little bearing on doses averaged over areas larger than a few mm^2 , but doses averaged over smaller areas could be affected, particularly if the contamination is in contact with skin.

4.2 Auger and Internal Conversion Electrons

The contribution to dose from Auger and internal conversion electrons can be modeled using SADDE Mod 2. The only input required is the electron energy in MeV and the electron yield expressed as a fraction. SADDE Mod 2 adds the contribution of the electrons to the beta spectrum, ϕ_{β} , weighted by the yield of the electron. The total yield of the radionuclide is also adjusted to reflect the additional radionuclides.

Internal conversion and Auger electrons should only be modeled if the yield of the electron relative to the beta-particle yield is greater than 0.005. In addition, electrons with energies less than 65 keV can be ignored unless skin dose calculations at depths less than 7 mg/cm^2 are needed.

5 Special Topics for Accurate Use of VARSKIN Mod 2

5.1 Infinite Sources

VARSKIN Mod 2 is designed to be very flexible while maintaining the required accuracy. However, VARSKIN Mod 2 can be misused, particularly in modeling infinitely large sources (sources with all dimensions greater than the X_{99} distance for these radionuclides) and in volume-averaging doses for point sources. This section describes these two possible misuses of VARSKIN Mod 2 and how to avoid them, and provides a method to determine the maximum dose to 1 cm^2 from multiple hot particles.

When modeling "infinite" or "semi-infinite" sources such as an enveloping cloud with VARSKIN Mod 2, the tendency is to choose very large dimensions for the source. This approach will result in the calculation of grossly inaccurate doses or zero doses because the integration routine becomes inaccurate. The correct method is to determine the maximum penetration distance (i.e., $1.8 \cdot X_{90}$ distance, or X_{99} distance) and set the source dimensions accordingly.

The X_{99} distance can be found either by looking at the file BETADATA.DAT or by running a simple calculation for the radionuclide of interest. To find the radionuclide in BETADATA.DAT, look for the radionuclide name. The next line contains three values: the average beta energy, the X_{90} distance (in cm), and the number of betas emitted per disintegration (yield). Multiplying the X_{90} distance by 1.8 gives the X_{99} distance. An alternative method of finding the X_{99} distance is to run a simple point source geometry problem with the radionuclide of interest. The X_{99} distance is printed on both the output screen and the output file as

$$1.8 \cdot X_{90} \text{ distance} :$$

When the X_{99} distance has been determined, the maximum source radius, r_{max} , for x- and y-side lengths is determined using the equation:

$$r_{\text{max}} = r_{\text{dos}} + (X_{99}/\rho_c) \quad (5.1)$$

where r_{dos} is the radius of the dose-averaging area (in cm) and ρ_c is the density of the covering material (in g/cm^3). If more than one covering material exists, use the density of the least dense material. Using the least-dense material will ensure that the area over which the dose averaged includes contributions from the entire source. If an air gap is used, use the density of air (0.001293 g/cm^3). If no cover material is used, use the density of tissue (1 g/cm^3). Remember to convert r_{max} from cm in Equation (5.1) to μm for VARSKIN Mod 2 input.

When modeling infinite sources, the use of three-dimensional slab geometry is recommended. When using slab geometry, the source thickness, Δt_{max} , should be determined using the equation:

$$\Delta t_{\text{max}} = X_{99} / \rho_s \quad (5.2)$$

where ρ_s is the source density in g/cm^3 . Again, remember to convert Δt_{max} from cm in Equation (5.2) to μm for VARSKIN Mod 2 input.

5.2 Volume-Averaged Doses for Point Sources

Point sources have very steep dose gradients at the interface between the source and skin. Attempting to use the volume-averaged dose model in VARSKIN Mod 2 for point sources in direct contact with the skin will produce erroneous results because the cubic spline function does not accurately describe such steep gradients. For the same reason, modeling a point source as a two-dimensional disk with a very small radius will not alleviate the problem. Note that this problem occurs only when the point source is in direct contact with the skin.

The only accurate method for calculating volume-averaged doses for point sources in direct contact with skin is to insert a cover material with a thickness of $1\ \mu\text{m}$ and a density of $1\ \text{g/cm}^3$ between the source and skin. At this depth, the dose gradient is not nearly so steep, and the cubic spline function describes the depth dose profile accurately. When the results of the volume-averaged dose are reported, the skin depth should be increased by $0.1\ \text{mg/cm}^2$ to account for the extra covering material.

5.3 Maximum Dose to $1\ \text{cm}^2$ from Multiple Hot Particles

Determining the maximum dose to $1\ \text{cm}^2$ for multiple hot particles requires numerous calculations and cannot be performed quickly. The calculations also require elements that are not available in VARSKIN Mod 2 but that can be accomplished with some graph paper and a calculator.

Before attempting to run the offset particle model (Section 3.5), determine the dose directly beneath each of the hot particles. The output screen for each of the calculations will display the radius of the irradiated area if the dose-averaging area is large enough. If not, entering a larger area will eventually provide the radius of the irradiated area. By comparing these areas for each source, it may be possible to eliminate one or more of the particles because there are no overlapping fields associated with them. For particles with overlapping fields, the doses and their relative positions should then be plotted on a sheet of graph paper, leaving plenty of room between the sources for results from additional calculations.

Next, calculations using the offset particle model should be performed for locations midway between any two particles. For more than two sources that are not in a straight line, a central location should be chosen and the dose at this point should be calculated using the offset particle model. Thus, for three particles in a triangular formation, a total of four calculations should be performed, choosing the value of the offset to be one-half of the distance between any two sources, with one additional dose calculation performed in the center of the triangle.

After these calculations have been performed, it is left to the user's discretion to determine the most probable area of highest dose based on the distribution of dose on the graph paper. After determining this area, a final calculation for each particle using the offset particle model can be performed. An accuracy of greater than 20% should not be sought since the error associated with determining the relative positions of the particles on skin or protective clothing will usually exceed 20%.

5.4 Short-Lived Radionuclides

Care must be exercised when calculating skin doses from radionuclides that have short half lives relative to the exposure time. VARSKIN Mod 2 calculates the total beta and gamma doses assuming that no significant decay occurs during the exposure time. For short-lived nuclides, such as $^{234\text{m}}\text{Pa}$ ($T_{1/2} = 1.18$ min), the source strength will decrease appreciably during most exposure times.

The method used to correct for a decaying source term is to multiply the calculated beta and/or gamma dose rate by a decay factor. That is, the corrected dose, D_{corr} , received during the exposure time, t_{exp} , is given by

$$D_{\text{corr}} = \frac{D_{\text{init}} T_{1/2}}{.693} \left[1 - \exp\left(-\frac{.693 t_{\text{exp}}}{T_{1/2}}\right) \right] \quad (5.3)$$

where D_{init} is initial dose rate in rad/hr and $T_{1/2}$ is the half-life of the radionuclide in hours.

6 References

- Attix, F. H. *Introduction to Radiological Physics and Radiation Dosimetry*, John Wiley and Sons, New York (1986).
- Berger, M. J. *Distribution of Absorbed Dose Around Point Sources of Electrons and Beta Particles in Water and Other Media*. Medical Internal Radiation Dose Committee, Pamphlet No. 7, *Journal of Nuclear Medicine* 12(5):5 (1971).
- Berger, M. J. *Improved Point Kernels for Electron and Beta-Ray Dosimetry*, NSBIR 73-107 (1973).
- Bray, L. G., Cooper, T. L., Goldin, E. M., and Warnock, R. V. Skin Dose Calculations for Fuel Particles, *Radiation Protection Management* 4(5):25-30 (1987).
- Burrows, T. W. 1988. *The Program RADLST*. Information Analysis Center Report BNL-NES-52142, Brookhaven National Laboratory, Upton, New York.
- Cross, W. G., Wong, P. Y., and Freedman, N. O. *Beta-Ray Depth Dose Distributions from Incident Beams and Skin Contamination*. Presented at the Health Physics Society Annual Meeting in Anaheim, CA, June 24-28 (1990).
- Durham, J. S., Reece, W. D., and Merwin, S. E. Modelling Three-Dimensional Beta Sources for Skin Dose Calculations Using VARSKIN Mod 2, *Radiation Protection Dosimetry* 37(2):89-94 (1991).
- Durham, J. S., and Lantz, M. W. Determination of Gamma Dose Rates and Charged Particle Equilibrium from Hot Particles. *Radiation Protection Management* 8(3):35-41 (1991).
- International Commission on Radiological Protection (ICRP). 1991. *1990 Recommendations of the International Commission on Radiological Protection*. Publication 60, Pergamon Press, Oxford.
- Kocher, D. C. *Radionuclide Decay Data Tables*. DOE/TIC-11026, U.S. Department of Energy, Washington, D.C. (1981).
- Lantz, M. W., and Lambert, M. W. Charged Particle Equilibrium Corrections for the Gamma Component of Hot Particle Skin Doses. *Radiation Protection Management* 7(5):38-48 (1990).
- Reece, W. D., Miller, S. D., and Durham, J. S. *SADDE (Scaled Absorbed Dose Distribution Evaluator), A Code to Generate Input for VARSKIN*. NUREG/CR-5276, U.S. Nuclear Regulatory Commission, Washington, D.C. (1989).
- Spencer, L. V. *Energy Dissipation by Fast Electrons*. Monograph No. 1, National Bureau of Standards, Washington, D.C. (1959).
- Titus, F. Measurements of the Energy Response Function of Scintillators for Monoenergetic Electrons. *Nuclear Instruments and Methods* 89:93-100 (1970).

Section 6

Traub, R. J., Reece, W. D., Scherpelz, R. I., and Sigalla, L. A. *Dose Calculation for Contamination of the Skin Using the Computer Code VARSKIN*. NUREG/CR-4418, U.S. Nuclear Regulatory Commission, Washington, D.C. (1987).

Unger, L. M., and Trubey, D. K. *Specific Gamma-Ray Dose Constants for Nuclides Important to Dosimetry and Radiological Assessment*, ORNL/RSIC-45/R1, Oak Ridge National Laboratory, Oak Ridge, Tennessee (1982).

Wilson, W. E., and W. D. Reece. *Calculation of Percentile Distance Ratios and Sealed Absorbed Dose Distributions for 0.05-30 keV Primary Electrons*. PNL-7848, Pacific Northwest Laboratory, Richland, Washington (1991).

APPENDIX A

BETA-DECAY RADIONUCLIDE DATABASE

APPENDIX A

BETA-DECAY RADIONUCLIDE DATABASE

This appendix is designed to be used to determine input to the code SADDE Mod 2 (Reece, Miller, and Durham 1989), which calculates the beta spectrum for a specific radionuclide given the number of decay paths and the maximum energy, yield, and forbiddenness of each decay path. The output from SADDE Mod 2 is used as input for the code VARSKIN Mod 2.

The Beta-Decay Radionuclide Database contains the type, yield, and forbiddenness of each decay path for every beta-emitting radionuclide with a half-life greater than 8 hours. The Beta-Decay Radionuclide Database was generated by RADLST (Burrows 1988) using the Evaluated Nuclear Structure Data Files (ENSDF) obtained from the National Nuclear Data Center at Brookhaven National Laboratory (Upton, NY). The ENSDF format allows the coding of nuclear structure and decay data and associated textual documentation in a form which may be used by computers. The RADLST code is designed to calculate the type, yield, and energy of nuclear and atomic radiations associated with the radioactive decay of nuclei. It uses the ENSDF database as primary input. This code was used to calculate yields and maximum beta energies associated with a radionuclide that undergoes beta decay. The computer code LOGFT was used to determine the forbiddenness of each decay path.

The computer code SADDE Mod 2 calculates the scaled absorbed dose distribution for any beta-emitting radioisotope. As described in section 4, SADDE Mod 2

first generates the beta spectrum of the radioisotope. Beta spectra are classified according to the change in momentum and parity between parent and daughter nuclei. These classifications, as well as the assigned forbiddenness for each classification, are summarized in Table A.1. The beta transitions in ENSDF are classified either on the basis of the change in momentum and parity as shown in Table A.1 (if the data is known) or on the basis of the systematics of Raman and Gove (1973) as summarized in Table A.2 if momentum and parity data are not known. The levels of forbiddenness are based on those assigned in ICRP-38 (1983). The values in the database (beginning on page A.3) are the maximum energy, yield, and forbiddenness.

REFERENCES

- Burrows, T. W. 1988. *The Program RADLST*. Information Analysis Center Report, BNL-NCS-52142, Brookhaven National Laboratory, Upton, New York.
- International Commission on Radiological Protection (ICRP). *Radionuclide Transformations*. ICRP Publication 38, Pergamon Press, New York, 1983.
- Raman, S., and N. G. Gove. 1973. "Rules for Spin and Parity Assignments Based on Log g Values." *Phys. Rev. C* 7:1995.
- Reece, W. D., S. D. Miller, and J. S. Durham. 1989. *SADDE (Scaled Absorbed Dose Distribution Evaluator)*. NUREG/CR-5276, PNL-6761, U.S. Nuclear Regulatory Commission, Washington, D.C.

Appendix A

**Table A.1. Determination of Forbiddenness of Beta Spectra
Based on Momentum and Parity Change**

Classification	Momentum Change	Parity Change	Forbiddenness
Superaligned ($\Delta T = 0$)	$0^+ \rightarrow 0^+$	No	0
Isospin forbidden ($\Delta T = 0$)	$0^+ \rightarrow 0^+$	No	0
Allowed	$0, \pm 1$ (not 0 to 0^+)	No	0
1st-forbidden nonunique	$0, \pm 1$	Yes	0
1st-forbidden unique	± 2	Yes	1
2nd-forbidden nonunique	± 2	No	1
2nd-forbidden unique	± 3	No	2
3rd-forbidden nonunique	± 3	Yes	2
3rd-forbidden unique	± 4	Yes	3

Table A.2. Determination of Forbiddenness Based on Log (ft)

Classification	LOGFT Ranges	Forbiddenness
Superaligned	$3.48 < \log(ft) < 3.5$	0
Allowed	$3.6 < \log(ft) < 5.9^{(a)}$	0
Isospin forbidden ($\Delta T = 1$)	$\log(ft) < 8.5$	0
Allowed		0
1st-forbidden nonunique		0
Isospin forbidden ($\Delta T = 1$)	$\log(ft) < 11.0$	0
Allowed		0
1st-forbidden nonunique		0
1st-forbidden unique		1
Isospin forbidden ($\Delta T = 1$)	$\log(ft) < 12.8$	0
Allowed		0
1st-forbidden nonunique		0
1st-forbidden unique		1
2nd-forbidden nonunique		1
1st-forbidden unique	$\log(ft) > 8.5$	1

(a) For the mass region around $Z = 82$, the upper limit should be lowered to 5.1.

BETA-DECAY RADIONUCLIDE DATABASE

Note: The format used in this table is as follows:

Radionuclide Name (half life)	$E_{\max}$ (MeV)	Yield	Forbiddenness			
226AC β - DECAY				110AG β - DECAY (249.76 D)		
1.1170	0.24000	0		0.5304	0.30560	0
1.0450	0.10000	0		0.4707	0.00080	0
0.8870	0.49000	0		0.1336	0.00410	0
				0.0836	0.67100	0
227AC β - DECAY				111AG β - DECAY		
0.0436	0.55000	0		1.0370	0.92000	0
0.0343	0.35000	0		0.7916	0.01000	1
0.0191	0.10000	0		0.6949	0.07100	0
228AC β - DECAY				28AL β - DECAY		
2.0840	0.10000	0		2.8642	0.99990	0
1.9550	0.01900	0		242AM β - DECAY (16.02 H)		
1.8140	0.00540	1		0.6625	0.37000	0
1.7460	0.11600	0		0.6204	0.46000	0
1.1730	0.31000	0		244AM β - DECAY (10.1 H)		
1.126	0.00300	0		0.3871	1.00000	0
1.1190	0.03000	0		244AM β - DECAY (26 M)		
1.0190	0.05820	0		1.5150	0.65000	0
0.9890	0.05600	0		1.4720	0.30000	0
0.9740	0.03540	0		246AM β - DECAY (25 M)		
0.9150	0.00800	0		2.3350	0.07000	0
0.7100	0.00900	0		1.5360	0.16100	0
0.6110	0.08100	0		1.5020	0.06900	0
0.6030	0.00180	0		1.2990	0.37400	0
0.5040	0.01150	0		1.2730	0.14700	0
0.4990	0.00780	0		246AM β - DECAY (39 M)		
0.4960	0.04180	0		1.1990	1.00000	0
0.4590	0.01180	0		39AR β - DECAY		
0.4540	0.02600	0		0.5650	1.00000	1
0.4180	0.01570	0				
108AG β - DECAY (2.37 M)						
1.6550	0.95400	0				
1.0220	0.01760	0				
110AG β - DECAY (24.6 S)						
2.8928	0.95200	0				
2.2353	0.04420	0				

Appendix A

41AR β - DECAY

2.4923	0.00800	1
1.1986	0.99000	0
0.8153	0.00052	0

74AS β - DECAY (17.77 D)

1.3539	0.18600	1
0.7191	0.15400	0
0.0843	0.00040	0

76AS β - DECAY

2.9635	0.51000	1
2.4044	0.35200	0
1.8412	0.00810	1
1.7473	0.07500	0
1.1758	0.01770	0
0.5344	0.01690	0
0.3082	0.01030	0

77AS β - DECAY (38.83 H)

0.6831	0.97000	0
0.4441	0.01600	0
0.4333	0.00630	0
0.1624	0.00630	0

198AU β - DECAY

0.9607	0.98700	0
0.2848	0.01300	0

199AU β - DECAY

0.4526	0.14300	0
0.2942	0.66400	0
0.2444	0.19300	0

200AU β - DECAY (18.7 H)

0.6100	1.00000	0
--------	---------	---

200AU β - DECAY (48.4 M)

2.2600	0.79000	0
1.8900	0.04700	0
1.2300	0.00230	0
0.6900	0.00640	0
0.6900	0.00020	0
0.6700	0.10900	0
0.6300	0.03900	0

140BA β - DECAY

1.0040	0.24000	1
0.9900	0.38000	0
0.8710	0.04400	1
0.5660	0.09300	0
0.4530	0.23800	0

10BE β - DECAY

0.5562	1.00000	2
--------	---------	---

210BI β - DECAY

1.1614	1.00000	0
--------	---------	---

211BI β - DECAY

0.5840	0.00280	0
--------	---------	---

212BI β - DECAY

2.2460	0.55310	0
1.5190	0.04490	0
0.7330	0.01460	0
0.6250	0.01890	0
0.5670	0.00244	0
0.4400	0.00650	0

214BI β - DECAY

3.2740	0.19900	0
1.8960	0.07180	0
1.8590	0.00870	0
1.7310	0.03050	0
1.6130	0.00640	0
1.5440	0.17500	0
1.5100	0.16900	0
1.4270	0.08260	0
1.3840	0.01590	0
1.2790	0.01380	0
1.2630	0.01660	0
1.2570	0.02900	0
1.1550	0.04140	0
1.1260	0.00560	0
1.0810	0.00830	0
1.0700	0.05540	0
0.8260	0.02740	0
0.7920	0.01450	0

249BK β - DECAY (320 D)			115CD β - DECAY (53.46 H)		
0.1257	0.99000	0	1.1060	0.62600	0
0.0632	0.01000	1	0.8450	0.01160	0
			0.6130	0.03300	0
			0.5780	0.33100	0
250BK β - DECAY			141CE β - DECAY		
1.7810	0.04800	1	0.5813	0.29800	0
1.7380	0.04800	0	0.4359	0.70200	0
0.7490	0.83400	0			
0.7100	0.06210	0			
82BR β - DECAY			143CE β - DECAY		
0.4441	0.98500	0	1.4042	0.35000	0
0.2644	0.01300	0	1.1110	0.48300	0
			0.7397	0.13200	0
14C β - DECAY			0.5238	0.01360	0
0.1565	1.00000	0			
45CA β - DECAY			144CE β - DECAY		
0.2569	1.00000	0	0.3182	0.76500	0
			0.2381	0.03900	0
			0.1847	0.19600	0
49 CA β - DECAY			253CF β - DECAY		
2.891	0.00410	0	0.2880	0.99700	0
2.178	0.91500	0			
1.7465	0.00180	0			
1.1912	0.07000	0	36CL β - DECAY		
0.7699	0.00660	0	0.7092	0.98100	1
0.5249	0.00210	0			
47CA β - DECAY			38CL β - DECAY		
1.9880	0.19000	0	4.915	0.57600	1
0.6910	0.81000	0	2.748	0.10800	0
			1.106	0.31600	0
113CD β - DECAY (14.1 Y)			60CO β - DECAY (10.47 M)		
0.5800	0.99980	0	1.549	0.00230	0
113CD β - DECAY (9.3E+15 Y)			60CO β - DECAY (5.2704 Y)		
0.3160	1.00000	3	1.4911	0.00057	2
			0.3179	0.99925	0
115CD β - DECAY (44.6 D)			61CO β - DECAY		
1.6230	0.97000	0	1.2547	0.95600	0
0.6890	0.01700	1	0.4129	0.04400	0
			134CS β - DECAY		
			0.6570	0.7010	0
			0.4152	0.0248	0
			0.0886	0.2740	0

Appendix A

132CS β - DECAY

0.8100	0.01570	0
0.2400	0.00370	0
0.1400	0.00060	0

135CS β - DECAY (2.3E+6 Y)

0.2050	1.00000	0
--------	---------	---

136CS β - DECAY (13.16 D)

0.6815	0.13000	0
0.5176	0.00200	1
0.4942	0.04700	0
0.4079	0.10500	0
0.3410	0.70300	0
0.1744	0.02040	0

137CS β - DECAY

1.1732	0.05570	1
0.5115	0.94430	1

64CU β - DECAY

0.5782	0.37100	0
--------	---------	---

67CU β - DECAY

0.5760	0.20000	0
0.4830	0.23000	0
0.3910	0.56000	0
0.1820	0.01100	0

166DY β - DECAY

0.4869	0.04900	0
0.4327	0.04900	1
0.4044	0.90200	0

169ER β - DECAY

0.3520	0.55000	0
0.3436	0.45000	0

171ER β - DECAY

1.4900	0.02300	0
1.0651	0.94000	0
0.8141	0.00190	0
0.5770	0.02190	0
0.4914	0.00520	0

172ER β - DECAY

0.8910	0.02800	1
0.4840	0.03100	0
0.4160	0.00940	0
0.3560	0.46700	0
0.2810	0.46480	0

254ES β - DECAY (275.7 D)

0.1590	1.00000	0
--------	---------	---

254ES β - DECAY (39.3 H)

1.1710	0.18000	0
1.1260	0.10000	0
1.0220	0.01000	0
0.4770	0.56000	0
0.4370	0.16000	0

150EU β - DECAY (12.8 H)

1.0130	0.89000	0
0.3750	0.00020	1

152EU β - DECAY

1.4778	0.08200	0
1.0667	0.00940	0
0.8915	0.00300	0
0.7129	0.00290	0
0.6989	0.13800	0
0.3881	0.02400	0
0.1787	0.01780	0

154EU β - DECAY

1.8458	0.10000	0
1.5979	0.00190	0
1.1534	0.00700	0
0.9726	0.03500	0
0.8411	0.16800	0
0.7173	0.00290	0
0.7051	0.00670	0
0.5713	0.36900	0
0.4376	0.00280	0
0.3517	0.01550	0
0.3080	0.00800	0
0.2493	0.28300	0

155EU β - DECAY

0.2527	0.13000	0
0.1927	0.08600	0
0.1662	0.28000	0
0.1474	0.50000	0
0.1347	0.00690	0
0.1066	0.00780	0

156EU β - DECAY

2.4530	0.32000	0
1.4040	0.01300	0
1.2850	0.04100	0
1.2110	0.05300	0
1.0870	0.02100	0
0.5010	0.00900	0
0.4870	0.29000	0
0.4260	0.05700	0
0.2660	0.10300	0
0.2480	0.02200	0
0.1830	0.04200	0

157EU β - DECAY

1.2990	0.48000	0
0.9290	0.15000	0
0.8880	0.22000	0
0.8480	0.03000	0
0.8380	0.04000	0
0.6800	0.04000	0
0.6760	0.03000	0
0.6120	0.02000	0

59FE β - DECAY

1.5650	0.00180	0
0.4660	0.53100	0
0.2730	0.45200	0
0.1310	0.01290	0

60FE β - DECAY

0.1810	1.00000	1
--------	---------	---

223FR β - DECAY

1.0970	0.63000	0
1.0680	0.13500	0
1.0170	0.02000	0
0.9130	0.12000	0
0.8050	0.00190	0
0.7780	0.02300	0

72GA β - DECAY

3.1584	0.10300	0
2.5284	0.08500	0
2.2641	0.00800	0
1.9274	0.02990	0
1.5900	0.00310	0
1.5285	0.00150	0
1.4776	0.08900	0
1.0489	0.01870	0
0.9568	0.27700	0
0.6674	0.21700	0
0.6506	0.15000	0
0.5530	0.00300	0
0.5371	0.00340	0
0.3143	0.00780	0

159GD β - DECAY

0.9747	0.62000	0
0.9167	0.26000	0
0.6265	0.00270	0
0.6112	0.11000	0

3H β - DECAY

0.0186	1.00000	0
--------	---------	---

181HF β - DECAY

0.5460	0.00500	1
0.4130	0.93000	0
0.4090	0.07000	0

182HF β - DECAY (61.5 M)

0.8940	0.08900	0
0.4310	0.37400	0
0.2100	0.01400	0

182HF β - DECAY (9E+6 Y)

0.1040	1.00000	1
--------	---------	---

184HF β - DECAY

1.1100	0.49000	0
0.8900	0.15000	0
0.7200	0.36000	0

203HG β - DECAY

0.2126	1.00000	0
--------	---------	---

Appendix A

166HO β - DECAY (26.80 H)

1.8539	0.50400	0
1.7733	0.48700	1
0.3940	0.00950	0

166HO β - DECAY (1200 Y)

0.0729	0.74700	0
0.0324	0.17300	0

129I β - DECAY

0.1540	1.00000	1
--------	---------	---

130I β - DECAY

1.7810	0.01400	0
1.1780	0.01450	0
1.0420	0.47700	0
0.9040	0.00175	0
0.8140	0.02140	0
0.6240	0.46000	0
0.5590	0.00185	0
0.3780	0.00500	0
0.3570	0.00330	0

131I β - DECAY

0.8069	0.00420	1
0.6063	0.89400	0
0.3338	0.07360	0
0.3039	0.00620	0
0.2479	0.02130	0

132I β - DECAY

2.1400	0.17600	0
1.6170	0.12700	0
1.4700	0.10200	0
1.4680	0.01900	0
1.4130	0.01700	0
1.2760	0.00910	0
1.1850	0.19000	0
1.1550	0.02110	0
0.9960	0.03790	0
0.9670	0.08100	0
0.9100	0.03600	0
0.8260	0.00370	0
0.7410	0.12800	0
0.7400	0.01810	0
0.6890	0.00880	0
0.5220	0.00340	0
0.4580	0.00380	0

133I β - DECAY

1.5300	0.01040	1
1.2300	0.83000	0
1.0200	0.01830	0
0.8800	0.04200	0
0.7100	0.00630	0
0.5200	0.03200	0
0.4600	0.03800	0
0.4100	0.00400	0
0.3700	0.01260	0

115IN β - DECAY

0.8230	0.05000	0
0.3260	0.00047	0

116IN β - DECAY (54.41 M)

1.0120	0.52100	0
0.8740	0.33800	0
0.6020	0.10200	0
0.3570	0.02710	0

192IR β - DECAY

0.6720	0.48100	0
0.5360	0.41600	0
0.2560	0.05550	0

194IR β - DECAY (171 D)

0.300	1.00	0
-------	------	---

194IR β - DECAY (19.15 H)

2.2486	0.85400	0
1.9202	0.09200	0
1.6266	0.01350	0
1.3259	0.00300	1
0.9815	0.01760	0
0.7694	0.00640	0
0.7367	0.00560	0

40K β - DECAY

1.3121	0.8933	3
--------	--------	---

42K β - DECAY

3.5251	0.81200	1
2.0002	0.18300	0
1.6876	0.00350	1

43K β - DECAY			177LU β - DECAY (6.71 D)		
1.8170	0.01500	1	0.4971	0.78600	0
1.4440	0.03000	0	0.3841	0.09100	0
1.2240	0.03400	0	0.1758	0.12200	0
0.8270	0.89000	0			
0.4220	0.03000	0			
85KR β - DECAY (10.756 Y)			179LU β - DECAY		
0.6874	0.99563	1	1.3500	0.87000	0
0.1734	0.00434	0	1.1400	0.10900	0
			1.0100	0.02000	0
87KR β - DECAY			28MG β - DECAY		
3.8870	0.30500	0	0.8596	0.01400	0
3.4840	0.41000	0	0.4589	0.94000	0
3.0420	0.07300	1	0.2118	0.04600	0
2.4970	0.00119	0			
2.3090	0.00120	0	56MN β - DECAY		
2.1460	0.00620	0	2.8489	0.56300	0
1.4730	0.05500	0	1.0382	0.27900	0
1.3320	0.09400	0	0.7358	0.14600	0
1.0760	0.00600	0	0.3260	0.01160	0
0.9260	0.04400	0			
138LA β - DECAY			99MO β - DECAY		
0.2550	0.33600	2	1.2143	0.82400	0
			0.8479	0.01140	0
			0.4363	0.16500	0
140LA β - DECAY			24NA β - DECAY		
2.1648	0.04800	0	1.3902	0.99944	0
1.6778	0.19200	0			
1.4131	0.04930	0	94NB β - DECAY (2.03E+4 Y)		
1.4113	0.00360	1	0.4716	0.98100	0
1.3490	0.44000	0			
1.2969	0.05450	0	95NB β - DECAY (35.6 D)		
1.2802	0.01070	0	0.1597	0.99950	0
1.2453	0.05680	0			
1.2396	0.10900	0	95NB β - DECAY (86.6 H)		
1.2138	0.00630	1	1.160	0.032	0
			0.956	0.023	0
176LU β - DECAY (3.6 E10 y)			0.374	0.00068	0
0.5970	0.99660	0			
0.1959	0.00340	0	96NB β - DECAY		
			0.7490	0.96700	0
176LU β - DECAY (3.68 H)			0.7460	0.02300	0
1.3170	0.39000	0	0.4320	0.00490	0
1.2286	0.61000	0	0.3120	0.00500	0
177LU β - DECAY (160.9 D)			97NB β - DECAY		
0.1518	0.79000	0	1.2759	0.98340	0
			0.9094	0.01080	0

Appendix A

98NB β - DECAY (51.3 M)

3.2380	0.01400	0
3.1600	0.08000	0
2.6520	0.00800	1
2.5650	0.00850	0
2.4460	0.15900	0
2.2510	0.02060	1
2.1640	0.05200	1
2.0490	0.01140	0
1.9910	0.28600	0
1.9020	0.07700	0
1.6930	0.00760	0
1.6490	0.06500	0
1.6190	0.02310	0
1.4590	0.11000	0
1.3440	0.02850	0
1.2750	0.02900	0
1.2150	0.01750	0
1.1230	0.01240	0
0.9270	0.01110	0

147ND β - DECAY (10.98 D)

0.8958	0.00150	0
0.8047	0.81000	0
0.4853	0.00600	0
0.4065	0.00800	0
0.3648	0.15300	0
0.2099	0.02200	0

63NI β - DECAY

0.0659	1.00000	0
--------	---------	---

66NI β - DECAY

0.2270	1.00000	0
--------	---------	---

236NP β - DECAY (22.5 H)

0.5370	0.39700	0
0.4920	0.08300	0

236NP β - DECAY (154000 Y)

0.1700	1.00000	0
--------	---------	---

238NP β - DECAY

1.2473	0.28000	0
0.3286	0.01370	0
0.3059	0.00590	0
0.2628	0.49600	0
0.2215	0.12600	0

239NP β - DECAY

0.7142	0.04000	0
0.6648	0.02000	0
0.4366	0.53000	0
0.3919	0.07000	0
0.3304	0.33000	0
0.2102	0.01800	0

240NP β - DECAY (61.9 M)

1.9000	0.03200	0
--------	---------	---

240NP β - DECAY (7.22 M)

2.1800	0.10000	0
2.1370	0.42000	0
2.0380	0.01500	0
1.5830	0.31000	0
1.5310	0.00100	0
1.3190	0.02500	0
1.2800	0.03800	0
1.2420	0.01400	0
1.2210	0.01260	0
0.7420	0.00360	0
0.6920	0.00580	0
0.6400	0.02300	0

191OS β - DECAY (15.4 D)

0.1414	1.00000	0
--------	---------	---

193OS β - DECAY

1.1370	0.55000	0
1.0640	0.18000	0
0.9980	0.12500	0
0.9570	0.02000	0
0.7750	0.00770	0
0.6770	0.07900	0
0.5800	0.02400	0
0.5780	0.00740	0

194OS β - DECAY

0.0970	0.24000	0
0.0539	0.76000	0

32P β - DECAY

1.7104	1.00000	0
--------	---------	---

33P β - DECAY

0.2485	1.00000	0
--------	---------	---

230PA β - DECAY

0.5020	0.08200	0
0.1870	0.00180	0

232PA β - DECAY

1.3370	0.00100	1
1.2890	0.00700	0
1.1800	0.00800	1
1.0150	0.00076	0
0.7740	0.01000	0
0.7080	0.00500	0
0.6460	0.00100	1
0.6020	0.00100	0
0.4700	0.01000	0
0.4260	0.00500	0
0.3200	0.73500	0
0.2860	0.25100	0

233PA β - DECAY

0.5721	0.08000	0
0.2599	0.17000	0
0.2316	0.40000	0
0.1735	0.16400	0
0.1563	0.27700	0

234PA β - DECAY (1.17 M)

2.2730	0.98400	0
1.4630	0.00620	0
1.2280	0.00740	0

234PA β - DECAY (6.70 H)

1.2510	0.01100	0
1.2300	0.08000	0
1.1750	0.02600	0
1.1750	0.05500	0
1.1300	0.04000	0
1.1070	0.10000	0
0.9240	0.01400	0
0.7030	0.05000	0
0.6470	0.23000	0
0.5060	0.06800	0
0.4760	0.16000	0
0.4760	0.35000	0
0.4610	0.03300	0
0.4370	0.03100	0
0.4170	0.05700	0
0.3880	0.01400	0
0.3180	0.01800	0

210PB β - DECAY

0.0630	0.20000	0
0.0165	0.80000	0

211PB β - DECAY

1.3790	0.91300	0
0.9740	0.01540	0
0.5470	0.06320	0

212PB β - DECAY

0.5730	0.11800	0
0.3340	0.83200	0
0.1580	0.05090	0

214PB β - DECAY

1.0320	0.09300	0
0.7370	0.40500	0
0.6800	0.46000	0
0.4980	0.01040	0
0.1930	0.02350	0

107PD β - DECAY (6.5E+6 Y)

0.0330	1.00000	1
--------	---------	---

109PD β - DECAY

1.0279	0.99900	0
--------	---------	---

146PM β - DECAY

0.7950	0.31000	0
0.1620	0.02100	0

147PM β - DECAY

0.2247	0.99994	0
--------	---------	---

148PM β - DECAY (41.29 D)

1.0160	0.00800	0
0.7040	0.22100	0
0.5150	0.22700	0
0.4160	0.50000	0

148PM β - DECAY (5.370 D)

2.4730	0.55000	0
1.9230	0.09400	0
1.0490	0.00240	1
1.0080	0.33300	0

149PM β - DECAY

1.0730	0.65100	0
1.0500	0.32600	0
0.7870	0.02300	0

Appendix A

1 151PM β - DECAY

1.1870	0.10000	0
1.1820	0.10000	0
1.1210	0.01300	0
1.1170	0.02700	0
1.0820	0.03000	0
1.0190	0.07900	0
1.0190	0.01400	0
0.9780	0.02300	0
0.8800	0.01700	0
0.8630	0.03300	0
0.8420	0.42000	0
0.7910	0.01900	0
0.7410	0.07100	0
0.6660	0.00770	0
0.4460	0.03100	0
0.4130	0.01140	0
0.3640	0.06100	0
0.2340	0.01000	0

142PR β - DECAY

2.1603	0.96300	1
0.5850	0.03700	0

143PR β - DECAY

0.9345	1.00000	0
--------	---------	---

144PR β - DECAY (17.28 M)

2.9960	0.97900	0
2.2990	0.01040	1
0.8100	0.01050	0

144PR β - DECAY (7.2 M)

2.3590	1.00000	0
--------	---------	---

145PR β - DECAY

1.8050	0.97000	0
1.7330	0.00330	0
1.0570	0.01000	0
0.7540	0.00400	0

197PT β - DECAY (18.3 H)

0.7190	0.11000	0
0.6417	0.81000	0
0.4502	0.08200	0

197PT β - DECAY (95.41 M)

0.7096	0.03300	0
--------	---------	---

200PT β - DECAY

0.6900	0.19000	0
0.6300	0.01000	1
0.6100	0.46000	0
0.5900	0.08200	0
0.5200	0.00480	0
0.4500	0.12900	0
0.4500	0.00300	0
0.3900	0.09500	0
0.3000	0.06000	0
0.2200	0.00480	0

241PU β - DECAY

0.0208	1.00000	0
--------	---------	---

243PU β - DECAY

0.5830	0.60000	0
0.5400	0.08500	0
0.4990	0.21000	0
0.4860	0.01700	0
0.4730	0.05000	0
0.4390	0.03500	0
0.1170	0.01200	0

246PU β - DECAY

0.3740	0.19000	1
0.3300	0.26200	0
0.1500	0.71000	0
0.0750	0.00836	0

225RA β - DECAY

0.3710	0.30500	0
0.3310	0.69500	0

228RA β - DECAY

0.0390	1.00000	0
--------	---------	---

86RB β - DECAY

1.7743	0.9136	1
0.6973	0.0864	0

186RE β - DECAY

1.0745	0.79800	0
0.9373	0.20200	0

187RE β - DECAY

0.0026	1.00000	1
--------	---------	---

188RE β - DECAY (16.98 H)			124SB β - DECAY (60.20 D)		
2.1202	0.70600	0	2.3023	0.23200	0
1.9652	0.26000	0	1.6564	0.02620	0
1.4872	0.01680	0	1.5795	0.04880	0
1.0338	0.00640	0	0.9471	0.02040	0
0.6577	0.00450	0	0.8657	0.03860	0
189RE β - DECAY			0.8134	0.00730	0
1.0080	0.64000	0	0.7225	0.00470	0
0.9770	0.04000	1	0.6113	0.51100	0
0.9720	0.03700	1	0.4217	0.00358	0
0.9380	0.02300	0	0.2113	0.08880	0
0.7910	0.13000	0	125SB β - DECAY		
0.7890	0.07900	0	0.6220	0.13500	1
0.7320	0.05400	0	0.4457	0.07140	0
0.4080	0.01300	0	0.3034	0.40200	0
102RH β - DECAY (207 D)			0.2416	0.01620	0
1.1390	0.18900	0	0.1308	0.18100	0
0.5820	0.01900	0	0.1246	0.05790	0
106RH β - DECAY (130 M)			0.0954	0.13600	0
0.9220	0.85000	0	126SB β - DECAY (12.4 D)		
0.7270	0.14500	0	1.8900	0.20000	1
106RH β - DECAY (29.8 S)			1.1700	0.16000	0
3.5400	0.78600	0	0.9000	0.04900	0
3.0280	0.08100	0	0.8500	0.08100	0
2.4120	0.00640	0	0.6800	0.04200	0
2.4060	0.10000	0	0.6000	0.08400	0
1.9780	0.01770	0	0.4900	0.05900	0
1.5380	0.00460	0	0.4700	0.29000	0
103RU β - DECAY			0.2100	0.02090	0
0.7660	0.00870	0	127SB β - DECAY (3.85 D)		
0.4710	0.00243	0	1.4930	0.02000	1
0.2290	0.92200	0	1.2410	0.02100	0
0.1160	0.06610	0	1.1080	0.22500	0
106RU β - DECAY			0.9500	0.04400	0
0.0394	1.00000	0	0.8960	0.34300	0
35S β - DECAY			0.7980	0.17200	0
0.1668	1.00000	0	0.7960	0.07870	0
122SB β - DECAY			0.6570	0.01100	0
1.9830	0.26100	1	0.5040	0.05200	0
1.4190	0.66800	0	0.4400	0.01590	0
0.7260	0.04600	0	0.4260	0.00900	0
			0.2910	0.00740	0
			46SC β - DECAY		
			0.3567	0.99996	0

Appendix A

47SC B- DECAY			123SN B- DECAY (40.08 M)		
0.6006	0.31700	0	1.2610	0.99920	0
0.4412	0.68300	0			
48SC B- DECAY			125SN B- DECAY (9.64 D)		
3.0100	0.00600	3	2.3500	0.83000	1
1.6980	0.00600	1	1.2610	0.02820	0
0.6610	0.90000	0	1.0010	0.00331	1
0.4850	0.09850	0	0.4600	0.06180	0
			0.3670	0.04020	0
			0.3480	0.02020	0
49SC B- DECAY			126SN B- DECAY		
1.9940	0.99940	0	0.2500	1.00000	0
79SE B- DECAY			89SR B- DECAY		
0.1490	1.00000	1	1.4920	0.99990	1
31SI B- DECAY			90SR B- DECAY		
1.4908	0.99930	0	0.5460	1.00000	1
0.2247	0.00070	0			
32SI B- DECAY			180TA B- DECAY		
0.2130	1.00000	0	0.7080	0.10500	0
			0.6040	0.03500	0
151SM B- DECAY			182TA B- DECAY		
0.0763	0.99090	0	1.7135	0.00058	0
0.0548	0.00910	0	1.4842	0.00096	0
153SM B- DECAY			0.5922	0.04000	0
0.8098	0.20700	0	0.5562	0.00880	0
0.7120	0.00570	0	0.5244	0.39700	0
0.7070	0.43800	0	0.4825	0.02200	0
0.6370	0.34700	0	0.4398	0.20500	0
			0.3708	0.00587	0
156SM B- DECAY			0.3261	0.01800	0
0.7140	0.00100	0	0.2604	0.29300	0
0.6910	0.52000	0			
0.4230	0.45000	0	183TA B- DECAY		
121SN B- DECAY (27.06 H)			0.6584	0.02300	0
0.3866	1.00000	0	0.6174	0.92000	0
			0.4752	0.00990	0
121SN B- DECAY (55 Y)			0.4477	0.05000	0
0.3560	1.00000	1			
123SN B- DECAY (129.2 D)					
1.3970	0.99370	1			
0.3080	0.00600	0			

184TA β - DECAY

1.4400	0.00490	1
1.2800	0.00210	0
1.1900	0.00390	0
1.1700	0.86100	0
1.1200	0.15400	0
0.8400	0.00890	0
0.4800	0.00760	0
0.3700	0.00340	0

158TB β - DECAY

0.8400	0.16900	0
0.6220	0.01100	0

160TB β - DECAY

1.7489	0.00340	0
0.8695	0.28800	0
0.7866	0.06300	0
0.6799	0.00200	0
0.5709	0.45600	0
0.5490	0.03440	0
0.4770	0.08540	0
0.4493	0.01010	0
0.4368	0.04390	0

161TB β - DECAY

0.5921	0.05000	0
0.5664	0.05000	0
0.5175	0.66000	0
0.4603	0.26000	0

98TC β - DECAY

0.3980	1.00000	0
--------	---------	---

99TC β - DECAY (2.111E+5 Y)

0.2936	0.99998	0
--------	---------	---

127TE β - DECAY (9.35 H)

0.6940	0.98800	0
0.2760	0.01190	0

127TE β - DECAY (109 D)

0.7250	0.02400	1
--------	---------	---

129TE β - DECAY (69.6 M)

1.4700	0.88000	0
1.2190	0.00560	0
1.0100	0.09300	0
0.9380	0.00251	0
0.3860	0.00881	0

129TE β - DECAY (33.6 D)

1.6040	0.33000	1
0.9080	0.03100	0
0.8740	0.00710	0

131TE β - DECAY (25.0 M)

2.1000	0.59200	0
1.7570	0.00780	0
1.6480	0.21800	0
1.3730	0.01177	0
1.1520	0.02590	0
1.1030	0.09980	0
0.9520	0.00540	0
0.8230	0.01340	0
0.8060	0.01186	0
0.7490	0.01199	0

131TE β - DECAY (30 H)

2.4320	0.03800	1
1.6590	0.00300	0
1.5800	0.00400	0
1.4260	0.00200	0
1.3730	0.00300	0
1.1170	0.00200	0
0.7860	0.02600	0
0.6350	0.00300	0
0.5450	0.01300	0
0.5330	0.16100	0
0.5080	0.02100	0
0.4520	0.37100	0
0.4310	0.05400	0
0.4210	0.02600	0
0.3690	0.00500	0
0.3180	0.02000	0
0.2640	0.01100	0
0.2620	0.00500	0
0.1910	0.00400	0
0.1620	0.00600	0

132TE β - DECAY

0.2150	1.00000	0
--------	---------	---

Appendix A

231TH β - DECAY

0.3310	0.00330	0
0.3119	0.00330	0
0.3054	0.35000	0
0.2882	0.37000	0
0.2873	0.12000	0
0.2154	0.01300	0
0.2061	0.12800	0
0.1423	0.02800	0

234TH β - DECAY

0.1960	0.72500	0
0.1040	0.18000	0
0.1030	0.07100	0
0.0830	0.02600	0

204TL β - DECAY

0.7634	1.00000	1
--------	---------	---

206TL β - DECAY

1.5312	0.99900	0
--------	---------	---

207TL β - DECAY

1.4180	0.99760	0
--------	---------	---

208TL β - DECAY

1.7960	0.48700	0
1.5190	0.21800	0
1.2860	0.24500	0
1.0740	0.00630	0
1.0330	0.03090	0

170TM β - DECAY

0.9681	0.76000	0
0.8838	0.24000	0

171TM β - DECAY

0.0965	0.98000	0
0.0298	0.02000	0

172TM β - DECAY

1.8700	0.29000	1
1.7910	0.36000	0
1.6100	0.00910	1
0.8270	0.00290	1
0.7520	0.00291	0
0.7150	0.00960	0
0.6980	0.06600	0
0.6710	0.00244	0
0.4040	0.10100	0
0.3930	0.01110	0
0.3210	0.02400	0
0.2620	0.10000	0
0.2070	0.01280	0

173TM β - DECAY

1.2930	0.02000	1
0.8940	0.76000	0
0.8320	0.22000	0

237U β - DECAY

0.2514	0.42000	0
0.2376	0.51000	0
0.1865	0.03400	0
0.1480	0.00800	0

240U β - DECAY

0.3600	0.29000	0
0.3160	0.61000	0

185W β - DECAY

0.4328	0.99930	0
--------	---------	---

187W β - DECAY

1.3124	0.29800	0
1.1782	0.00700	1
0.8006	0.00024	0
0.6940	0.04700	0
0.6869	0.03300	0
0.6266	0.54900	0
0.5395	0.04230	0
0.4856	0.00010	0
0.4478	0.00644	0
0.4329	0.00369	0

188W β - DECAY

0.3490	0.99000	0
0.2850	0.00150	1
0.0580	0.00830	0

133XE β - DECAY

0.3460	0.99000	0
0.2660	0.00810	0

90Y β - DECAY

2.2792	0.99984	1
--------	---------	---

91Y β - DECAY

1.5456	0.99700	1
--------	---------	---

93Y β - DECAY

2.8840	0.90400	1
2.6170	0.04500	0
1.9370	0.02500	0
1.4590	0.00240	0
1.4340	0.00330	0
0.6990	0.01500	0

175YB β - DECAY

0.4677	0.86500	0
0.3539	0.03300	0
0.2162	0.00800	1
0.0714	0.10300	0

69ZN β - DECAY (13.76 H)

0.7700	1.00000	1
--------	---------	---

69ZN β - DECAY (56.4 M)

0.9060	0.99999	0
--------	---------	---

72ZN β - DECAY

0.2960	0.85300	0
0.2490	0.14700	0

93ZR β - DECAY

0.0597	0.95000	1
--------	---------	---

95ZR β - DECAY

0.8870	0.01110	1
0.3990	0.44200	0
0.3660	0.54600	0

97ZR β - DECAY

1.9151	0.88100	0
1.4075	0.04100	0
1.2249	0.00600	1
1.1100	0.00710	0
0.9079	0.00300	0
0.8941	0.01820	0
0.5526	0.05600	0

APPENDIX B

INDEPENDENT VERIFICATION OF VARSKIN MOD 2 DOSE CALCULATIONS

APPENDIX B

INDEPENDENT VERIFICATION OF VARSKIN MOD 2 DOSE CALCULATIONS

Verification of VARSKIN Mod 2 was performed by several independent users who agreed to test the program in a draft form and compare VARSKIN Mod 2 results to results obtained using other calculational methods. Most of the comments on the draft VARSKIN Mod 2 have been accommodated; the details of these comments will not be presented here. Several users compared the results obtained using VARSKIN Mod 2 to results obtained using independent methods, and those results are provided in this appendix.

B.1 POINT SOURCE ON CLOTHING

The model of Chabot et al. (1988) was used in this test. The types of protective clothing modelled were

- one layer of brown cotton coveralls, of thickness 0.37 mm and density 0.7 g cm^{-3} (1B)
- two layers of brown cotton coveralls, double the above thickness (2B)
- one layer of brown coveralls plus one layer of plastic suit material, the latter of thickness 0.4 mm and density 1.1 g cm^{-3} (B+P). For VARSKIN Mod 2, the material densities were combined according to the instructions in this document.

The calculations were done for the isotopes ^{60}Co , ^{137}Cs , and $^{90}\text{Sr/Y}$, assuming a point source of $1 \mu\text{Ci}$ of each and no self-absorption. Air gaps of 0.2 and 1.0 cm were used for the first two clothing types, and 1.0 and 5.0 cm for the third. It was assumed that there was no air gap between layers of protection clothing.

Gamma-ray doses were calculated using the analytical expression in Chabot et al. (1988), assuming no attenuation in clothing, no scatter, and 1 rem R^{-1} .

The results of these calculations and the same calculations done with VARSKIN Mod 2 are shown in

Table B.1. In general, there is reasonable agreement between the two calculations for both the beta and gamma dose rate calculations. The largest differences occur for the case of ^{137}Cs on two layers of cotton coveralls.

B.2 POINT SOURCE ON SKIN

In this test, calculations were done for the case of a point source directly on the skin, i.e., no material and no air gap between the source and skin. For a $1\text{-}\mu\text{Ci}$ hot particle on the skin, the beta dose rate to 1 cm^2 at 7 mg cm^{-2} was calculated using both VARSKIN and VARSKIN Mod 2. For ^{60}Co , a comparison of beta and gamma dose rates given by Chabot et al. (1988) to those predicted by VARSKIN Mod 2 was made. The results are shown in Table B.2. There is again reasonable agreement among the beta dose rates. The difference in the gamma dose calculation reflects the inclusion of charged particle equilibrium effects in VARSKIN Mod 2.

B.3 DISTRIBUTED CONTAMINATION ON SKIN

The final set of calculations was for the case of distributed contamination on the skin. A concentration of $1 \mu\text{Ci cm}^{-2}$ over a circular area of 100 cm^2 was assumed, and the beta dose rate to 1 cm^2 of skin centered under the contamination was calculated. The calculations were done with both versions of VARSKIN, and the results compared with values published by Rohloff and Heinzelmann (1986) and by Kocher and Eckerman (1987). The results from VARSKIN Mod 1, VARSKIN Mod 2, and Kocher and Eckerman (1987), shown in Table B.3, agree quite well, while those from Rohloff and Heinzelmann (1986) are somewhat lower because they neglected backscatter from air. At the time of this test, the backscatter model had not been incorporated into VARSKIN Mod 2.

Appendix B

Table B.1. Comparison of Chabot's Method and VARSKIN Mod 2 for 1- μ Ci Hot Particle Point Source on Clothing

Isotope	Air Gap (cm)	Clothing	Beta Dose Rate (rem h ⁻¹)			Gamma Dose Rate (rem h ⁻¹)		
			Chabot et al.	VARSKIN Mod 2	Diff. (%)	Chabot et al.	VARSKIN Mod 2	Diff. (%)
⁶⁰ Co	0.2	1B	0.203	0.194	-4	0.077	0.0725	-6
	1.0	1B	0.080	0.078	-2	0.011	0.0102	-7
	0.2	2B	0.002	0	-	0.067	0.064	-5
	1.0	2B	0.004	0	-	0.010	0.0096	-4
	1.0	B+P	0	0	-	0.010	0.0095	-5
	5.0	B+P	0	0	-	0.0005	0.0005	0
¹³⁷ Cs	0.2	1B	1.33	1.39	+4	0.019	0.020	+5
	1.0	1B	0.295	0.275	-7	0.0027	0.0028	+4
	0.2	2B	0.357	0.474	+32	0.0167	0.0175	+5
	1.0	2B	0.121	0.140	+16	0.0025	0.0026	+4
	1.0	B+P	0.067	0.075	+12	0.0025	0.0026	+4
	5.0	B+P	0.0035	0.0037	+6	0.0001	0.0001	0
⁹⁰ Sr/Y	0.2	1B	3.534	3.68	+4			
	1.0	1B	0.596	0.587	-2			
	0.2	2B	2.245	2.38	+6			
	1.0	2B	0.409	0.438	+7			
	1.0	B+P	0.337	0.365	+8			
	5.0	B+P	0.018	0.0185	+3			

Table B.2. Comparison of Calculated Skin Dose Rates for a 1- μ Ci Hot Particle on the Skin

Isotope	Beta Dose Rate (rad h ⁻¹)			Gamma Dose Rate (rad h ⁻¹)	
	VARSKIN	VARSKIN Mod 2	Chabot	VARSKIN Mod 2	Chabot
⁶⁰ Co	4.13	4.12	4.33	0.185	0.364
¹³⁷ Cs	6.42	6.36	-	0.075	-
⁹⁰ Sr/Y	15.9	15.8	-	-	-

Table B.3. Comparison of Calculated Beta Skin Doses for Distributed Contamination of 1 μ Ci cm⁻² (over 100 cm²) on the Skin

Isotope	Beta Dose Rate (rad h ⁻¹)			
	VARSKIN	VARSKIN Mod 2	Rohloff and Heinzelmann (1986)	Kocher and Eckerman (1987)
⁶⁰ Co	4.13	4.07	3.24	4.18
¹³⁷ Cs	6.46	6.3	-	5.91
⁹⁰ Sr/Y	16.1	15.7	12.06	15.61

D. Delacroix and J. P. Bourion of Centre D'Études Nucléaires de Saclay compared the results of calculations using VARSKIN Mod 2 (V) and the work of the following:

- (D): Delacroix 1986
- (K): Kocher and Eckerman 1987
- (P): Piechowski et al. 1988.

These three papers give maximum dose rates (B e) from a source modelled as an "infinitely thick," uniformly

contaminated (1 μ Ci/cm²) plane surface. Doses were calculated at different depths in the skin. The VARSKIN Mod 2 input data were

- 2-D disk geometry
- 2-cm diameter
- 3.14- μ Ci activity.

Tables B.4 and B.5 show that the results are in good agreement.

Appendix B

Table B.4. 70- μ m Depth Dose Rates

rad/h per μ Ci/cm ²		¹⁴ C	³² P	¹³¹ I	⁹⁰ Sr	⁹⁰ Y
V	a	1.08	8.94	6.22	6.67	9.04
	b	1.08	9.07	6.21	6.60	8.17
	c	1.08	9.09	6.24	6.65	9.21
	d	1.07	9.09	6.23	6.73	9.21
	e	1.06	9.09	6.23	6.72	9.21
D		1.07	9.15	6.42	6.99	9.18
K		1.22	8.87	6.34	6.76	8.87
P		1.2	7.0	6.0	5.9	7.5

a: beta dose rate averaged over 1 cm²
b: beta dose rate averaged over 0.1 cm²
c: beta dose rate averaged over 0.01 cm²
d: beta dose rate averaged over 0.001 cm²
e: beta dose rate averaged over 0.0001 cm²

Table B.5. Dose Rates Versus Depth for ⁹⁰Y Averaged Over 0.01 cm²

rad/h per μ Ci/cm ²	40 μ m	70 μ m	100 μ m	400 μ m
V	10.6	9.21	8.38	5.18
D	10.46	9.18	8.37	5.24
K	10.14	8.87	-	5.07

REFERENCES

- Chabot, G. E., K. W. Krable, and C. S. French. 1988. When Hot Particles are Not on the Skin. *Radiation Protection Management* 5(6):31-42.
- Delacroix, D. 1986. Beta Particle and Electron Absorbed Dose Calculations for Skin Surface Contaminations (in French). DCES/SPR/SRI/86-656, Commissariat à l'Energie Atomique, Paris.
- Kocher, D. C., and K. F. Eckerman. 1987. Electron Dose-Rate Conversion Factors for External Exposure of the Skin from Uniformly Deposited Activity on the Body Surface. *Health Physics* 53:135-141.
- Piechowski et al. 1988. Dosimetry and Therapy of Skin Contaminations (in French). CEA-R-5441, Commissariat à l'Energie Atomique, Paris.
- Rohloff, F., and M. Heinzelmann. 1986. Calculation of Dose Rates for Skin Contamination by Beta Radiation. *Radiation Protection Dosimetry* 14:279-287.

APPENDIX C

TEXT OF VARSKIN MOD 2 CODE

```

C  PROGRAM VARSKIN-MOD2
C
C
C  Calculates doses from a one, two, or three-dimensional source
C  uniformly distributed with a beta source to a plane located
C  below the source. The plane can be covered with any combination
C  of air, skin, or other material to simulate the presence of
C  protective clothing and air gaps.
C  JS Durham  2/25/91
C
C  Functions & Subroutines called:
C    QUAD1
C    QUAD2
C    QUAD3
C    QUAD4
C    QUAD5
C    ARG0 - Point
C    ARG1 - Disk and Cylinder
C    ARG2 - Sphere
C    ARG3 - Slab
C    SPLINE
C    SEVAL
C
C  DIMENSION X(30),Q(30),B(30),C(30),D(30),FB(30)
C  DIMENSION DOSE(60),XB(60),bx(60),cx(60),dx1(60)
C  EXTERNAL ARG1, ARG2, ARG3
C  CHARACTER*1 ANS
C  CHARACTER*7 NUCLD(5),NUCLID,nuctes
C  CHARACTER*10 FILNAME
C  character*80 title
C  LOGICAL*4 EXXT,IFONCE
C  REAL EBETA(5), XNINTY(5), BYIELD(5), FBETA(5,30), ssn(5), igm(5)
C  REAL GEAV(5),GFAC(5),XDepth(21),VDose(21),VB(21),VC(21),VD(21)
C  REAL XBS(14), BACK(14), BB(14), CB(14), DB(14)
C  COMMON /QUADS/ A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,RELERR
C  COMMON X,FB,B,C,D,EAVE,X90
C  COMMON /DENSE/ DENS,DENA,RMAX,DMAX,TA,TC,DC,XMAX,YMAX,PS
C  PARAMETER ( PI = 3.141592654 )
C  DATA Q/0.,0.01,0.02,0.03,0.04,0.05,0.1,0.15,0.2,0.25,0.3,
C  &0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,0.75,0.8,0.85,0.9,0.95,
C  &1.,1.1,1.2,1.4,1.6,1.8/

```


Appendix C

```
DATA xbs/2.67,4.77,9.00,13.71,18.71,24.14,29.57,35.29,  
& 41.00,46.86,75.71,105.71,165.71,224.29/  
DATA BACK/1.0,1.13,1.22,1.27,1.30,1.32,1.34,1.35,1.36,1.36,  
& 1.34,1.33,1.31,1.28/  
DATA ifonce/.true./
```

C

C THIS ROUTINE READS IN THE BERGER SCALED ABSORBED DOSE DISTRIBUTION,
C SET UP THE INTEGRATION AND GENERATES THE OUTPUT

C

```
      DO 1 I=1,30  
        X(I)=Q(I)  
1      CONTINUE  
3      format( a1 )  
31     format( a )  
        filename = 'VMOD2.OUT'  
        INQUIRE ( FILE = filename, EXIST = EXXT)  
        IF (EXXT) THEN  
          ICR = 64  
          FILNAME(1:5)='VMOD2'  
          FILNAME(7:10)= '.OUT'  
4          ICR = ICR + 1  
          IF(ICR.GT.90)THEN  
            WRITE(*,*) 'VM2OUTA-Z.OUT ALL EXIST'  
            WRITE(*,*) 'PLEASE ERASE OR RENAME FILES AND RESTART THE PROGRAM'  
            GO TO 800  
          ENDIF  
          FILNAME(6:6) = CHAR(ICR)  
          INQUIRE ( FILE = FILNAME , EXIST = EXXT)  
          IF (EXXT) GO TO 4  
        ENDIF
```

C

C Read Input Data

C

```
OPEN (UNIT=13, FILE = 'OUTPUT.DAT',STATUS = 'OLD')  
READ(13,5)rmax1  
READ(13,5)xmax1  
READ(13,5)ymax1  
READ(13,5)dens  
READ(13,5)relerr  
READ(13,5)dmax1  
READ(13,5)tc1  
READ(13,5)dc  
READ(13,5)dth1  
READ(13,5)ta1  
READ(13,5)ttime  
READ(13,5)earca  
READ(13,51)igeo  
READ(13,51)nnuc  
READ(13,3)ans
```

```

ivol = 0
if(ans.eq.'y'.or.ans.eq.'Y')ivol=1
READ(13,51)isors
  if(igeo.eq.0)isors=0
  do nn = 1,nnuc
    READ(13,3)ans
    igm(nn)=0
    if(ans.eq.'y'.or.ans.eq.'Y')igm(nn)=1
    READ(13,74)nuctes
    backspace(13)
    if(nuctes(4:4).eq.' ')then
      READ(13,7)nuclid(nn),ebeta(nn),xninty(nn),byield(nn),
1 (fbeta(nn,j),j=1,30)
      elseif(nuctes(5:5).eq.' ')then
        READ(13,71)nuclid(nn),ebeta(nn),xninty(nn),byield(nn),
1 (fbeta(nn,j),j=1,30)
        elseif(nuctes(6:6).eq.' ')then
          READ(13,72)nuclid(nn),ebeta(nn),xninty(nn),byield(nn),
1 (fbeta(nn,j),j=1,30)
          elseif(nuctes(7:7).eq.' ')then
            READ(13,73)nuclid(nn),ebeta(nn),xninty(nn),byield(nn),
1 (fbeta(nn,j),j=1,30)
            else
              READ(13,74)nuclid(nn),ebeta(nn),xninty(nn),byield(nn),
1 (fbeta(nn,j),j=1,30)
            endif
          READ(13,8)geav(nn),gfacs(nn)
          READ(13,5)ssn(nn)
        enddo
5 format(f12.0)
51 format(i1)
7 FORMAT(a3,3X,3F9.4,/4X,10F8.4,/4X,10F8.4,/4X,10F8.4)
71 FORMAT(a4,3X,3F9.4,/4X,10F8.4,/4X,10F8.4,/4X,10F8.4)
72 FORMAT(a5,3X,3F9.4,/4X,10F8.4,/4X,10F8.4,/4X,10F8.4)
73 FORMAT(a6,3X,3F9.4,/4X,10F8.4,/4X,10F8.4,/4X,10F8.4)
74 FORMAT(a7,3X,3F9.4,/4X,10F8.4,/4X,10F8.4,/4X,10F8.4)
8 FORMAT(2F9.4)
C
C Initialize Variables
C
  idos = 0
  IPAR = 0
  rmax = rmax1 / 20000.
  dth = dth1 / 10000.
  xmax = xmax1 / 20000.
  ymax = ymax1 / 20000.
  dmax=dmax1/1000.
  tc = tc1/10.
  ta = ta1 / 10.

```

Appendix C

```
dena = .001293
npt=26
C
C Start the loop for multiple radionuclides
C
  do 10 jj = 1,nnuc
    NUCLID = NUCLD(jj)
    EAVE = EBETA(jj)
    X90 = XNINTY(jj)
    YIELD = BYIELD(jj)
    geavg = geav(jj)
    gamfac = gfac(jj)
    SS=ssn(jj)
    igam = igm(jj)
    DO 1150 IX=1,30
1150   FB(IX) = FBETA(jj,IX)
C
C Spline fit for X vs chosen FB array--for later interpolations
C
  CALL SPLINE(30,X,FB,B,C,D)
  darea = 1.
  bsfa = 1.
  bsf1 = 1.
  ss1 = ss
  dist = 1.8 * X90
C
C Determine if the gamma dose can be calculated
C
  dimax = 2. * max(xmax,ymax)
  if(igeo.ge.1.and.igeo.le.3.and.rmax.gt.0.1)igam = 0
  if(igeo.eq.4.and.dimax.gt.0.1)igam = 0
  if(ta.gt.5.)igam = 0
  if (ivol.eq.1)igam = 0
C
C Spline fit for Backscatter model
C
  If(igeo.eq.1.or.igeo.eq.0)then
    CALL SPLINE(14,xbs,back,Bb,Cb,Db)
C
C Calculate the Backscatter factor (used for igeo = 0,1 only)
C
  if(dmax+tc*dc+ta*dena.gt.0.)then
    xbs1 = X90/(dmax + tc*dc + ta*dena)
  else
    xbs1 = 224.29
  endif
  if(xbs1.le.2.67) xbs1 = 2.67
  if(xbs1.ge.224.29) xbs1 = 224.29
  bsf1 = seval(14,xbs1,xbs,back,bb,cb,db)
```

```

      Endif
C
C Point Geometry
C
      if(igeo.eq.0)then
        dth = 0.0001
        rmax = 0.0001
        if(isors.eq.0)SS1=ss/(pi * rmax*rmax*dth)
        FACTOR=SS1*3.7E4*YIELD*1.6E-8*EAVE*3600./(2.*pi*X90*bsf1)
C
C Disk Geometry
C
      elseif(igeo.eq.1)then
        dth = 0.0001
        if(isors.eq.0)SS1=ss/(pi * rmax*rmax*dth)
        if(isors.eq.1)SS1=ss/dth
        FACTOR=SS1*3.7E4*YIELD*1.6E-8*EAVE*3600./(2.*pi*X90*bsf1)
C
C Cylindrical Geometry
C
      elseif(igeo.eq.2)then
        if(isors.eq.0)SS1=ss/(pi * rmax*rmax*dth)
        FACTOR=SS1*3.7E4*YIELD*1.6E-8*EAVE*3600./(2.*pi*X90)
C
C Spherical Geometry
C
      elseif(igeo.eq.3)then
        if(isors.eq.0)SS1=(ss*3.)/(4.*pi * rmax*rmax*rmax)
        FACTOR=SS1*3.7E4*YIELD*1.6E-8*EAVE*3600./(2.*pi*X90)
C
C Slab Geometry
C
      else
        if(isors.eq.0)SS1 = 0.001 * ss / (4. * xmax * ymax * dth)
        FACTOR=SS1*3.7E7*YIELD*1.6E-8*EAVE*3600./(4.*pi*X90)
      endif
C
C Save the output file, if desired
C
      if(ifonce)then
        WRITE(*,1001)filename
1001 FORMAT(/ ' Do you wish to save the output file '
1 / ' (File name = ',a10,') (Default = No) ? ', $)
        read(*,3)ans
        if(ans.eq.'y'.or.ans.eq.'Y')iout=1
        ifonce=.false.
      endif
      if(iout.eq.1)then
        WRITE(*,2)

```

Appendix C

```
2  FORMAT( /20X, ' Program VARSKIN-MOD2',
1  //1X,'Enter a descriptive title for this run:' , $)
   read(*,31) title
   endif
C
C Calculate the maximum skin depth penetration of the radiation
C
   SkinMx = Dist - TC*DC - TA*DenA
C
C Initiate Volume Averaged Calculations if necessary.
C
2330 IF (ivol.eq.1) THEN
   if(skinmx.le.0.) then
   write(*,2331)
2331 format(/ ' The cover depth shields the beta dose completely')
   go to 2341
   endif
   dmax1 = 0.
   ICount = 1
   NDep = 20
   skinmx1 = skinmx * 1000.
   DO 233 I = 1,NDep
   XDepth(I) = SkinMx*float((I-1)*(I-1))/Float((NDep-1)*(ndep-1))
233  CONTINUE
   vdose(ndep) = 0.
   ENDIF
C
C This is where the iteration loop begins for calculations of the
C volume averaged dose
C
C Evaluate the Dose at XDepth
C
234  IF (ivol.EQ.1) DMax = XDepth(ICount)
C
C Check that the betas can penetrate the cover, air, and skin layers
C
2341 IF (DMax.GT.SkinMx.or.skinmx.le.0.) THEN
C
C Skin Depth is too deep... dose is zero.
C
   dos = 0.
   idos = -1
   GOTO 1000
   ENDIF
C
C Calculate Doses for NPT pts from the center of the skin
C to a distance equal to a distance corresponding to
C 99% of the range of the beta
C
```

```

411  if(abs(darea-1.).ge.0.001)bsfa = bsf1
      if(IGEO.LE.2)then
C
C Determine the outermost radius of irradiation on the skin
C
      rdmax1 = sqrt(darea/pi)
      depth = dth + ta + tc + dmax
      rhomax = dist/dena
      if(depth.gt.0.)rhomax=dist*depth/((dth+ta)*dena+tc*dc+dmax)
      rdmax = rmax
      if(rhomax.gt.depth)rdmax=rmax+sqrt(rhomax*rhomax-depth*depth)
      if(rdmax1.lt.rdmax)rdmax=rdmax1
      elseif(IGEO.EQ.3)then
      rdmax1 = sqrt(darea/pi)
      DEPTH = RMAX + TA + TC + DMAX
      RHOMAX = DIST*DEPTH / ((RMAX+TA)*DENA + TC*DC + DMAX )
      RDMAX = RMAX + SQRT(RHOMAX*RHOMAX - DEPTH*DEPTH)
      if(rdmax.gt.rdmax1)rdmax = rdmax1
      elseif(IGEO.EQ.4)THEN
      dpar = 0.
      write(*,420)
420  format(/' Do you wish to calculate the dose from multiple ',
1 'particles (default is No,',' Instructions will follow if ',
2 'Yes) ? ',)$
      read(*,3)ans
      if(ans.eq.'Y'.or.ans.eq.'y')then
      Write(*,421)
421  Format(/' VARSKIN Mod 2 offers the option to calculate doses ',
1 'from multiple particles.',' To do so, the dose from each ',
2 'particle must be calculated separately.',' First, choose ',
3 'the location of the CENTER of the area over which to average ',
4 ' the dose. Second, determine the location of the CENTER of ',
5 'the particle',' for which the dose is to be calculated. Now',
6 ' enter the distance',' (offset) between these two points in ',
7 'um : ',)$
      read(*,5)dpar1
      dpar = dpar1 / 10000.
      ipar = 1
      If(xmax1-ymax1.gt.0.27)then
      xsugg = sqrt(xmax1*ymax1)
      Write(*,422)xsugg,xsugg
422  format(' For this model, the X-side length must equal the ',
1 'Y-side length.',' The suggested value is ',f6.0,' um.',
2 ' Please enter a',' new side length in um (or <enter> ',
3 'to accept ',f6.0,' um) : ',)$
      read(*,5) xmax1
      if(xmax1.le.0.) xmax1 = xsugg
      ymax1 = xmax1
      xmax = xmax1 / 20000.

```

Appendix C

```

ymax = ymax1 / 20000.
if(isors.eq.0)SS1 = 0.001 * ss / (4. * xmax * ymax * dth)
FACTOR=SS1*3.7E7*YIELD*1.6E-8*EAVE*3600./(4.*pi*X90)
EndIf
endif
GO TO 503
ENDIF
DO 500 I=1,NPT
C
C PS is the distance to the dose point from the center of the skin
C
  PS = FLOAT(I-1)/FLOAT(NPT-1) * rdmax
  if(rmax/rdmax.le.0.15)
1  PS = (FLOAT(I-1)/FLOAT(NPT-1) * sqrt(rdmax))**2
  if(rmax/rdmax.ge.0.85)
1  PS = sqrt(FLOAT(I-1)/FLOAT(NPT-1) * rdmax * rdmax)
  XB(I) = PS
  if(i.eq.1)write(*,5000)
5000 format(/ 'Performing Calculations')
  IF(IGEO.EQ.3)GO TO 502
  radmax = rmax
  a3 = 0.000027
  b3 = radmax
  depth = dth + ta + tc + dmax
  rhomax = dist/dena
  rhomax=dist*depth/((dth+ta)*dena+tc*dc+dmax)
  if(rhomax.gt.depth)a3=ps-sqrt(rhomax*rhomax-depth*depth)
  if(rhomax.gt.depth)b3=ps+sqrt(rhomax*rhomax-depth*depth)
  if(a3.lt.0.000027)a3 = 0.000027
  if(b3.gt.radmax)b3 = radmax
  A4 = 0.0
  B4 = pi
  a5 = 0.0
  b5 = dth
  DDOSE = QUAD3(dum1,dum2,arg1)
  go to 504
502  A3 = 0.000027
  B3 = RMAX
  A4 = 0.0
  B4 = pi
  A5 = 0.0
  B5 = pi
  DDOSE = QUAD3(dum1,dum2,arg2)
504  DDOSE = DDOSE * bsfa
  DOSE(I) = FACTOR * DDOSE
  IF( DOSE(I) .LT. 0. ) DOSE(I)=0.
500  CONTINUE
  GO TO 1000
C

```

C Slab Geometry

```

C
503  RADTAR = sqrt (darea/pi)
      A1 = 0.000027
      B1 = RADTAR
      A2 = 0.0
      B2 = 2.* pi
      A3 = -YMAX
      B3 = YMAX
      A4 = DPAR - XMAX
      B4 = DPAR + XMAX
      A5 = 0.0
      B5 = dth
      write(*,*) ' Working on the slab calculation'
      DDOSE = QUAD1(arg3)
      DOS = DDOSE * FACTOR / darea
C
C Write results to lineprinter file
C
1000 IF (ICOUNT.GT.1)go to 625
      if(igeo.eq.0)write(*,333)
333  format(/'      Point Source Geometry')
      if(igeo.eq.1) write(*,334)
334  format(/'      2-D Disk Source Geometry')
      if(igeo.eq.2) write(*,335)
335  format(/'      Cylindrical Source Geometry')
      if(igeo.eq.3) write(*,336)
336  format(/'      Spherical Source Geometry')
      if(igeo.eq.4) write(*,337)
337  format(/'      Slab Source Geometry')
      WRITE(*,*)      Nuclide : ',NUCLID
      WRITE(*,*)      1.8*X90 Distance : ',dist,' cm'
      WRITE(*,*)      Average Beta Energy : ',eave,' MeV'
      if(isors.eq.0)WRITE(*,*)      Source Strength : ',SS,' uCi'
      if(isors.eq.1)then
      if(igeo.eq.1)WRITE(*,*)      Source Strength : ',SS,' uCi/cm ^ 2'
      if(igeo.gt.1)WRITE(*,*)      Source Strength : ',SS,' uCi/cm ^ 3'
      endif
      if(igeo.gt.1)WRITE(*,*)      Source Density : ',dens,' g/cm ^ 3'
      IF(IGEO.EQ.1.OR.IGEO.EQ.2)
1  WRITE(*,*)      Diameter of Disk : ',rmax1,' um'
      if(igeo.eq.1)WRITE(*,*)      Area of Disk : ',earea,' cm ^ 2'
      if(igeo.eq.2)WRITE(*,*)      Thickness of Disk : ',dth1,' um'
      if(igeo.eq.3)WRITE(*,*)      Diameter of Sphere : ',rmax1,' um'
      if(igeo.eq.4)then
      WRITE(*,*)      X Side Length : ',xmax1,' um'
      WRITE(*,*)      Y Side Length : ',ymax1,' um'
      WRITE(*,*)      Slab Thickness : ',dth1,' um'
      endif

```


Appendix C

```

if(ipar.eq.1)WRITE(*,*) Particle Offset : ',dpar1,' um'
WRITE(*,*) Skin Depth : ',dmax1,' mg/cm ^ 2'
WRITE(*,*) Thickness of Cover : ',tc1,' mm'
if(tc1.gt.0.)WRITE(*,*) Cover Density : ',dc,' g/cm ^ 3'
WRITE(*,*) Air Gap Thickness : ',ta1,' mm'
WRITE(*,*) Irradiation Time : ',ttime,' min'
if(iout.eq.1)then
OPEN (UNIT=15, FILE = FILNAME, STATUS = 'NEW')
WRITE(15,6) title
6 FORMAT( /20X, ' Program VARSKIN-MOD2',//a,/ )
if(igeo.eq.0)write(15,*) Point Source Geometry'
if(igeo.eq.1) write(15,*) 2-D Disk Source Geometry'
if(igeo.eq.2) write(15,*) Cylindrical Source Geometry'
if(igeo.eq.3) write(15,*) Spherical Source Geometry'
if(igeo.eq.4) write(15,*) Slab Source Geometry'
WRITE(15,*)
WRITE(15,*)
WRITE(15,*) Nuclide : ',NUCLID
WRITE(15,*) 1.8*X90 Distance : ',dist,' cm'
WRITE(15,*) Average Beta Energy : ',eave,' MeV'
if(igam.eq.1)then
write(15,*) Average Gamma Energy : ',geavg,' keV'
write(15,*) Gamma Factor : ',gamfac,' R-cm ^ 2/mCi-h'
else
write(15,*) No gamma dose calculation'
endif
if(isors.eq.0)WRITE(15,*) Source Strength : ',SS,' uCi'
if(isors.eq.1)then
if(igeo.eq.1)WRITE(15,*) Source Strength : ',SS,' uCi/cm ^ 2'
if(igeo.gt.1)WRITE(15,*) Source Strength : ',SS,' uCi/cm ^ 3'
endif
IF(IGEO.GT.1)WRITE(15,*) Source Density : ',dens,' g/cm ^ 3'
IF(IGEO.EQ.1.OR.IGEO.EQ.2)
1 WRITE(15,*) Diameter of Disk : ',rmax1,' um'
if(igeo.eq.1)WRITE(15,*) Area of Disk : ',earea,' cm ^ 2'
IF(IGEO.EQ.2)WRITE(15,*) Thickness of Disk : ',dth1,' um'
IF(IGEO.EQ.3)WRITE(15,*) Diameter of Sphere : ',rmax1,' um'
IF(IGEO.EQ.4)THEN
WRITE(15,*) X Side Length : ',xmax1,' um'
WRITE(15,*) Y Side Length : ',ymax1,' um'
WRITE(15,*) Thickness : ',dth1,' um'
if(ipar.eq.1)WRITE(15,*) Particle Offset : ',dpar1,' um'
ENDIF
WRITE(15,*) Skin Depth : ',dmax1,' mg/cm ^ 2'
WRITE(15,*) Thickness of Cover : ',tc1,' mm'
if(tc1.gt.0.)WRITE(15,*) Cover Density : ',dc,' g/cm ^ 3'
WRITE(15,*) Air Gap Thickness : ',ta1,' mm'
WRITE(15,*) Irradiation Time : ',ttime,' min'
if(idos.lt.0)go to 1100

```

```

    if(IGEO.EQ.4)go to 1100
    if(IVOL.EQ.1)go to 625
    WRITE(15,600)
600  FORMAT(/ ' Calculated Results:',
      1 // ' Radial ',6X,' Dose ',/ ' Distance', 6x,' Rate ',
      2 // ' (cm) ',6x,' (rad/hr)',/ ' -----',6X,'-----')
    DO 610 I=1,npt
610  WRITE(15,620) XB(I), DOSE(I)
620  FORMAT( 0pF10.4, 1pe16.2 )
      ENDIF
625  if(idos.lt.0)go to 1100
      if(IGEO.EQ.4)go to 1100
C
C Calculate the dose rate averaged over the radius of the target sphere
C
C First, spline-fit the calculated dose-distance data for the
C depth dose points
C
      CALL SPLINE(npt,xb,dose,Bx,Cx,Dx1)
C
C Evaluate the spline for 100 points over the target radius
C STEP is the step size for the averaging.
C
C Set the target radius for the average
C
630  radtar = sqrt( darea/pi )
      radtem = radtar
      if(radtar.gt.xb(npt))radtar = xb(npt)
      step=(radtar-xb(1))/99.
      dostar = seval(npt,radtar,xb,dose,bx,cx,dx1)
      dos = radtar * dostar
      Do 640 I=1,49
      stepo=float(2*i-1)*step
      stepe=float(2*i)*step
C
C Use Simpson's 1/3 rule to calculate the average dose
C
      aone= seval(npt,stepo,xb,dose,bx,cx,dx1)
      bone= seval(npt,stepe,xb,dose,bx,cx,dx1)
      dos=dos+ 4.*stepo*aone + 2.*stepe*bone
640  continue
C
C Complete the calculation of the averages
C
      dos = 2. * dos * step / (3. * radtem * radtem)
C
C Write the results to the lineprinter file
C
      if(xb(npt).lt.radtem)then

```

Appendix C

```

        dos1 = dos * radtem*radtem / xb(npt) / xb(npt)
        write(*,649)xb(npt),dos1
        if(iout.eq.1)write(15,649)xb(npt),dos1
649  format(/' The dose averaged over the area of irradiation',
        1/' (radius = ',f10.4,' cm) = ',1pe10.2,' rad/hr')
        else
        write(*,648)darea
        if(iout.eq.1)write(15,648)darea
648  format(/' The area of irradiation is larger than ',f10.4,
        1' square cm')
        endif
1100 write(*,650)darea,dos
        if(iout.eq.1)write(15,650)darea,dos
650  format(/' The beta dose rate averaged over ',f10.4,' square cm',
        1' = ',
        1 1pe10.2,' rad/hr')
        dost = ttime * dos / 60.
        write(*,6601)darea,dost
        if(iout.eq.1)write(15,6601)darea,dost
6601 format(/' The total beta dose averaged over ',f10.4,' square cm',
        1' = ',1pe10.2,' rad')
C
C Continue the volume averaging routine
C Loop to line 234 to calculate another dose, if necessary.
C
        IF (ivol.EQ.1) THEN
        write(*,6499)
6499  format(/' Volume-Averaged Dose Model')
        VDose(ICount) = Dos
        ICount = ICount + 1
        DMax = XDepth(ICount)
        IF (ICount.LT.NDep) THEN
        percnt=100*Float(ICount-1)/Float(NDep-1)
        WRITE(*,6500)percnt
6500  format(2x,f6.2,' % complete.',/)
        GOTO 234
        ELSE
        WRITE(*,6501)
6501  format(' Intial Calculations are complete')
        ENDIF
C
C Compute Spline Coefficients for VDose array
C
        WRITE(*,651)
        if(iout.eq.1)WRITE(15,651)
651  format(' DEPTH (mg/cm ^ 2)      DOSE (rad/h)')
        DO 1111 I = 1,NDEP
        xdepa = 1000. * xdepth(i)
        WRITE(*,652) XDEPA,VDOSE(I)

```

```

      if(iout.eq.1)WRITE(15,652)XDEPTH(I),VDOSE(I)
652  format(5x,1pe10.2,15x,1pe10.2)
1111  CONTINUE
      CALL SPLINE(NDep,XDEPTH,VDOSE,VB,VC,VD)
C
C Ask the user for the range of values over which to compute the
C volume-averaged dose.
C
1112  Write(*,11121)skinmx1
11121 format(/' The range of values allowed for calculating the '
1 'volume-averaged dose is 0 to ',f10.3,/' Enter the depth ',
2 '(mg/cm2) corresponding to the top of the cell',
3 /' (the shallower depth) over ',
4 'which to average the dose (default is 0): ',)$)
      read(*,5)xlow1
      if(xlow1.lt.0.)then
        write(*,11123)
11123 format(/' ERROR: The shallow depth must be non-negative')
        go to 1112
      endif
      if(xlow1.ge.skinmx1)then
        write(*,21123)skinmx1
21123 format(/' ERROR: The shallow depth must be less than ',f10.3)
        go to 1112
      endif
      xlow = xlow1 / 1000.
11124 Write(*,11122)skinmx1
11122 format(/' Enter the depth (mg/cm2) corresponding to the ',
1 'bottom of the cell',/' (the deeper depth) over ',
2 'which to average the dose (maximum is ',f10.3,'): ',)$)
      read(*,5)xhigh1
      if(xhigh1.le.0.)xhigh1 = skinmx1
      if(xhigh1.le.xlow1)then
        write(*,11125)
11125 format(/' The deep depth must be greater than the shallow depth')
        go to 11124
      endif
      if(xhigh1.gt.skinmx1)then
        write(*,11127)skinmx1
11127 format(/' The deep depth must be less than ',f10.3)
        go to 11124
      endif
      xhigh = xhigh1 / 1000.
C
C Use Simpson's 1/3 rule to evaluate the dose between xlow and xhigh
C
      step=(xhigh-xlow)/99.
      doslow = seval(ndep,xlow,xdepth,vdose,vb,vc,vd)
      doshi = seval(ndep,xhigh,xdepth,vdose,vb,vc,vd)

```

Appendix C

```
dos = doslow + doshi
Do 1640 I=1,49
stepo = xlow + float(2*i-1)*step
stepe = xlow + float(2*i)*step
C
C Use Simpson's 1/3 rule to calculate the average dose
C
aone= seval(ndep,stepo,xdepth,vdose,vb,vc,vd)
bone= seval(ndep,stepe,xdepth,vdose,vb,vc,vd)
dos=dos+ 4.*aone + 2.*bone
1640 continue
C
C Complete the calculation of the averages
C
Volume = (XHigh-XLow)*DArea
dos = step*dos / (3.*(xhigh-xlow))
WRITE(*,1642) Volume,xlow1,xhigh1,DOS
1642 format(/, ' The dose rate averaged over ',f10.4,' cubic cm ',
1 'between ',f8.2,' mg/cm ^ 2',/ and ',f8.2,' mg/cm ^ 2 = ',1pe10.2,
2 ' rad/hr')
if(iout.eq.1)WRITE(15,1642) Volume,xlow1,xhigh1,DOS
dost = ttime * dos / 60.
write(*,1651)Volume,xlow1,xhigh1,dost
if(iout.eq.1)WRITE(15,1651) Volume,xlow1,xhigh1,DOST
1651 format(/ ' The total dose averaged over ',f10.4,' cubic cm ',
1 'between ',f8.2,' mg/cm ^ 2',/ and ',f8.2,' mg/cm ^ 2 = ',1pe10.2,
2 ' rad')
WRITE(*,1641)
1641 format(///, ' Would you like to evaluate the dose for another ',
1 'cell ("RETURN" for no) ? ', $)
read(*,3)ans
IF (Ans.EQ.'Y'.or.ans.eq.'y') GOTO 1112
ENDIF
C
C Hot Particle Gamma dose Calculation
C Gamma doses averaged over 1 cm ^ 2 are calculated using the method
C published by Lantz and Lambert. There are limitations to the
applicability
C of the model, including:
C Any air gap present should be less than 10 cm thick
C The dose is averaged over 1 cm ^ 2 only
C The source can be accurately modeled as a point source
C (i.e., any source dimension [other than thickness]
C is smaller than 1 mm)
C
700 if (igam.eq.0)go to 701
if (abs(1.-darea).gt.0.0001)go to 701
grad = sqrt(darea/pi)
gdepth = dmax + tc + ta
```

```

if(gdepth.le.0.)gdepth = 0.000027
gdos1=pi*gamfac*alog(1.+grad*grad/gdepth/gdepth)
C
C Electronic Equilibrium Model
C
gdep1 = dmax + ta * dena + tc * dc
if(gdep1.le.0.02)then
afac = 0.129 + 0.000338 * geavg
bfac = 171.8 * exp(-0.00162 * geavg)
else
afac = 0.062 + 0.0003055 * geavg
bfac = 156.0 * exp(-0.00193 * geavg)
endif
eleceq = 1. - afac * exp(-bfac * gdepth)
ssg = ss
if(isors.eq.1.and.igeo.le.2)ssg = ss1 * pi * rmax*rmax*dth
if(isors.eq.1.and.igeo.eq.3)ssg = ss1*4.*pi*rmax*rmax*rmax/3.
if(isors.eq.1.and.igeo.eq.4)ssg = 4. * ss1 * xmax * ymax * dth
gamdos = (SSG/1000.) * gdos1 * eleceq * 0.96
if(igam.eq.1)write(*,655)darea,gamdos
if(iout.eq.1.and.igam.eq.1)write(15,655)darea,gamdos
655 format(/' The gamma dose rate averaged over ',f10.4,' square cm'
1' = ',1pe10.2,' rad/hr')
gdost = ttime * gamdos / 60.
if(igam.eq.1)write(*,656)darea,gdost
if(iout.eq.1.and.igam.eq.1)write(15,656)darea,gdost
656 format(/' The total gamma dose averaged over ',f10.4,' square cm'
1' = ',1pe10.2,' rad')
701 if(nnuc.gt.1.and.iint.eq.0.and.ivol.eq.0)then
dosrt = dosrt + dos
if(igam.eq.1) gdosrt = gdosrt + gamdos
iint = 1
endif
darea = 0.
igam = 0
idos = 0
if(jj.eq.nnuc.and.nnuc.eq.1)then
write(*,660)
660 format(/' Enter new area (cm ^ 2) over which to average dose'
1 /' or <RETURN> to exit VARSKIN Mod 2: ', $)
elseif(jj.eq.nnuc.and.nnuc.gt.1)then
write(*,667) nnuc
667 format(/' Enter new area (cm ^ 2) over which to average dose or '
1 '<RETURN> to view the total doses from the ',i1,' nuclides',$)
else
write(*,661)
661 format(/' Enter new area (cm ^ 2) over which to average dose'
1 ' or <RETURN> for next nuclide: ', $)
endif

```

Appendix C

```

read(*,5) darea
if(darea.le.0.)then
    if(jj.eq.nnuc.and.nnuc.gt.1)then
        dostot = dosrt * ttime / 60.
        if(gdosrt.gt.0.)gdostt = gdosrt * ttime / 60.
        write(*,662)ttime,nnuc,dosrt
        if(iout.eq.1)write(15,662)ttime,nnuc,dosrt
662 format(/'Irradiation time = ',1pe10.1,' min',/ ' The beta dose ',
    1'rate for the ',i1,' radionuclides, averaged over',/ ' 1 square',
    2' cm, = ',1pe10.2,' rad/hr')
        write(*,663)nnuc,dostot
        if(iout.eq.1)write(15,663)nnuc,dostot
663 format(/ ' The total beta dose for the ',i1,' radionuclides, ',
    & 'averaged over',/ ' 1 square cm, = ',1pe10.2,' rad')
        if(gdosrt.gt.0.)then
            write(*,664)nnuc,gdosrt
            if(iout.eq.1)write(15,664)nnuc,gdosrt
664 format(/ ' The gamma dose rate for the ',i1,' radionuclides, ',
    & 'averaged over',/ ' 1 square cm, = ',1pe10.2,' rad/hr')
            write(*,665)nnuc,gdostt
            if(iout.eq.1)write(15,665)nnuc,gdostt
665 format(/ ' The total gamma dose for the ',i1,' radionuclides, ',
    & 'averaged over',/ ' 1 square cm, = ',1pe10.2,' rad')
            endif
        write(*,668)
668 format(/ ' Hit <ENTER> when you are ready to exit VARSKIN Mod 2',
    & '$')
        read(*,5)
        endif
        iint = 0
        go to 10
    endif
    if(igeo.eq.4)go to 503
    radtr2 = sqrt(darea/pi)
    if(ivol.eq.1)go to 2330
    if(xb(npt).lt.radtem.and.xb(npt).lt.radtr2)then
        dos = dos * radtem*radtem / radtr2 / radtr2
        radtem = radtr2
        go to 1100
    endif
    if (radtr2.gt.radtem)go to 411
    go to 630
10 continue
    if(iout.eq.1)close(15)
    if(iout.eq.1)Write(*,681)filename
681 format(/ 'a10,' has been saved to disk.')
800 write(*,690)
690 FORMAT(/ ' End of Varskin-Mod2')
STOP

```

```

END
C
C*****
C
SUBROUTINE READX(Default,X)
C This subroutine Reads upto 12 characters from the keyboard and
C returns REAL*4 Default value of X if the RETURN key is pressed.
C Otherwise the characters are converted to a real number and
C returned in X.      R.D. Stewart 4-11-91
REAL*4 X,Default
CHARACTER*12 Ans
1  FORMAT(A12)
  READ(*,1) Ans
  IF (Ans.EQ.' ') THEN
C    Use Default Value
    X = Default
  ELSE
    READ(Ans,'(F12.0)') X
  ENDIF
  RETURN
END
C
C*****
C
REAL FUNCTION QUAD1( ARG )
EXTERNAL ARG
DIMENSION F(8),X(8),XSAVE(4,30),FSAVE(4,30),QSAVE(30)
COMMON /QUADS/ A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,RELERR
PARAMETER(W0=0.3111111111,W1=1.4222222222,W2=0.5333333333)
PARAMETER(E0=0.279082892, E1=1.661516755 ,EE2=0.261869489)
PARAMETER(E3=2.961834215, EE4=1.281128748)
C
  E2=-EE2
  E4=-EE4
  A = A1
  B = B1
C
  ANS=0.
  AREA=0.
  QPREV=0.
C
  LEV=0
  X0=A
  X(8)=B
C
  F0=QUAD2( x0, ARG)
  X(4)=(X0+X(8))*0.5
  X(2)=(X0+X(4))*0.5
  X(6)=(X(4)+X(8))*0.5

```


Appendix C

```

C
DO 25 J=2,8,2
F(J)=QUAD2( X(J), ARG)
25  CONTINUE
30  X(1)=(X0+X(2))*0.5
F(1)=QUAD2( X(1), ARG)
DO 35 J=3,7,2
X(J)=(X(J-1)+X(J+1))*0.5
F(J)=QUAD2( X(J), ARG)
35  CONTINUE
STEP=(X(8)-X0)/8.

C
QRIGHT=(W0*(F(4)+F(8))+W1*(F(5)+F(7))+W2*F(6))*STEP
QLEFT=(W0*(F0 +F(4))+W1*(F(1)+F(3))+W2*F(2))*STEP
EIGHT=(E0*(F0 +F(8))+E1*(F(1)+F(7))+E2*(F(2)+F(6))+
1E3*(F(3)+F(5))+E4*F(4))*STEP

C
QADD=QLEFT+QRIGHT
DIFF=QADD-QPREV
AREA=AREA+DIFF

C
IF( ABS(QADD-EIGHT) .LE. RELERR*ABS(AREA) ) GOTO 99

C
SIM=STEP*(F(6)+F(4)+4.*(F(7)+F(5))+F(8)+F(6))/3.

C
IF( ABS(QRIGHT-SIM) .LE. RELERR*ABS(AREA) ) GOTO 60

C
LEV=LEV+1
IF(LEV.GE.30)GOTO900

C
FSAVE(1,LEV)=F0
XSAVE(1,LEV)=X0
DO 52 I=2,4
FSAVE(I,LEV)=F(I-1)
XSAVE(I,LEV)=X(I-1)
52  CONTINUE
QSAVE(LEV)=QLEFT

C
X0=X(4)
F0=F(4)

C
DO 55 I=1,3
F(2*I)=F(4+I)
X(2*I)=X(4+I)
55  CONTINUE
QPREV=QRIGHT
GOTO30

60  ANS=ANS+QRIGHT
DO 65 I=4,1,-1

```

```

      X(2*I)=X(I)
      F(2*I)=F(I)
65   CONTINUE
C
      QPREV=QLEFT
      GOTO30
C
99   ANS=ANS+QADD
      IF(LEV.LE.0)GOTO 500
      X(8)=X0
      F(8)=F0
      X0=XSAVE(1,LEV)
      F0=FSAVE(1,LEV)
      DO 100 I=1,3
      X(2*I)=XSAVE(I+1,LEV)
      F(2*I)=FSAVE(I+1,LEV)
100  CONTINUE
      LEV=LEV-1
      QPREV=QSAVE(LEV)
      GOTO30
500  QUAD1=ANS
      RETURN
900  WRITE(6,*)' NO GO....LEV.GE.30 IN QUAD1'
      STOP
      END
C
*****
C
      REAL FUNCTION QUAD2( RAD1, ARG)
      EXTERNAL ARG
      DIMENSION F(8),X(8),XSAVE(4,30),FSAVE(4,30),QSAVE(30)
      COMMON /QUADS/ A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,RELERR
      PARAMETER(W0=0.3111111111,W1=1.4222222222,W2=0.5333333333)
      PARAMETER(E0=0.279082892, E1=1.661516755 ,EE2=0.261869489)
      PARAMETER(E3=2.961834215, EE4=1.281128748)
C
      E2=-EE2
      E4=-EE4
      A = A2
      B = B2
C
      ANS=0.
      AREA=0.
      QPREV=0.
C
      LEV=0
      X0=A
      X(8)=B
C

```

Appendix C

```

F0=QUAD3( RAD1, X0, ARG)
X(4)=(X0+X(8))*0.5
X(2)=(X0+X(4))*0.5
X(6)=(X(4)+X(8))*0.5
C
DO 25 J=2,8,2
F(J)=QUAD3( RAD1, X(J), ARG)
25  CONTINUE
30  X(1)=(X0+X(2))*0.5
F(1)=QUAD3( RAD1, X(1), ARG)
DO 35 J=3,7,2
X(J)=(X(J-1)+X(J+1))*0.5
F(J)=QUAD3( RAD1, X(J), ARG)
35  CONTINUE
STEP=(X(8)-X0)/8.
C
QRIGHT=(W0*(F(4)+F(8))+W1*(F(5)+F(7))+W2*F(6))*STEP
QLEFT =(W0*(F0 +F(4))+W1*(F(1)+F(3))+W2*F(2))*STEP
EIGHT =(E0*(F0 +F(8))+E1*(F(1)+F(7))+E2*(F(2)+F(6))+
1E3*(F(3)+F(5))+E4*F(4))*STEP
C
QADD=QLEFT+QRIGHT
DIFF=QADD-QPREV
AREA=AREA+DIFF
C
IF( ABS(QADD-EIGHT) .LE. RELERR*ABS(AREA) ) GOTO 99
C
SIM=STEP*(F(6)+F(4)+4.*(F(7)+F(5))+F(8)+F(6))/3.
C
IF( ABS(QRIGHT-SIM) .LE. RELERR*ABS(AREA) ) GOTO 60
C
LEV=LEV+1
IF(LEV.GE.30)GOTO900
C
FSAVE(1,LEV)=F0
XSAVE(1,LEV)=X0
DO 52 I=2,4
FSAVE(I,LEV)=F(I-1)
XSAVE(I,LEV)=X(I-1)
52  CONTINUE
QSAVE(LEV)=QLEFT
C
X0=X(4)
F0=F(4)
C
DO 55 I=1,3
F(2*I)=F(4+I)
X(2*I)=X(4+I)
55  CONTINUE

```

```

    QPREV=QRIGHT
    GOTO30
60  ANS=ANS+QRIGHT
    DO 65 I=4,1,-1
    X(2*I)=X(I)
    F(2*I)=F(I)
65  CONTINUE
C
    QPREV=QLEFT
    GOTO30
C
99  ANS=ANS+QADD
    IF(LEV.LE.0)GOTO 500
    X(8)=X0
    F(8)=F0
    X0=XSAVE(1,LEV)
    F0=FSAVE(1,LEV)
    DO 100 I=1,3
    X(2*I)=XSAVE(I+1,LEV)
    F(2*I)=FSAVE(I+1,LEV)
100 CONTINUE
    LEV=LEV-1
    QPREV=QSAVE(LEV)
    GOTO30
500 QUAD2=ANS
    RETURN
900 WRITE(6,*)' NO GO....LEV.GE.30 IN QUAD2'
    STOP
    END
C
C *****
C
    REAL FUNCTION QUAD3( RAD1, RAD2, ARG)
    EXTERNAL ARG
    DIMENSION F(8),X(8),XSAVE(4,30),FSAVE(4,30),QSAVE(30)
    COMMON /QUADS/ A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,RELERR
    PARAMETER(W0=0.3111111111,W1=1.4222222222,W2=0.5333333333)
    PARAMETER(E0=0.279082892, E1=1.661516755 ,EE2=0.261869489)
    PARAMETER(E3=2.961834215, EE4=1.281128748)
C
    E2=-EE2
    E4=-EE4
    A = A3
    B = B3
C
    ANS=0.
    AREA=0.
    QPREV=0.
C

```

Appendix C

```

    LEV=0
    X0=A
    X(8)=B
C
    F0=QUAD4(X0,RAD1,RAD2,ARG )
    X(4)=(X0+X(8))*0.5
    X(2)=(X0+X(4))*0.5
    X(6)=(X(4)+X(8))*0.5
C
    DO 25 J=2,8,2
    F(J)=QUAD4(X(J),RAD1,RAD2,ARG )
25  CONTINUE
30  X(1)=(X0+X(2))*0.5
    F(1)=QUAD4(X(1),RAD1,RAD2,ARG )
    DO 35 J=3,7,2
    X(J)=(X(J-1)+X(J+1))*0.5
    F(J)=QUAD4(X(J),RAD1,RAD2,ARG )
35  CONTINUE
    STEP=(X(8)-X0)/8.
C
    QRIGHT=(W0*(F(4)+F(8))+W1*(F(5)+F(7))+W2*(F(6))*STEP
    QLEFT=(W0*(F0 +F(4))+W1*(F(1)+F(3))+W2*(F(2))*STEP
    EIGHT=(E0*(F0 +F(8))+E1*(F(1)+F(7))+E2*(F(2)+F(6))+
1E3*(F(3)+F(5))+E4*(F(4))*STEP
C
    QADD=QLEFT+QRIGHT
    DIFF=QADD-QPREV
    AREA=AREA+DIFF
C
    IF( ABS(QADD-EIGHT) .LE. RELERR*ABS(AREA) ) GOTO 99
C
    SIM=STEP*(F(6)+F(4)+4.*(F(7)+F(5))+F(8)+F(6))/3.
C
    IF( ABS(QRIGHT-SIM) .LE. RELERR*ABS(AREA) ) GOTO 60
C
    LEV=LEV+1
    IF(LEV.GE.30)GOTO900
C
    FSAVE(1,LEV)=F0
    XSAVE(1,LEV)=X0
    DO 52 I=2,4
    FSAVE(I,LEV)=F(I-1)
    XSAVE(I,LEV)=X(I-1)
52  CONTINUE
    QSAVE(LEV)=QLEFT
C
    X0=X(4)
    F0=F(4)
C

```

```

DO 55 I=1,3
F(2*I)=F(4+I)
X(2*I)=X(4+I)
55  CONTINUE
QPREV=QRIGHT
GOTO30
60  ANS=ANS+QRIGHT
DO 65 I=4,1,-1
X(2*I)=X(I)
F(2*I)=F(I)
65  CONTINUE
C
QPREV=QLEFT
GOTO30
C
99  ANS=ANS+QADD
IF(LEV.LE.0)GOTO 500
X(8)=X0
F(8)=F0
X0=XSAVE(1,LEV)
F0=FSAVE(1,LEV)
DO 100 I=1,3
X(2*I)=XSAVE(I+1,LEV)
F(2*I)=FSAVE(I+1,LEV)
100 CONTINUE
LEV=LEV-1
QPREV=QSAVE(LEV)
GOTO30
500 QUAD3=ANS
RETURN
900 WRITE(6,*)' NO GO....LEV.GE.30 IN QUAD3'
STOP
END
C
C *****
C
REAL FUNCTION QUAD4( RAD3, RAD1, RAD2, ARG)
EXTERNAL ARG
DIMENSION F(8),X(8),XSAVE(4,30),FSAVE(4,30),QSAVE(30)
COMMON /QUADS/ A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,RELERR
PARAMETER(W0=0.311111111,W1=1.422222222,W2=0.533333333)
PARAMETER(E0=0.279082892, E1=1.661516755 ,EE2=0.261869489)
PARAMETER(E3=2.961834215, EE4=1.281128748)
C
E2=-EE2
E4=-EE4
A = A4
B = B4
C

```

Appendix C

```

ANS=0.
AREA=0.
QPREV=0.
C
LEV=0
X0=A
X(8)=B
C
F0=quad5(rad3,x0,RAD1,RAD2,ARG)
X(4)=(X0+X(8))*0.5
X(2)=(X0+X(4))*0.5
X(6)=(X(4)+X(8))*0.5
C
DO 25 J=2,8,2
F(J)=quad5(rad3,x(J),RAD1,RAD2,ARG)
25  CONTINUE
30  X(1)=(X0+X(2))*0.5
F(1)=quad5(rad3,x(1),RAD1,RAD2,ARG)
DO 35 J=3,7,2
X(J)=(X(J-1)+X(J+1))*0.5
F(J)=quad5(rad3,x(J),RAD1,RAD2,ARG)
35  CONTINUE
STEP=(X(8)-X0)/8.
C
QRIGHT=(W0*(F(4)+F(8))+W1*(F(5)+F(7))+W2*F(6))*STEP
QLEFT=(W0*(F0+F(4))+W1*(F(1)+F(3))+W2*F(2))*STEP
EIGHT=(E0*(F0+F(8))+E1*(F(1)+F(7))+E2*(F(2)+F(6))+
1E3*(F(3)+F(5))+E4*F(4))*STEP
C
QADD=QLEFT+QRIGHT
DIFF=QADD-QPREV
AREA=AREA+DIFF
C
IF( ABS(QADD-EIGHT) .LE. RELERR*ABS(AREA) ) GOTO 99
C
SIM=STEP*(F(6)+F(4)+4.*(F(7)+F(5))+F(8)+F(6))/3.
C
IF( ABS(QRIGHT-SIM) .LE. RELERR*ABS(AREA) ) GOTO 60
C
LEV=LEV+1
IF(LEV.GE.30)GOTO900
C
FSAVE(1,LEV)=F0
XSAVE(1,LEV)=X0
DO 52 I=2,4
FSAVE(I,LEV)=F(I-1)
XSAVE(I,LEV)=X(I-1)
52  CONTINUE
QSAVE(LEV)=QLEFT

```

```

C
  X0=X(4)
  F0=F(4)
C
  DO 55 I=1,3
    F(2*I)=F(4+I)
    X(2*I)=X(4+I)
55  CONTINUE
    QPREV=QRIGHT
    GOTO30
60  ANS=ANS+QRIGHT
    DO 65 I=4,1,-1
      X(2*I)=X(I)
      F(2*I)=F(I)
65  CONTINUE
C
  QPREV=QLEFT
  GOTO30
C
99  ANS=ANS+QADD
    IF(LEV.LE.0)GOTO 500
    X(8)=X0
    F(8)=F0
    X0=XSAVE(1,LEV)
    F0=FSAVE(1,LEV)
    DO 100 I=1,3
      X(2*I)=XSAVE(I+1,LEV)
      F(2*I)=FSAVE(I+1,LEV)
100  CONTINUE
    LEV=LEV-1
    QPREV=QSAVE(LEV)
    GOTO30
500  QUAD4=ANS
    RETURN
900  WRITE(6,*)' NO GO....LEV.GE.30 IN QUAD4'
    STOP
    END
C
C *****
C
C  REAL FUNCTION QUAD5( RAD3, RAD4, RAD1, RAD2, ARG)
C  EXTERNAL ARG
C  DIMENSION F(8),X(8),XSAVE(4,30),FSAVE(4,30),QSAVE(30)
C  COMMON /QUADS/ A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,RELERR
C  PARAMETER(W0=0.3111111111,W1=1.4222222222,W2=0.5333333333)
C  PARAMETER(E0=0.279082892, E1=1.661516755 ,EE2=0.261869489)
C  PARAMETER(E3=2.961834215, EE4=1.281128748)
C
C  E2=-EE2

```


Appendix C

```

E4=-EE4
A = A5
B = B5
if (b.le.0.00001)then
quad5=arg(0.,RAD3,RAD4,RAD1,RAD2)
return
endif
C
ANS=0.
AREA=0.
QPREV=0.
C
LEV=0
X0=A
X(8)=B
C
F0=arg(x0,RAD3,RAD4,RAD1,RAD2)
X(4)=(X0+X(8))*0.5
X(2)=(X0+X(4))*0.5
X(6)=(X(4)+X(8))*0.5
C
DO 25 J=2,8,2
F(J)=arg(x(j),RAD3,RAD4,RAD1,RAD2)
25  CONTINUE
30  X(1)=(X0+X(2))*0.5
F(1)=arg(x(1),RAD3,RAD4,RAD1,RAD2)
DO 35 J=3,7,2
X(J)=(X(J-1)+X(J+1))*0.5
F(J)=arg(x(j),RAD3,RAD4,RAD1,RAD2)
35  CONTINUE
STEP=(X(8)-X0)/8.
C
QRIGHT=(W0*(F(4)+F(8))+W1*(F(5)+F(7))+W2*F(6))*STEP
QLEFT=(W0*(F0+F(4))+W1*(F(1)+F(3))+W2*F(2))*STEP
EIGHT=(E0*(F0+F(8))+E1*(F(1)+F(7))+E2*(F(2)+F(6))+
1E3*(F(3)+F(5))+E4*F(4))*STEP
C
QADD=QLEFT+QRIGHT
DIFF=QADD-QPREV
AREA=AREA+DIFF
C
IF( ABS(QADD-EIGHT) .LE. RELERR*ABS(AREA) ) GOTO 99
C
SIM=STEP*(F(6)+F(4)+4.*(F(7)+F(5))+F(8)+F(6))/3.
C
IF( ABS(QRIGHT-SIM) .LE. RELERR*ABS(AREA) ) GOTO 60
C
LEV=LEV+1
IF(LEV.GE.30)GOTO900

```

```

C
  FSAVE(1,LEV)=F0
  XSAVE(1,LEV)=X0
  DO 52 I=2,4
    FSAVE(I,LEV)=F(I-1)
    XSAVE(I,LEV)=X(I-1)
52  CONTINUE
  QSAVE(LEV)=QLEFT
C
  X0=X(4)
  F0=F(4)
C
  DO 55 I=1,3
    F(2*I)=F(4+I)
    X(2*I)=X(4+I)
55  CONTINUE
  QPREV=QRIGHT
  GOTO30
60  ANS=ANS+QRIGHT
  DO 65 I=4,1,-1
    X(2*I)=X(I)
    F(2*I)=F(I)
65  CONTINUE
C
  QPREV=QLEFT
  GOTO30
C
99  ANS=ANS+QADD
  IF(LEV.LE.0)GOTO 500
  X(8)=X0
  F(8)=F0
  X0=XSAVE(1,LEV)
  F0=FSAVE(1,LEV)
  DO 100 I=1,3
    X(2*I)=XSAVE(I+1,LEV)
    F(2*I)=FSAVE(I+1,LEV)
100 CONTINUE
  LEV=LEV-1
  QPREV=QSAVE(LEV)
  GOTO30
500 QUAD5=ANS
  RETURN
900 WRITE(6,*)' NO GO....LEV.GE.30 IN QUADS'
  STOP
  END
C
C *****
C
C  REAL FUNCTION ARG1(DRAD,SRAD,ALPHA,DUM1,DUM2)

```

Appendix C

```
DIMENSION X(30),B(30),C(30),D(30),FB(30)
COMMON X,FB,B,C,D,EAVE,x90
COMMON /DENSE/ DENS,DENA,RMAX,DMAX,TA,TC,DC,XMAX,YMAX,PS
dum1 = 0.
dum2 = 0.
N = 30
C Calculate the actual distance from source to point
depth = dmax + tc + drad + ta
sarg = depth*depth + srad*srad + ps*ps - 2.*srad*ps*cos(alpha)
if(sarg.gt.-.0001.and.sarg.lt.0.)sarg=0.
rho = sqrt(sarg)
if (rho.lt..000027)rho=.000027
C Calculate the projected distance
sarg = rho*rho - depth*depth
if(sarg.gt.-.0001.and.sarg.lt.0.)sarg=0.
rhop = sqrt(sarg)
if (rhop.lt..000027)rhop=.000027
rhoa=0.
xsors = 0.
if(depth.gt.0.)xsors = rho*drad/depth
C Calculate the distance traveled in the source
if(ps.le.rmax)then
C Exists through bottom
rhos = xsors
else
if(srad.le.0.00001)then
srad=0.0
cosb=1.
else
cosb=(ps*ps-srad*srad-rhop*rhop)/(2.*srad*rhop)
endif
C Look at source from side in plane of rho:
C xout is the projected distance from the center of the disk to the
C location at which the path crosses the bottom of the disk
xout = 0.
if(depth.gt.0.)xout = drad*rhop/depth
C Look at source from the top: xproj is the projected distance
C inside the source
sarg = srad*srad*cosb*cosb+rmax*rmax-srad*srad
if(sarg.le.0)sarg = 0.
xproj=srad*cosb+sqrt(sarg)
if(xproj.le.0.000027)xproj=0.
if(xproj.lt.xout)then
C Exists through side of source
rhos = xproj*rho/rhop
rhoa = xsors - rhos
else
C Exists through bottom
rhos = 0.
```

```

    if(drad.gt.0.)rhos = drad * rho/depth
  endif
endif
C Calculate the actual distances in water, air, and cover material
  rhoc = 0.
  if(depth.gt.0.)rhoc = rho * tc / depth
  rair = 0.
  if(depth.gt.0.)rair = rho * ta / depth
  rhow = 0.
  if(depth.gt.0.)rho = rho * (dmax/depth)
  path = rhos * dens + (rhoa+rair) * dena + rhoc * dc + rhow
  if(path.le.0.000027)path = 0.000027
  SQIGL = path / X90
  IF(SQIGL.GT.1.7999)THEN
    ARG1=0.
  ELSE
    ARG1 = SRAD * SEVAL(N,SQIGL,X,FB,B,C,D) / (RHO*RHO)
  ENDIF
  RETURN
END
C
C *****
C
  REAL FUNCTION ARG2(PHI,SRAD,THETA,DUM1,DUM2)
  DIMENSION X(30),B(30),C(30),D(30),FB(30)
  COMMON X,FB,B,C,D,EAVE,x90
  COMMON /DENSE/ DENS,DENA,RMAX,DMAX,TA,TC,DC,XMAX,YMAX,PS
c
  if(srads.eq.0.0)srad = 0.000027
C
C Calculate the actual distance from source to point
C
  dum1 = 0.
  dum2 = 0.
  n = 30
  dep1 = dmax + rmax + srad*cos(phi) + tc + ta
  d1 = dmax + rmax + tc + ta
  rsphi = srad*sin(phi)
  side = dep1*dep1 + rsphi*rsphi + ps*ps - 2.*rsphi*ps*cos(theta)
  if(side.gt..0001.and.side.lt.0.)side=0.
  rho = sqrt(side)
C Eliminate points that can not contribute
  if (rho.lt..000027)rho=.000027
C
C Calculate the distance above skin and skin covering
C
  rhoask = rho * ( rmax + srad*cos(phi) )/dep1
C
C Calculate the distance traveled in the source

```

Appendix C

```

sarg2 = ps*ps + d1*d1
cosb = (srad*srad+rho*rho-sarg2)/(2.*srad*rho)
rhos = srad*cosb + sqrt( srad*srad*(cosb*cosb-1.) + rmax*rmax )
C
C Calculate the projected distances in the source and outside the water
C
rhoa = rhoask - rhos
rhow = rho - rhoask
deep = tc + ta + dmax
path = rhos * dens + rhoa * dena
if(deep.gt.0.)path = rhos*dens+rhoa*dena+rhow*(ta/deep)*dena+
1 rhow * dmax / deep + rhow * (tc/deep) * dc
SQIGL = path / X90
IF(SQIGL.GT.1.7999)THEN
    ARG2=0.
ELSE
    ARG2 =SRAD*SRAD*sin(phi)*SEVAL(N,SQIGL,X,FB,B,C,D)/(RHO*RHO)
ENDIF
RETURN
END
C
C *****
C
REAL FUNCTION ARG3(ZRAD,YRAD,XRAD,SRAD,ALPHA)
DIMENSION X(30),B(30),C(30),D(30),FB(30)
COMMON X,FB,B,C,D,EAVE,x90
COMMON /DENSE/ DENS,DENA,RMAX,DMAX,TA,TC,DC,XMAX,YMAX,PS
N = 30
C Convert srad and alpha to cartesian coordinates
xcar = srad * cos(alpha)
ycar = srad * sin(alpha)
C Calculate the actual distance from source to point
xdis = xrad - xcar
ydis = yrad - ycar
dep = ta + tc + dmax + zrad
sarg = xdis*xdis + ydis*ydis + dep*dep
if(sarg.gt.-.0001.and.sarg.lt.0.)sarg=0.
rho = sqrt(sarg)
if (rho.lt..000027)rho=.000027
rhoa=0.
C Calculate the actual distance above the source level
dout = 0.
if(dep.gt.0.)dout = rho * zrad/dep
C Check x direction for exiting through side of source
if(xcar.gt.xmax)then
    zunk = dep * (1.+(xrad-xmax)/(xcar-xrad))
    if(zunk.gt.tc+dmax+ta)then
C Exits through x-side of source
rhoa = dout * (zunk-tc-dmax-ta) / dep

```

```

    go to 1
  endif
endif
C Check y direction for exiting through side of source
  if(ycar.le.ymax)go to 1
    zunk = dep * (1.+(yrad-ymax)/(ycar-yrad))
C Exits through y-side of source
  if(zunk.gt.tc+dmax+ta)rhoa = dout * (zunk-tc-dmax-ta) / dep
C Calculate the actual distances in the source, air, cover and water
1  rhos = dout - rhoa
  rhow = 0.
  if(dep.gt.0.)rhow = rho * (dmax/dep)
  rhoc = 0.
  if(dep.gt.0.)rhoc = rho * (tc/dep)
  rair = 0.
  if(dep.gt.0.)rair = rho * (ta/dep)
  path = rhow + rhoc*dc + rhos*dens + (rair+rhoa)*dena
  if(path.lt.0.000027)path = 0.000027
  SQIGL = path / X90
  IF(SQIGL.GT.1.7999)THEN
    ARG3=0.
  ELSE
    ARG3 = SRAD * SEVAL(N,SQIGL,X,FB,B,C,D) / (RHO*RHO)
  ENDIF
  RETURN
END
C*****

```

```

SUBROUTINE SPLINE(M,X,Y,B,C,D)
  INTEGER N,M
  REAL X(M),Y(M),B(M),C(M),D(M)
C
C THE COEFFICIENTS B(I), C(I), AND D(I), I=1,2...N ARE COMPUTED
C FOR A CUBIC INTERPOLATING SPLINE
C
C  $S(X) = Y(I) + B(I) * (X - X(I)) + C(I) * (X - X(I))^2 + D(I) * (X - X(I))^3$ 
C
C FOR X(I).LE.X.LE.X(I+1)
C
C INPUT.
C
C N= NUMBER OF DATA POINTS OF KNOTS (N.GE.2)
C X= THE ABSCISSAS OF THE KNOTS IN STRICTLY INCREASING ORDER
C Y= THE ORDINATES OF THE KNOTS
C
C OUTPUT.
C
C B,C,D = ARRAYS OF SPLINE COEFFICIENTS AS DEFINED ABOVE

```

Appendix C

```
C
C USING P TO DENOTE DIFFERENTIATION
C
C Y(I) = S(X(I))
C B(I) = SP(X(I))
C C(I) = SPP(X(I))/2
C D(I) = SPPP(X(I))/6 (DERIVATIVE FROM THE RIGHT)
C
C FUNCTION SEVAL CAN BE USED TO EVALUATE THE SPLINE
C
  INTEGER NM1,IB,I
  REAL T
C
  N=M
  NM1=N-1
  IF(N.LT.2) RETURN
  IF(N.LT.3) GO TO 50
C
C SET TRIDIAGONAL SYSTEM
C
C B=DIAGONAL, D=OFFDIAGONAL, C=RIGHT HAND SIDE
C
  D(1)=X(2)-X(1)
  C(2)=(Y(2)-Y(1))/D(1)
  DO 10 I=2,NM1
    D(I)=X(I+1)-X(I)
    B(I)=2.*(D(I-1)+D(I))
    C(I+1)=(Y(I+1)-Y(I))/D(I)
    C(I)=C(I+1)-C(I)
10  CONTINUE
C
C END CONDITIONS. THIRD DERIVATIVES AT X(1) AND X(N)
C OBTAINED FROM DIVIDED DIFFERENCES
C
  B(1)=-1.*D(1)
  B(N)=-1.*D(N-1)
  C(1)= 0.
  C(N)= 0.
  IF (N.EQ.3) GO TO 15
  C(1)=C(3)/(X(4)-X(2)) - C(2)/(X(3)-X(1))
  C(N)=C(N-1)/(X(N)-X(N-2)) - C(N-2)/(X(N-1)-X(N-3))
  C(1)=C(1)*D(1)**2/(X(4)-X(1))
  C(N)=-C(N)*D(N-1)**2/(X(N)-X(N-3))
C
C FORWARD ELIMINATION
C
15  DO 20 I=2,N
    T=D(I-1)/B(I-1)
    B(I)=B(I)-T*D(I-1)
```

```

      C(I)=C(I)-T*C(I-1)
20  CONTINUE
C
C BACK SUBSTITUTION
C
      C(N)=C(N)/B(N)
      DO 30 IB=1,NM1
        I=N-IB
        C(I)=(C(I)-D(I)*C(I+1))/B(I)
30  CONTINUE
C
C C(I) IS NOW THE SIGMA(I) OF TEXT
C
C COMPUTE POLYNOMIAL COEFFICIENTS
C
      B(N)=(Y(N)-Y(NM1))/D(NM1)+D(NM1)*(C(NM1)+2.*C(N))
      DO 40 I=1,NM1
        B(I)=(Y(I+1)-Y(I))/D(I)-D(I)*(C(I+1)+2.*C(I))
        D(I)=(C(I+1)-C(I))/D(I)
        C(I)=3.*C(I)
40  CONTINUE
      C(N)=3.*C(N)
      D(N)=D(N-1)
      RETURN
C
50  B(I)=(Y(2)-Y(1))/(X(2)-X(1))
      C(1)=0.
      D(1)=0.
      B(2)=B(1)
      C(2)=0.
      D(2)=0.
      RETURN
      END
C
C *****
C
      REAL FUNCTION SEVAL(M,U,X,Y,B,C,D)
      INTEGER N,M
      REAL U,X(M),Y(M),B(M),C(M),D(M)
C
C THIS SUBROUTINE EVALUATES THE CUBIC SPLINE FUNCTION
C
      INTEGER I,J,K
      REAL DX
      DATA I/1/
      N=M
      IF(I.GE.N)I=1
      IF(U.LT.X(I)) GO TO 10
      IF(U.LE.X(I+1)) GO TO 30

```


Appendix C

```
C
C BINARY SEARCH
C
10  I=1
    J=N+1
20  K=(I+J)/2
    IF(U.LT.X(K))J=K
    IF(U.GE.X(K))I=K
    IF(J.GT.I+1) GO TO 20
C EVALUATE SPLINE
30  DX=U-X(I)
    SEVAL=Y(I)+DX*(B(I)+DX*(C(I)+DX*D(I)))
    RETURN
END
```

APPENDIX D

TEXT OF THE USER INTERFACE MODULES

APPENDIX D

TEXT OF THE USER INTERFACE MODULES

PROGRAM FILE VARMAIN.C

```
/****** This is the main program of VARSKIN *****/
#include <graph.h>
#include <stdio.h>
#include "varskin.h"
#include "varglob.h"

extern void screen1(void); /* in testscr4.c file */
extern screen0(); /* in screen0.c file */
extern select_source_type(); /* in src.c file */
extern select_nuclides(); /* in select1.c file */
extern void arr_read_for_nuclides(); /* in arrread.c file */
extern disc_point_input(); /* IN DISCPT.C FILE */
extern disc_input(); /* IN DISC.C FILE */
extern sphere_input(); /* in sphere.c file */
extern cylin_input(); /* in cylin.c file */
extern slab_input(); /* in slab.c file */
extern data_read(); /* in dataread.c file */
extern previous_value_read(); /* in dataread.c file */
extern data_output(); /* in output.c file */
extern gamma(); /* in gamma.c file */
extern help_screen (char *string); /* in help.c file */
extern int selected_source_type ; /* indicates sourcetype selected ;
                                   declared in src.c file */

char vol_answer;
int isource;

main()
{
    char ans;
    _clearscreen ( _GCLEARSCREEN );
    _settextposition ( 10,13);
    printf ("Developed by J. S. Durham, Pacific Northwest Laboratory,");
    _settextposition ( 12,5);
    printf ("for the United States Nuclear Regulatory Commission Office of Research.");
    _settextposition ( 20,25);
    printf ("Press any key to continue...");
    getch();
    _clearscreen ( _GCLEARSCREEN );
    _settextposition ( 20,25);
```

Appendix D

```

printf ("Reading Data - Please Wait .... ");

ans = 'y';
data_read();

for ( ; (ans != 'n') && (ans != 'N'); ) {
    previous_value_read();
    screen0();
    select_source_type();
    _clearscreen ( _GCLEARSCREEN );
    isource = 0;
    if ( selected_source_type > 0 ) {
        do { /*for isource */
            _settextposition ( 15,10);
            printf ("Do you wish to use a distributed source (Y/N)? ");
            _setbkcolor(2);
            _settextcolor(0);
            window(25,4,25,78,POP_UP_COLOR);
            _settextposition ( 25,32);
            _outtext("PRESS <F1> FOR HELP .... ");
            _setbkcolor(0);
            _settextcolor(7);
            ans = getch();
            if (ans == F1_KEY) {
                _settextposition(25,1);
                printf("
                    help_screen("Distributed Source Model:");
                    continue;
                );
            }
        }
    }
    while ( (ans != 'n') && (ans != 'N') && (ans != 'y') && (ans != 'Y')) ;
    if ( (ans == 'y') || (ans == 'Y')) {
        isource = 1;
    }
}
screen1();
select_nuclides();
arr_read_for_nuclides();
_clearscreen ( _GCLEARSCREEN );

/***** For point and Disc source *****/
if ( selected_source_type == 0 ) {
    disc_point_input();
}
if ( selected_source_type == 1 ) {
    disc_input();
}

```

```

/***** For Cylinder source *****/
if ( selected_source_type == 2 ) {
    cylin_input();
}
/***** For Sphere source *****/
if ( selected_source_type == 3 ) {
    sphere_input();
}
/***** For Slab source *****/
if ( selected_source_type == 4 ) {
    slab_input();
}
_clearscreen ( _GCLEARSCREEN );

do { /*for vol_answer */
    _settextposition ( 15,10);
    printf ("Do you wish to perform volume averaging (Y/N)? ");
    _setbkcolor(2);
    _settextcolor(0);
    window(25,4,25,78,POP_UP_COLOR);
    _settextposition ( 25,32);
    _outtext("PRESS <F1> FOR HELP .... ");
    _setbkcolor(0);
    _settextcolor(7);
    vol_answer = getch();
    if (vol_answer == F1_KEY) {
        _settextposition(25,1);
        printf("                               ");
        help_screen("Volume-Averaging Model:");
        continue;
    }
}

while ( (vol_answer != 'n') && (vol_answer != 'N') && (vol_answer != 'y') && (vol_answer != 'Y')) ;

gamma();
_clearscreen ( _GCLEARSCREEN );
_settextposition ( 20,10);
data_output();
do { /*for another analysis */
    _settextposition ( 23,10);
    printf ("Do you want to re-enter the input (Y/N)? ");
    ans = getch();
}
while ( (ans != 'n') && (ans != 'N') && (ans != 'y') && (ans != 'Y')) ;
}
}

```

Appendix D

/***** End of main program of VARSKIN *****/

```
INCLUDE FILE VARSKIN.H
```

```
typedef struct {  
    char nuclide_name[7];  
    float nuclide_strength;  
    int nuclide_serial_no;  
} NUCLIDE_DATA_RECORD ;
```

```
typedef struct {  
    NUCLIDE_DATA_RECORD nuclide_data[5] ;  
    int number_of_nuclide;  
} VARSKIN_DATA_TYPE ;
```

```
typedef struct {  
    char nuclide_name[7];  
    float ebeta, xninty, byield, fbeta[30];  
} FILEREC_TYPE;
```

Appendix D

```
INCLUDE FILE VARGLOB.H
#define BASE 0xb8000000L /* video address */
#define LENGTH_OF_SRC 8 /* length of each SOURCE item */
#define LENGTH_OF_NUCLIDE 7 /* length of each NUCLIDE item */
#define LEN 8 /* length of each item */
#define HIGH 0x71 /* intensified attribute for item highlight */
#define BK_COLOR 0x17 /* reverse backgroun color for nuclides */
#define POP_UP_COLOR 0x27 /* pop up_window color */
#define WINDOW_COL 0x47
#define ESCAPE_KEY 27
#define ENTER_KEY 13
#define MAX_NUMBER_OF_SELECTION 5
#define DOWN_KEY 80
#define UP_KEY 72
#define LEFT_KEY 75
#define RIGHT_KEY 77
#define F1_KEY 59
#define PGDN_KEY 81
#define PGUP_KEY 73
#define SPACE 0x20
#define BACKSPACE 8
#define DEL_KEY 83
```



```
INCLUDE FILE NUCLIDE.H
```

```
#define ROW1 3          /* Row position of 1st nuclide */  
#define COL1 5          /* Column position of 1st nuclide */  
#define NUCLIDE_PER_LINE 6  
#define NUMBER_OF_ROW 14  
#define COL_DISTANCE 13 /* distance between adjacent nuclides */  
#define ROW_DISTANCE 1  /* distance between rows of nuclides */
```

Appendix D

INCLUDE FILE SRCTYPE.H

```
#define ROW1 8          /* Row position of 1st nuclide */
#define COL1 45         /* Column position of 1st nuclide */
#define SOURCE_PER_LINE 1
#define NUMBER_OF_ROW 5
#define COL_DISTANCE 0  /* distance between adjacent source_type */
#define ROW_DISTANCE 2  /* distance between rows of source_type */
```

PROGRAM FILE SRC.C

```

#include <stdlib.h>
#include <graph.h>
#include <stdio.h>
#include "varskin.h"
#include "varglob.h"
#include "srctype.h"

extern char *source_type[]; /* in select0.c file */
extern get_string(char *string, int string_size, int text_row, int text_col); /* in select1.c file */
extern save_back_ground( int top_row, int left_col, int bottom_row, int right_col);
extern restore_back_ground ( int top_row, int left_col, int bottom_row, int right_col);
extern memory_copy( char far *source, char far *dest, int bytes_in_a_line );
extern high_light ( int row, int col, int length);
extern normal_light ( int row, int col, int length);
extern help_screen (char *string); /* in help.c file */
extern window( int window_row1, int window_col1, int window_row2, int window_col2, char attr);
/* in select0.c file */

int selected_source_type; /* indicates sourcetype selected */

/***** This function selects an item from a list *****/

select_source_type()
{
    const int string_size = 8;
    int row, col, size;
    char c;
    char skin_string[8];
    char diameter_string[8];

    screen0();
    row = col = 0;
    size = 0;
    diameter_string[0] = 0;
    while ( ((c) != ENTER_KEY) || (size == 0) ) {
        _setbkcolor(2);
        _settextcolor(0);
        window(25,4,25,78,POP_UP_COLOR);
        _settextposition ( 25,32);
        _outtext("PRESS <F1> FOR HELP ....");
        _setbkcolor(0);
        _settextcolor(7);
        c = getch();
        if ( c == 0 ) {
            c = getch ();
            normal_light ((ROW1+ ROW_DISTANCE*row), (COL1 + col* COL_DISTANCE ),

```

Appendix D

```

LENGTH_OF_SRC);
    /** changes previous highlighted
    item to normal mode */
    if ( c == DOWN_KEY ) /** Down Key */
        row = (row + 1) % NUMBER_OF_ROW;

    if ( c == UP_KEY ) { /** Up Key */
        row = (row - 1) % NUMBER_OF_ROW;
        if ( row < 0 )
            row = row + NUMBER_OF_ROW;
    }

    if ( c == RIGHT_KEY ) /** Right Key */
        col = (col + 1) % SOURCE_PER_LINE;

    if ( c == LEFT_KEY ) { /** Left Key */
        col = (col - 1) % SOURCE_PER_LINE;
        if ( col < 0 )
            col = col + SOURCE_PER_LINE;
    }

    high_light ( (ROW1 + ROW_DISTANCE*row), ( COL1 + col* COL_DISTANCE ),
LENGTH_OF_SRC);
    /* Makes a new highlighted item */

}

if (c == F1_KEY) {
    _settextposition(25,1);
    printf("                                ");
    help_screen("geometry option:");
    continue;
}

/* ENTER key */
if ((c == ENTER_KEY) && (row == 0)) {
    selected_source_type = 0;
    break;
}
if ((c == ENTER_KEY) && (row == 1)) {
    selected_source_type = 1;
    break;
}
if ((c == ENTER_KEY) && (row == 2)) {
    selected_source_type = 2;
    break;
}

if ((c == ENTER_KEY) && (row == 3)) {

```

```
        selected_source_type = 3;
        break;
    }
    if ((c == ENTER_KEY) && (row == 4)) {
        selected_source_type = 4;
        break;
    }

}
_setbkcolor(0);
_settextcolor(7);
}
```

Appendix D

PROGRAM MODULE SCREEN0.C

```
#include <stdio.h>
#include <graph.h>
#include "varglob.h"
#include "srctype.h"

char *source_type[] = {"Point" , "2-D disc","3-D disc","Sphere","3-D Slab" };

extern string_display( char *s, int row, int col);
extern window( int window_row1, int window_col1, int window_row2, int window_col2, char attr); /* in testscr4.c file */
extern high_light ( int row, int col, int length ); /* in select1.c file */
extern normal_light ( int row, int col, int length ); /* in select1.c file */

screen0()

/***** This program makes a Pull-Down Menu to select an item *****/

{
    int col_count, row_count, row , col ;

    _clearscreen(_GCLEARSCREEN);
    border(2,2,78,20);
    _settextposition( 4, (80 - strlen("PROGRAM VARSKIN Mod 2"))/2);
    printf("PROGRAM VARSKIN Mod 2");
    row = ROW1;
    col = COL1;
    _settextposition ( 9, 13);
    printf("Select the type of source : ");
    window ( 8,44,18,55,BK_COLOR); /* makes a highlighted window */
    for ( row_count = 0; row_count < NUMBER_OF_ROW; row_count ++ ) {
        for ( col_count = 0; col_count < SOURCE_PER_LINE; col_count ++ ) {
            string_display ( source_type[row_count*SOURCE_PER_LINE + col_count] , row , col );
            col += COL_DISTANCE;
        }
        row += ROW_DISTANCE;
        col = COL1;
    } /* displays source_type in the window */

    high_light (ROW1 , COL1, LENGTH_OF_SRC ); /* highlights the first item */

}

/***** End of screen1() *****/

border(tx, ty, bx, by)
int tx,ty,bx,by;
{
    register int loop;
    _settextposition(ty, tx);
```

```
putch(218);
for (loop = 0; loop < (bx-tx-1); loop++)
    putch(196);
putch(191);
for (loop = 1; loop <= (by-ty-1); loop++)
{
    _settextposition(ty + loop, tx);
    putch(179);
    _settextposition(ty + loop, bx);
    putch(179);
}
_settextposition(by, tx);
putch(192);
for (loop = 1; loop <= (bx-tx-1); loop++)
    putch(196);
putch(217);
}
```

Appendix D

PROGRAM MODULE TESTSCR4.C

```
#include <stdio.h>
#include <graph.h>
#include "varglob.h"
#include "nuclide.h"

extern high_light ( int row, int col, int length ); /* in select1.c file */
extern normal_light ( int row, int col, int length ); /* in select1.c file */
extern char nuclides_all[100][8];
extern int total_nuclides;

void screen1(void)

/***** This program makes a Pull-Down Menu to select an item *****/

{
    int col_count, row_count, row , col ;

    _clearscreen(_GCLEARSCREEN);
    _settextposition( 1, (80 - strlen("Program VARSKIN Mod 2"))/2);
    printf("Program VARSKIN Mod 2");
    row = ROW1;
    col = COL1;
    window ( 3,4,17,78,BK_COLOR); /* makes a highlighted window */
    for ( row_count = 0; row_count < NUMBER_OF_ROW; row_count ++ ) {
        for ( col_count = 0; col_count < NUCLIDE_PER_LINE; col_count ++ ) {
            string_display ( nuclides_all[row_count*NUCLIDE_PER_LINE + col_count] , row , col );
            col += COL_DISTANCE ;
        }
        row += ROW_DISTANCE;
        col = COL1;
    } /* displays nuclides in the window */

    high_light (ROW1 , COL1, LENGTH_OF_NUCLIDE ); /* highlights the first item */
}

/***** End of screen1() *****/

/*****
*** Displays a string at a particular position ***
*****/

string_display( s, row, col)
char *s;
int row, col ;
{
    char far *pt;
    register char c;
```



```

int width;

width = col + LEN - 1;
pt = (char far *) (BASE + 160L * (long)row + ((long) col << 1));
    /* finding appropriate video memory location */
for (; col <= width; col++)
{
    if ((c = *s++) == '\0')
        break;
    *pt++ = c;
    *pt++; /* skip attribute byte */
}

}
/***** End of string_display *****/

/***** This function makes an window with a particular attribute ****/

window( window_row1, window_col1, window_row2, window_col2, attr)
int window_row1, window_col1, window_row2, window_col2 ;
char attr;
{
    char far *ch_ptr;
    int c, j, width, height;

    width = window_col2 - window_col1 + 1;
    height = window_row2 - window_row1 + 1;
    for (c = 0; c < height; c++) {
        ch_ptr = (char far *) (BASE + (160L * (long) (window_row1 - 1)) + ((long) ((window_col1 - 1) * 2)));
        /* finding the upper left corner of window */
        for (j = 0; j < width; j++) {

            *ch_ptr++ = SPACE;
            *ch_ptr++ = attr; /* changing attribute of SPACE character for the window */
        }
        window_row1++;
    }

}

/***** End of window function *****/

```

Appendix D

PROGRAM MODULE DATAREAD.C

```
#include <stdio.h>
#include <io.h>
#include <string.h>
#include "varskin.h"
#include "varglob.h"

struct RECORD
{
    char nuclide_name[8];
    float ebeta, xninty, byield, fbeta[30];
} filerec ;

int total_nuclides, file_exist;
char nuclides_all[100][8], data_array[12][9];
float ebeta_all[100], xninty_all[100], byield_all[100], fbeta_all[100][30];
float geavg_all[100], gfac_all[100];

data_read()
{
    int n, c, i, newrec;
    float g1,g2;
    FILE *infile1;
    if( (infile1 = fopen( "betadata.dat", "r")) == NULL ) {
        perror( "Can't find BETADATA.DAT" );
        exit( 1 );
    }

    for( c = 0; ; c++ )
    {
        fscanf (infile1,"%s",filerec.nuclide_name);
        if (!strcmp(filerec.nuclide_name,"ENDOFI")) {
            break;
        }
        fscanf (infile1, "%6f %6f %6f", &filerec.ebeta, &filerec.xninty, &filerec.byield);
        for ( i = 0; i < 30; i++ )
            fscanf (infile1, "%7f", &filerec.fbeta[i]);
        fscanf (infile1, "%f %f", &g1,&g2);
        strcpy(&nuclides_all[c][0],filerec.nuclide_name);
        ebeta_all[c]=filerec.ebeta;
        xninty_all[c]=filerec.xninty;
        byield_all[c]=filerec.byield;
        for ( i = 0; i < 30; i++ )
            fbeta_all[c][i]=filerec.fbeta[i];
        geavg_all[c] = g1;
        gfac_all[c] = g2;
    }
}
```

```

    total_nuclides = c;
/*
    do
    {
        printf( "Enter record between 1 and 79 (or 0 to quit): " );
        scanf( "%d", &newrec );

        if( (newrec >= 1) && (newrec <= 79) )
        {
            n = newrec - 1;
            printf( "\n%s %6.4f %6.4f %6.4f", nuclides_all[n], ebeta_all[n], xninty_all[n], byield_all[n] );
            for ( i = 0; i < 30; i++ )
                printf( " %7.4f ", fbeta_all[n][i] );
            printf( "\n%8f %8f", geavg_all[n], gfac_all[n] );

        }
    } while( newrec );
*/

    fclose(infile1);
}

previous_value_read()
{
    int c;
    FILE *infile2;

    file_exist = 1;
    if ( (infile2 = fopen( "output.dat", "rt" )) == NULL ) {
        file_exist = 0;
        if ( (infile2 = fopen( "betadata.dat", "r" )) == NULL ) {
            perror( "Can't open BETADATA.DAT" );
            exit( 1 );
        }
        fclose (infile2);
    }
    if (file_exist == 1) {
        for( c = 0; c < 12; c++ ) {
            fscanf (infile2, "%s", &data_array[c][0]);
        }
    }
    fclose(infile2);
}

```

Appendix D

PROGRAM MODULE ARRREAD.C

```
#include <graph.h>
#include <stdio.h>
#include "varskin.h"

extern VARSKIN_DATA_TYPE varskin_data; /* definition in varskin.h file */
extern char nuclides_all[100][8];
extern float ebeta_all[100], xninty_all[100], byield_all[100], fbeta_all[100][30];
extern float geavg_all[100], gfac_all[100];

float ebeta[6], xninty[6], byield[6], fbeta[6][30];
float geavg[6], gfac[6];

/***** This function reads other nuclide information from file *****/

void arr_read_for_nuclides()
{
    int c, i, newrec;
    for ( i = 0; i < varskin_data.number_of_nuclide ; i++ ) {
        newrec = varskin_data.nuclide_data[i].nuclide_serial_no ;
        ebeta[i] = ebeta_all[newrec];
        xninty[i] = xninty_all[newrec];
        byield[i] = byield_all[newrec];
        geavg[i] = geavg_all[newrec];
        gfac[i] = gfac_all[newrec];
        for ( c = 0; c < 30; c++ )
            fbeta[i][c] = fbeta_all[newrec][c];
    }
}

/***** End of fileread_for_nuclides() *****/
```

PROGRAM MODULE SELECT1.C

```

#include <stdlib.h>
#include <graph.h>
#include <stdio.h>
#include "varskin.h"
#include "varglob.h"
#include "nuclide.h"

#define BELL 7
#define SPACE_CHAR 32

VARSKIN_DATA_TYPE varskin_data; /* definition in varskin.h file */
extern int total_nuclides;
extern char nuclides_all[100][8]; /* in testscr4.c file */
extern window( int window_row1, int window_col1, int window_row2, int window_col2, char attr);
/* in testscr4.c file */
extern msg_screen (char *str); /*in cylin.c file */
extern int isource; /*indicates distributed source or not ; in varmain.c file*/
extern int selected_source_type ; /*indicates sourcetype selected */

/***** This function selects an item from a list *****/

select_nuclides ()
{
    const int string_size = 8;
    int row, col, loop, number_of_nuclide, n, already_selected;
    char c, nuc[8];
    float source_strength;
    char source_strength_string[8];

    row = col = 0;
    number_of_nuclide = 0;
    loop = 0;
    source_strength_string[0] = 0;
    while ( ((c) != ESCAPE_KEY ) && (loop < MAX_NUMBER_OF_SELECTION)) {

        _setbkcolor(2);
        _settextcolor(0);
        window(25,4,25,78,POP_UP_COLOR);
        _settextposition ( 25,28);
        _outtext("PRESS <ESC> WHEN FINISHED .... ");
        _setbkcolor(0);
        _settextcolor(7);

        _settextposition (19+loop,5);
        printf("Select nuclide no. %d -- (%d nuclides maximum): ",loop+1, MAX_NUMBER_OF_SELECTION);
    }
}

```

Appendix D

```

while ( ((c = getch()) != ESCAPE_KEY) || ( number_of_nuclide == 0) ) {
    if ((c == ESCAPE_KEY) && ( number_of_nuclide == 0)) {
        putchar(BELL);
        msg_screen ("Select atleast one nuclide ");
        _settextposition (19,54);
    }
    if ( c == 0 ) {
        c = getch ();
        normal_light ((ROW1+ ROW_DISTANCE*row), (COL1 + col* COL_DISTANCE
),LENGTH_OF_NUCLIDE);
        /** changes previous highlighted
        item to normal mode ***/
        if ( c == DOWN_KEY ) /** Down Key ***/
            row = (row + 1) % NUMBER_OF_ROW;

        if ( c == UP_KEY ) { /** Up Key ***/
            row = (row - 1) % NUMBER_OF_ROW;
            if ( row < 0 )
                row = row + NUMBER_OF_ROW;
        }

        if ( c == RIGHT_KEY ) /* Right Key */
            col = (col + 1) % NUCLIDE_PER_LINE;

        if ( c == LEFT_KEY ) { /* Left Key */
            col = (col - 1) % NUCLIDE_PER_LINE;
            if ( col < 0 )
                col = col + NUCLIDE_PER_LINE;
        }

        high_light ( (ROW1+ ROW_DISTANCE*row), ( COL1 + col* COL_DISTANCE ),
        LENGTH_OF_NUCLIDE);
        /* Makes a new highlighted item */

    }

    /** ENTER key */
    if ((c == ENTER_KEY) &&
        ((row * NUCLIDE_PER_LINE + col) < total_nuclides)){
        already_selected = 0;
        for ( n = 0; n < loop; n++ ) {
            if ( varskin_data.nuclide_data[n].nuclide_serial_no == (row * NUCLIDE_PER_LINE + col)) {
                already_selected = 1;
            }
        }
        if ( already_selected ) {
            putchar(BELL);
            msg_screen ("This nuclide has already been selected");
            _settextposition (19+loop,54);
        }
    }
}

```

```

    }
    else {
        _setbkcolor(2);
        _settextcolor(0);
        window(25,4,25,78,POP_UP_COLOR);
        _settextposition ( 25,23);
        _outtext("PRESS <ESC> TO SKIP THIS NUCLIDE .... ");
        save_back_ground(11,21,18,71); /* saves the window (11,21) to ( 18,71) */
        window(11,21,18,71,POP_UP_COLOR);
        _settextposition ( 12,22);
        _outtext("Enter Source strength for ");
        _outtext (nuclides_all[row * NUCLIDE_PER_LINE + col]);
        _settextposition ( 12,57);
        window (12,57,12,64,0x07);
        /* printf("      "); */ /* makes input number area */
        _settextposition ( 14,22);
        if (isource == 0) {
            _outtext ("Enter source strength in microcuries");
        }
        if (isource == 1) {
            if ( selected_source_type == 1) {
                _outtext ("Enter source strength in microCi/cm ^ 2");
            }
            if ( selected_source_type > 1) {
                _outtext ("Enter source strength in microCi/cm ^ 3");
            }
        }
    }
    get_string ( source_strength_string, string_size, 12, 57);
    /* Reads string with valid digits */
    if (strlen (source_strength_string) == 0) { /* Escaping from inputting strength */
        restore_back_ground( 11,21,18,71); /* retrieves window (11,21) to ( 18,71) */

        window(25,4,25,78,POP_UP_COLOR);
        _settextposition ( 25,23);
        _outtext("PRESS <ESC> WHEN FINISHED .... ");

        _settextposition (19+loop,54);
        continue ;
    }
    _settextposition (19+loop,54);
    printf ("%s",nuclides_all[row * NUCLIDE_PER_LINE + col] );
    source_strength = atof(source_strength_string); /* converts ascii to float */
    _settextposition (19+loop,65);
    printf("%f",source_strength);
    strcpy (varskin_data.nuclide_data[loop].nuclide_name , nuclides_all [row * NUCLIDE_PER_LINE + col] );
    varskin_data.nuclide_data[loop].nuclide_strength = source_strength;
    varskin_data.nuclide_data[loop].nuclide_serial_no = row * NUCLIDE_PER_LINE + col ;
    number_of_nuclide = loop + 1;
    restore_back_ground( 11,21,18,71); /* retrieves window (11,21) to ( 18,71) */

```

Appendix D

```

        break;
    }
}

}
_setbkcolor(0);
_settextcolor(7);
loop ++;
}
varskin_data.number_of_nuclide = number_of_nuclide;
}

/***** This function gets a string with digits only *****/

get_string(string, string_size, text_row, text_col)
char *string;
int string_size, text_row, text_col;
{
    int j,k,dot;
    char c;

    k=0;
    dot = 0;
    _settextposition(text_row, text_col);
    for ( ; (c!=ENTER_KEY); ) {
        /* Takes care of ENTER Key */
        c=getche();
        if ( c == ESCAPE_KEY ) {      /* Takes care of Escape Key */
            k = 0;
            break;
        }
        /*****/
        if (( c == BACKSPACE ) && ( k > 0 )){
            /*takes care of backspace key*/
            if (string[k-1] == '.') dot--;
            _settextposition( text_row, text_col + k);
            putchar(SPACE_CHAR);/*wipes out previous character*/
            _settextposition(text_row, text_col + k);
            k = k - 1;
            _settextposition( text_row, text_col + k);
            putchar(SPACE_CHAR);/*wipes out previous character*/
            _settextposition(text_row, text_col + k);
            continue;
        }
        /*****/

        if ((isdigit(c) == 0) && (c != '.')) {

```



```

        /* Filtering out invalid characters */

        _settextposition(text_row, text_col+k);
        putchar(SPACE_CHAR);
        _settextposition(text_row, text_col+k);
        continue;
    }
    if ( c == '.' ) {
        if (k>0) {
            _settextposition(text_row, text_col+k);
            putchar(SPACE_CHAR);
            _settextposition(text_row, text_col+k);

            continue;
        }
    }
    if (c == ',') dot++;
    if ( c == ':' ) {
        if (dot>1) {
            dot--;
            _settextposition(text_row, text_col+k);
            putchar(SPACE_CHAR);
            _settextposition(text_row, text_col+k);
            continue;
        }
    }
}

string[k++] = c;
if ( k == string_size ) break ;

}
string[k]=0;          /* Fixes the size of the string */

}

/***** End of get_string *****/

/**** This function saves a portion of a screen *****/

#include <malloc.h>

char far *video_mem_save_buff;

save_back_ground( top_row, left_col, bottom_row, right_col)
int left_col, top_row, right_col, bottom_row;
{

```

Appendix D

```
int mem_sz, bytes_in_a_line;
int i;
char far *dest;
char far *source;

bytes_in_a_line = (right_col-left_col+1)*2;
mem_sz = bytes_in_a_line * (bottom_row-top_row+1);
dest = video_mem_save_buff = malloc(mem_sz);
if( dest == 0L ) { printf("no mem\n"); exit(0); }
for( i=top_row; i <= bottom_row; i++ ) {
    source = (char far *) (BASE + 160L*(long)(i-1) + ((long) ((left_col-1)*2)));
    memory_copy( source, dest, bytes_in_a_line );
    dest = dest + bytes_in_a_line;
}
}

/***** End of save_background *****/

/***** This function retrieves a saved portion of a screen *****/

restore_back_ground ( top_row, left_col, bottom_row, right_col)
int left_col, top_row, right_col, bottom_row;
{
    int mem_sz, bytes_in_a_line;
    int i;
    char far *dest;
    char far *source;

    bytes_in_a_line = (right_col-left_col+1)*2;
    source = video_mem_save_buff;

    for( i=top_row; i <= bottom_row; i++ ) {
        dest = (char far *) (BASE + 160L*(long)(i-1) + ((long) ((left_col-1)*2)));
        memory_copy( source, dest, bytes_in_a_line );
        source = source + bytes_in_a_line;
    }
    free( (char near *) video_mem_save_buff );
}

/***** End of retrieve_background *****/

/***** This function moves contents of memory from source to dest **/

memory_copy( source, dest, bytes_in_a_line )

char far *source;
```

```

char far *dest;
int bytes_in_a_line;

{
    int count;

    for ( count = 0; count < bytes_in_a_line; count++ ) {
        dest [ count ] = source [ count ];
    }
}

/***** End of memory_copy *****/

/***** this funtion highlights a particular item *****/

high_light ( row, col, length)

int row, col, length ;
{
    char far *pt;
    int width;

    width = col + length - 1;
    pt = (char far *) (BASE + 160L * (long)row + ((long) col < 1)) + 1;
    for (; col <= width; col++) {
        *pt++ = HIGH;
        pt++;
    }
}

/***** End of high_light *****/

/**** This funtion returns normal attribute to a particular item ****/

normal_light ( row, col, length)
int row, col, length ;
{
    char far *pt;
    int width;

    width = col + length - 1;
    pt = (char far *) (BASE + 160L * (long)row + ((long) col < 1)) + 1;
    for (; col <= width; col++) {
        *pt++ = BK_COLOR;
        pt++;
    }
}

```

Appendix D

}

/****** End of normal_light *****/

PROGRAM MODULE DISCPT.C

```

#include <stdlib.h>
#include <stdio.h>
#include <graph.h>
#include "varglob.h"
#include "varskin.h"

#define NO_OF_FIELDS 6 /*number of input fields */
#define STRING_SIZE 9
#define BELL 7
#define READ_COL 66 /*the column from which the input will be read*/
#define SPACE_CHAR 32
#define NULL_CH 0
#define DELAY 1000000
#define FIRST_LINE 4

extern get_all_string(int field_no); /*in CYLIN.c file*/
extern msg_screen (char *str); /*in cylin.c file */
extern int selected_source_type ; /*indicates sourcetype selected ;
                                   declared in srctype.c file*/
extern file_exist; /*in dataread.c file */
extern char data_array[12][9]; /*in dataread.c file */

char thskin[9], time_exp[9], tc[9], dc[9], relerr[9], airgap[9] ;
extern int point;
char input_string[NO_OF_FIELDS][STRING_SIZE];
extern char c , decision;

disc_point_input()
{
    int true = 1;
    int row, col;
    long loop;
    float real_value[NO_OF_FIELDS];

    char ans;

    row = 2;
    col = 8;
    for (loop = 0; loop < NO_OF_FIELDS; loop++) { /*initializing strings*/
        input_string[loop][0] = 0;
    }
    if (file_exist) {
        strcpy ( input_string[0], data_array[5]);
        strcpy ( input_string[1], data_array[10]);
        strcpy ( input_string[2], data_array[4]);
        strcpy ( input_string[3], data_array[9]);
        strcpy ( input_string[4], data_array[6]);
    }

```

Appendix D

```

strcpy ( input_string[5], data_array[7]);

}

_clearscreen ( _GCLEARSCREEN);
_settextposition( 1, (80 - strlen("POINT SOURCE GEOMETRY"))/2);
printf("POINT SOURCE GEOMETRY");
_settextposition (row += 2, col);
printf ("Enter the skin density thickness in mg/cm ^ 2      :");
_settextposition (row += 2, col);
printf ("Enter the exposure time in minutes      :");
_settextposition (row += 2, col);
printf ("Enter the relative error      :");
_settextposition (row += 2, col);
printf ("Enter the air gap thickness in mm      :");
_settextposition (row += 2, col);
printf ("Enter the thickness of material between the source and :");
_settextposition (row += 1, col);
printf (" skin (protective clothing) in mm");
_settextposition (row += 1, col);
printf ("Enter the density of covering material in g/cm ^ 3      :");


row = 2;
if (file_exist) {
    for ( loop = 0; loop < NO_OF_FIELDS; loop++) {
        _settextposition (row += 2, READ_COL);
        printf ("%s",input_string[loop]);
    }
}

while (true) {

    _settextposition (20,8); /* to clear the confirmation line*/
    printf ("");
    get_all_string (NO_OF_FIELDS); /* reads inputs as strings*/
    for ( loop = 0; loop < NO_OF_FIELDS; loop++) { /*convert string
        to real number*/
        real_value[loop] = atof(input_string[loop]);
    }
    if ( real_value[0] < 0 ) { /*validate input for thskin */
        c = 0; /*initialize the input character*/
        point = 0;
        putchar(BELL);
        msg_screen ("Enter a non-negative value for the skin density thickness");
        continue;
    }
}

```

```

}
if ( real_value[1] < 0 ) { /*validate input for time_exp */
    c = 0; /*initialize the input character*/
    point = 1;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the exposure time ");
    continue;
}
if ( real_value[2] < 0 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 2;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the relative error");
    continue;
}
if ( real_value[2] >= 1 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 2;
    putchar(BELL);
    msg_screen ("The relative error must be less than 1");
    continue;
}

if ( real_value[3] < 0 ) { /*validate input for airgap */
    c = 0; /*initialize the input character*/
    point = 3;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the air gap thickness");
    continue;
}
if ( real_value[4] < 0 ) { /*validate input for tc */
    c = 0; /*initialize the input character*/
    point = 4;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the cover material thickness ");
    continue;
}
if ( real_value[5] < 0 ) { /*validate input for dmax */
    c = 0; /*initialize the input character*/
    point = 5;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the cover material density ");
    continue;
}

_setbkcolor(2);
_settextcolor(0);
_settextposition ( 25,12);

```

Appendix D

```
_outtext("      FINAL CONFIRMATION FOR INPUT DATA ....");
_setbkcolor(0);
_settextcolor(7);

_settextposition (20,8);
putchar(BELL);
printf ("Are all entries correct (Y/N) ? ");/*confirmation*/
ans = getche();
if ( (ans == 'N') || (ans == 'n')) {
    c = 0; /*initialize the input character*/
    continue;
}
if ( (ans == 'Y') || (ans == 'y')) {
    true = 0; /*input is complete */
    c = 0; /*initialize the input character*/
    point = 0;
    _clearscreen ( _GCLEARSCREEN);
}
}

strcpy ( data_array[5], input_string[0]);
strcpy ( data_array[10], input_string[1]);
strcpy ( data_array[4], input_string[2]);
strcpy ( data_array[9], input_string[3]);
strcpy ( data_array[6], input_string[4]);
strcpy ( data_array[7], input_string[5]);

strcpy ( thskin , input_string[0]);
strcpy ( time_exp , input_string[1]);
strcpy ( relerr , input_string[2]);
strcpy ( airgap , input_string[3]);
strcpy ( tc , input_string[4]);
strcpy ( dc , input_string[5]);
}
```


PROGRAM MODULE DISC.C

```

#include <stdlib.h>
#include <stdio.h>
#include <graph.h>
#include "varglob.h"
#include "varskin.h"

#define NO_OF_FIELDS 8 /*number of input fields */
#define STRING_SIZE 9
#define BELL 7
#define READ_COL 66 /*the column from which the input will be read*/
#define SPACE_CHAR 32
#define NULL_CH 0
#define DELAY 1000000
#define FIRST_LINE 4
#define PI 3.1428

extern get_all_string(int field_no); /*in CYLIN.c file*/
extern msg_screen (char *str); /*in cylin.c file */
extern int selected_source_type ; /*indicates sourcetype selected ;
                                   declared in srctype.c file*/
extern file_exist; /*in dataread.c file */
extern char data_array[12][9]; /*in dataread.c file */

char diameter[9], thskin[9], time_exp[9], tc[9], dc[9], relerr[9], airgap[9],
    area_exp[9] ;
extern int point;
char input_string[NO_OF_FIELDS][STRING_SIZE];
extern char c , decision;

disc_input()
{
    int true = 1;
    int row, col;
    long loop;
    float real_value[NO_OF_FIELDS];
    float area_value;

    char ans;

    row = 2;
    col = 8;
    area_value = .00000078;
    for (loop = 0; loop < NO_OF_FIELDS; loop++) { /*initializing strings*/
        input_string[loop][0] = 0;
    }
    if (file_exist) {
        strcpy ( input_string[0], data_array[0]);
    }

```

Appendix D

```

strcpy ( input_string[1], data_array[11]);
strcpy ( input_string[2], data_array[5]);
strcpy ( input_string[3], data_array[10]);
strcpy ( input_string[4], data_array[4]);
strcpy ( input_string[5], data_array[9]);
strcpy ( input_string[6], data_array[6]);
strcpy ( input_string[7], data_array[7]);

}

_clearscreen ( _GCLEARSCREEN);
_settextposition( 1, (80 - strlen("2-D DISC GEOMETRY"))/2);
printf("2-D DISC GEOMETRY");
_settextposition (row += 2, col);
printf ("Enter the 2-D disk diameter in micrometers      :");
_settextposition (row += 2, col);
printf ("Enter the 2-D disk area in cm ^ 2              :");
_settextposition (row += 2, col);
printf ("Enter the skin density thickness in mg/cm ^ 2    :");
_settextposition (row += 2, col);
printf ("Enter the exposure time in minutes              :");
_settextposition (row += 2, col);
printf ("Enter the relative error                        :");
_settextposition (row += 2, col);
printf ("Enter the air gap thickness in mm                :");
_settextposition (row += 2, col);
printf ("Enter the thickness of material between the source and :");
_settextposition (row += 1, col);
printf (" skin (protective clothing) in mm");
_settextposition (row += 1, col);
printf ("Enter the density of covering material in g/cm ^ 3 :");

row = 2;
if (file_exist) {
    for ( loop = 0; loop < NO_OF_FIELDS ; loop++) {
        _settextposition (row += 2, READ_COL);
        printf ("%s",input_string[loop]);
    }
}

while (true) {

    _settextposition (20,8); /* to clear the confirmation line*/
    printf ("");
    get_all_string (NO_OF_FIELDS); /* reads inputs as strings*/
    for ( loop = 0; loop < NO_OF_FIELDS; loop++) { /*convert string

```

```

        to real number*/
real_value[loop] = atof(input_string[loop]);
}

if ( real_value[0] < 1.0 ) { /*validate input for diameter */
    c = 0; /*initialize the input character*/
    point = 0;
    putchar(BELL);
    msg_screen ("The diameter must be at least 1 micrometer.");
    continue;
}
if ( real_value[1] < area_value ) { /*validate input for area_exp */
    c = 0; /*initialize the input character*/
    point = 1;
    putchar(BELL);
    msg_screen ("The area must be at least .00000078 cm ^ 2.");
    continue;
}

if ( real_value[2] < 0 ) { /*validate input for thskin */
    c = 0; /*initialize the input character*/
    point = 2;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the skin density thickness");
    continue;
}
if ( real_value[3] < 0 ) { /*validate input for time_exp */
    c = 0; /*initialize the input character*/
    point = 3;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the exposure time ");
    continue;
}
if ( real_value[4] < 0 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 4;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the Relative error");
    continue;
}
if ( real_value[4] >= 1 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 4;
    putchar(BELL);
    msg_screen ("The relative error must be less than 1");
    continue;
}
}

```

Appendix D

```

if ( real_value[5] < 0 ) { /*validate input for airgap */
    c = 0; /*initialize the input character*/
    point = 5;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the airgap");
    continue;
}
if ( real_value[6] < 0 ) { /*validate input for tc */
    c = 0; /*initialize the input character*/
    point = 6;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the cover material thickness ");
    continue;
}
if ( real_value[7] < 0 ) { /*validate input for dmax */
    c = 0; /*initialize the input character*/
    point = 7;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the cover material density ");
    continue;
}

    _setbkcolor(2);
    _settextcolor(0);
    _settextposition ( 25,12);
    _outtext("      FINAL CONFIRMATION FOR INPUT DATA ....");
    _setbkcolor(0);
    _settextcolor(7);

    _settextposition (20,8);
    putchar(BELL);
    printf ("Are all entries correct (Y/N) ? "); /*confirmation*/
    ans = getche();
    if ( (ans == 'N') || (ans == 'n') ) {
        c = 0; /*initialize the input character*/
        continue;
    }
    if ( (ans == 'Y') || (ans == 'y') ) {
        true = 0; /*input is complete */
        c = 0; /*initialize the input character*/
        point = 0;
        _clearscreen ( _GCLEARSCREEN);
    }
}

strcpy ( data_array[0], input_string[0]);
strcpy ( data_array[1], input_string[1]);
strcpy ( data_array[5], input_string[2]);
strcpy ( data_array[10], input_string[3]);

```

```
strcpy ( data_array[4], input_string[4]);  
strcpy ( data_array[9], input_string[5]);  
strcpy ( data_array[6], input_string[6]);  
strcpy ( data_array[7], input_string[7]);
```

```
strcpy ( diameter , input_string[0]);  
strcpy ( area_exp , input_string[1]);  
strcpy ( thskin , input_string[2]);  
    strcpy ( time_exp , input_string[3]);  
    strcpy ( relerr , input_string[4]);  
    strcpy ( airgap , input_string[5]);  
    strcpy ( tc , input_string[6]);  
    strcpy ( dc , input_string[7]);
```

```
}
```

Appendix D

PROGRAM MODULE CYLIN.C

```
#include <stdlib.h>
#include <stdio.h>
#include <graph.h>
#include <string.h>
#include <math.h>
#include <errno.h>
#include "varglob.h"
#include "varskin.h"

#define NO_OF_FIELDS 9 /*number of input fields */
#define STRING_SIZE 9
#define BELL 7
#define READ_COL 66 /*the column from which the input will be read*/
#define SPACE_CHAR 32
#define NULL_CH 0
#define DELAY 1000000
#define FIRST_LINE 4
#define PI 3.1415926

extern VARSKIN_DATA_TYPE varskin_data; /* definition in varskin.h file */
extern float xninty[6];
extern window( int window_row1, int window_col1, int window_row2, int window_col2, char attr);
/* in testscr4.c file */
extern help_screen (char *string); /* in help.c file */
extern file_exist; /*in dataread.c file */
extern char data_array[12][9]; /*in dataread.c file */
extern int selected_source_type; /*indicates sourcetype selected;
decalred in src.c file*/
char diameter[9], dth1[9], time_exp[9], dens[9], relerr[9], dmax1[9],
airgap[9], tc[9], dc[9];
int point = 0;
char input_string[NO_OF_FIELDS][STRING_SIZE];
char c = 0, decision;

cylin_input()
{
    int true = 1;
    int row, col, f, invalid_dmax, iteration;
    long loop;
    float real_value[NO_OF_FIELDS];

    char ans;

    row = 2;
    col = 8;
```

```

for (loop = 0; loop < NO_OF_FIELDS; loop++) { /*initializing strings*/
    input_string[loop][0] = 0;
}
if (file_exist) {
    strcpy ( input_string[0], data_array[0]);
    strcpy ( input_string[1], data_array[8]);
    strcpy ( input_string[2], data_array[10]);
    strcpy ( input_string[3], data_array[3]);
    strcpy ( input_string[4], data_array[4]);
    strcpy ( input_string[5], data_array[5]);
    strcpy ( input_string[6], data_array[9]);
    strcpy ( input_string[7], data_array[6]);
    strcpy ( input_string[8], data_array[7]);
}
_clearscreen ( _GCLEARSCREEN);
_settextposition( 1, (80 - strlen("3-D DISK GEOMETRY"))/2);
printf("3-D DISK GEOMETRY");
_settextposition (row += 2, col);
printf ("Enter the 3-D disk diameter in micrometers      :");
_settextposition (row += 2, col);
printf ("Enter the 3-D disk thickness in micrometers      :");
_settextposition (row += 2, col);
printf ("Enter the exposure time in minutes                :");
_settextposition (row += 2, col);
printf ("Enter the source material density in g/cm ^ 3      :");
_settextposition (row += 2, col);
printf ("Enter the relative error                            :");
_settextposition (row += 2, col);
printf ("Enter the skin density thickness in mg/cm ^ 2       :");
_settextposition (row += 2, col);
printf ("Enter the air gap thickness in mm                    :");
_settextposition (row += 2, col);
printf ("Enter the thickness of material between the source and :");
_settextposition (row += 1, col);
printf ("  skin (protective clothing) in mm");
_settextposition (row += 1, col);
printf ("Enter the density of the covering material in g/cc    :");

row = 2;
if (file_exist) {
    for ( loop = 0; loop < NO_OF_FIELDS ; loop++) {
        _settextposition (row += 2, READ_COL);
        printf ("%s",input_string[loop]);
    }
}
while (true) {

```

Appendix D

```

_settextposition (23,8); /* to clear the confirmation line*/
printf ("
");
get_all_string (NO_OF_FIELDS); /* reads inputs as strings*/
for ( loop = 0; loop < NO_OF_FIELDS; loop++ ) { /*convert string
to real number*/
    real_value[loop] = atof(input_string[loop]);
}
if ( real_value[0] < 1.0 ) { /*validate input for diameter */
    c = 0; /*initialize the input character*/
    point = 0;
    putchar(BELL);
    msg_screen ("The disk diameter must be at least 1 micrometer.");
    continue;
}
if ( real_value[1] < 1.0 ) { /*validate input for thickness */
    c = 0; /*initialize the input character*/
    point = 1;
    putchar(BELL);
    msg_screen ("The disk thickness must be at least 1 micrometer.");
    continue;
}
if ( real_value[2] < 0 ) { /*validate input for time_exp */
    c = 0; /*initialize the input character*/
    point = 2;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the exposure time ");
    continue;
}
if ( real_value[3] <= 0 ) { /*validate input for dens */
    c = 0; /*initialize the input character*/
    point = 3;
    putchar(BELL);
    msg_screen ("Enter a positive value for the source density ");
    continue;
}
if ( real_value[4] < 0 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 4;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the relative error");
    continue;
}
if ( real_value[4] >= 1 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 4;
    putchar(BELL);
    msg_screen ("The relative error must be less than 1");
    continue;
}
}

```



```

if ( real_value[5] < 0 ) { /*validate input for dmax1 */
    c = 0; /*initialize the input character*/
    point = 5;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the skin density thickness");
    continue;
}
if ( real_value[6] < 0 ) { /*validate input for airgap */
    c = 0; /*initialize the input character*/
    point = 6;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the air gap thickness");
    continue;
}
if ( real_value[7] < 0 ) { /*validate input for tc */
    c = 0; /*initialize the input character*/
    point = 7;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the material thickness ");
    continue;
}
if ( real_value[8] < 0 ) { /*validate input for dmax */
    c = 0; /*initialize the input character*/
    point = 8;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the material density ");
    continue;
}

f = varskin_data.number_of_nuclide;
invalid_dmax = 0;

_setbkcolor(2);
_settextcolor(0);
_settextposition ( 25,12);
_outtext("      FINAL CONFIRMATION FOR INPUT DATA .... ");
_setbkcolor(0);
_settextcolor(7);

_settextposition (23,8);
putchar(BELL);
printf ("Are all entries correct (Y/N) ? "); /*confirmation*/
ans = getche();
if ( (ans == 'N') || (ans == 'n')) {
    c = 0; /*initialize the input character*/
    continue;
}

```

Appendix D

```
if ( (ans == 'Y') || (ans == 'y')) {
    true = 0; /*input is complete */
    c = 0; /*initialize the input character*/
    point = 0;
    _clearscreen ( _GCLEARSCREEN);
}
}
strcpy ( data_array[0], input_string[0]);
strcpy ( data_array[8], input_string[1]);
strcpy ( data_array[10], input_string[2]);
strcpy ( data_array[3], input_string[3]);
strcpy ( data_array[4], input_string[4]);
strcpy ( data_array[5], input_string[5]);
strcpy ( data_array[9], input_string[6]);
strcpy ( data_array[6], input_string[7]);
strcpy ( data_array[7], input_string[8]);
```

```
strcpy ( diameter , input_string[0]);
strcpy ( dth1 , input_string[1]);
strcpy ( time_exp , input_string[2]);
strcpy ( dens , input_string[3]);
strcpy ( relerr , input_string[4]);
strcpy ( dmax1 , input_string[5]);
strcpy ( airgap , input_string[6]);
strcpy ( tc , input_string[7]);
strcpy ( dc , input_string[8]);
```

```
}
```

```
/***** This function gets strings with digits only *****/
```

```
get_all_string(field_no)
int field_no;
{
    int length_of_str, text_col, text_row, dot, prev_point = 0;
    float temp_value;
    char temp[9], temp2[9];
    dot = 0;
    if (strstr (input_string[point], ".")) {
        dot = 1;
    }
    else {
        dot = 0;
    }
    _setbkcolor(2);
    _settextcolor(0);
    window(25,2,25,79,POP_UP_COLOR);
```

```

_settextposition ( 25,13);
_outtext("<ESC=FINISHED> <DEL=DELETE PRESENT INPUT> <F1=HELP> ....");
_setbkcolor(0);
_settextcolor(7);

text_col = READ_COL;
length_of_str = strlen(input_string[point]);
text_row = FIRST_LINE + 2 * point;
_settextposition(text_row, text_col + length_of_str);
while ( c != ESCAPE_KEY) { /*takes care of escape key*/
    c = getche();
    if ( c == ENTER_KEY) { /*takes care of enter key*/
        input_string[point][length_of_str] = NULL_CH;
        /*ends the current string*/
        prev_point = point;
        point = (point + 1) % field_no;
        if ( selected_source_type == 1 ) {
            if ( prev_point == 0 ) {
                strcpy ( temp,input_string[0] );
                temp_value = (atof(temp))/10000.0;
                temp_value = PI * temp_value * temp_value / 4;
                sprintf(temp2,"%f",temp_value);
                if ( strlen(temp2) > (STRING_SIZE-1) ) {
                    temp2[STRING_SIZE-1] = NULL_CH;
                }
                strcpy ( input_string[1], temp2);
                _settextposition (6, READ_COL);
                printf ("          ");
                _settextposition (6, READ_COL);
                printf ("%s",input_string[1]);
            }
            if ( prev_point == 1 ) {
                strcpy ( temp,input_string[1] );
                temp_value = atof(temp);
                temp_value = (sqrt ( temp_value * 4 / PI))*10000.0;
                sprintf(temp2,"%f",temp_value);
                if ( strlen(temp2) > (STRING_SIZE-1) ) {
                    temp2[STRING_SIZE-1] = NULL_CH;
                }
                strcpy ( input_string[0], temp2);
                _settextposition (4, READ_COL);
                printf ("          ");
                _settextposition (4, READ_COL);
                printf ("%s",input_string[0]);
            }
        }
        if (strstr (input_string[point],".")) {
            dot = 1;
        }
    }
}

```

Appendix D

```

        else {
            dot = 0;
        }
length_of_str = strlen(input_string[point]);
text_row = FIRST_LINE + 2 * point;
_settextposition( text_row, text_col + length_of_str);
}
if ( c == 0 ) {
    c = getch();
    if ( c == DEL_KEY ) {
        input_string[point][0] = NULL_CH;
        text_row = FIRST_LINE + 2 * point;
        _settextposition ( text_row, READ_COL );
        printf ("          ");
        length_of_str = strlen(input_string[point]);
        text_row = FIRST_LINE + 2 * point;
        _settextposition( text_row, text_col + length_of_str);
        dot = 0;
        continue;
    }
    if ( c == F1_KEY ) {
        help_options();
    }
    if ( c == DOWN_KEY ) { /*takes care of down key*/
        input_string[point][length_of_str] = NULL_CH;
        /*ends the current string*/
        prev_point = point;
        point = (point + 1) % field_no;
        if (strstr (input_string[point], ".") ) {
            dot = 1;
        }
        else {
            dot = 0;
        }
    }
    if ( c == UP_KEY ) { /*takes care of up key*/
        input_string[point][length_of_str] = NULL_CH;
        /*ends the current string*/
        prev_point = point;
        point = (point - 1) % field_no;
        if (strstr (input_string[point], ".") ) {
            dot = 1;
        }
        else {
            dot = 0;
        }
    }

    if ( point < 0 ) { /*WRAP AROUND*/

```

```

        prev_point = point ;
point = point + field_no ;
    }
}

if ( selected_source_type == 1 ) {
    if ( prev_point == 0 ) {
        strcpy ( temp,input_string[0] );
        temp_value = (atof(temp))/10000.0;
        temp_value = PI * temp_value * temp_value / 4;
        sprintf(temp2,"%f",temp_value);
        if ( strlen(temp2) > (STRING_SIZE-1) ) {
            temp2[STRING_SIZE-1] = NULL_CH;
        }
        strcpy ( input_string[1], temp2);
        _settextposition (6, READ_COL);
        printf ( "          ");
        _settextposition (6, READ_COL);
        printf ("%s",input_string[1]);
    }
    if ( prev_point == 1 ) {
        strcpy ( temp,input_string[1] );
        temp_value = atof(temp);
        temp_value = (sqrt ( temp_value * 4 / PI))*10000.0;
        sprintf(temp2,"%f",temp_value);
        if ( strlen(temp2) > (STRING_SIZE-1) ) {
            temp2[STRING_SIZE-1] = NULL_CH;
        }
        strcpy ( input_string[0], temp2);
        _settextposition (4, READ_COL);
        printf ( "          ");
        _settextposition (4, READ_COL);
        printf ("%s",input_string[0]);
    }
}

length_of_str = strlen(input_string[point]);
text_row = FIRST_LINE + 2 * point;
_settextposition (text_row, text_col + length_of_str);
}

if (( c == BACKSPACE ) && ( length_of_str > 0)){
    /*takes care of backspace key*/
    if (input_string[point][length_of_str - 1] == '.') dot--;
    length_of_str = length_of_str - 1;
    _settextposition( text_row, text_col + length_of_str);
    putchar(SPACE_CHAR);/*wipes out previous character*/
    _settextposition(text_row , text_col + length_of_str);
    input_string[point][length_of_str] = NULL_CH;
    continue;
}

```

```

if ((isdigit(c) == 0) && (c != '.')) {
    /* Filtering out invalid characters */
    _settextposition(text_row, text_col + length_of_str);
    putchar(SPACE_CHAR);
    _settextposition(text_row, text_col + length_of_str);
    continue;
}

if (c == '.') {
    if (length_of_str > 0) {
        _settextposition(text_row, text_col + length_of_str);
        putchar(SPACE_CHAR);
        _settextposition(text_row, text_col + length_of_str);

        continue;
    }
}

if (c == '.') dot++;
if (c == '.') {
    if (dot > 1) {
        dot--;
        _settextposition(text_row, text_col + length_of_str);
        putchar(SPACE_CHAR);
        _settextposition(text_row, text_col + length_of_str);
        continue;
    }
}

input_string[point][length_of_str++] = c;
if (length_of_str == STRING_SIZE) {
    /*takes care of input larger than maximum string size */
    length_of_str--;
    _settextposition(text_row, text_col + length_of_str);
    putchar(SPACE_CHAR);
    _settextposition(text_row, text_col + length_of_str);
    continue;
}
}

input_string[point][length_of_str] = NULL_CH; /* Fixes the size of string */

if (selected_source_type == 1) {
    if (point == 0) {
        strcpy(temp, input_string[0]);
        temp_value = (atof(temp)) / 10000.0;
        temp_value = (PI * temp_value * temp_value) / 4;
        sprintf(temp2, "%f", temp_value);
        if (strlen(temp2) > (STRING_SIZE - 1)) {
            temp2[STRING_SIZE - 1] = NULL_CH;
        }
        strcpy(input_string[1], temp2);
    }
}

```

```

        _settextposition (6, READ_COL);
        printf ("          ");
        _settextposition (6, READ_COL);
        printf ("%s",input_string[1]);
    }

    if ( point == 1 ) {
        strcpy ( temp,input_string[1] );
        temp_value = atof(temp);
        temp_value = (sqrt ( temp_value * 4 / PI))*10000.0;
        sprintf(temp2,"%f",temp_value);
        if ( strlen(temp2) > (STRING_SIZE-1) ) {
            temp2[STRING_SIZE-1] = NULL_CH;
        }
        strcpy ( input_string[0], temp2);
        _settextposition (4, READ_COL);
        printf ("          ");
        _settextposition (4, READ_COL);
        printf ("%s",input_string[0]);
    }
}

}

/***** End of get_all_string *****/

help_options()
{
    switch (selected_source_type) {
        case 0 : point_help();
            break;
        case 1 : two_d_disk_help();
            break;
        case 2 : three_d_disk_help();
            break;
        case 3 : sphere_help();
            break;
        case 4 : three_d_slab_help();
            break;
        default:break;
    }
}

point_help()
{
    switch (point) {

```

Appendix D

```
    case 0 :help_screen ("skin depth:");
        break;
    case 2 :help_screen ("relative error:");
        break;
    case 3 :help_screen ("air gap thickness:");
        break;
    case 4 :
    case 5 :help_screen ("covering material:");
        break;
    default:break;
}
}
```

two_d_disk_help()

```
{    switch (point) {
    case 0 :help_screen ("diameter:");
        break;
    case 2 :help_screen ("skin depth:");
        break;
    case 4 :help_screen ("relative error:");
        break;
    case 5 :help_screen ("air gap thickness:");
        break;
    case 6 :
    case 7 :help_screen ("covering material:");
        break;

    default:break;
}
}
```

three_d_disk_help()

```
{    switch (point) {
    case 0 :help_screen ("diameter:");
        break;
    case 1 :help_screen ("thickness:");
        break;
    case 3 :help_screen ("source density:");
        break;
    case 4 :help_screen ("relative error:");
        break;
    case 5 :help_screen ("skin depth:");
        break;
    case 6 :help_screen ("air gap thickness:");
        break;
}
```



```

        case 7 :
        case 8 :help_screen ("covering material:");
            break;

        default:break;
    }
}

sphere_help()
{
    switch (point) {
        case 0 :help_screen ("diameter:");
            break;
        case 2 :help_screen ("source density:");
            break;
        case 3 :help_screen ("relative error:");
            break;
        case 4 :help_screen ("skin depth:");
            break;
        case 5 :help_screen ("air gap thickness:");
            break;
        case 6 :
        case 7 :help_screen ("covering material:");
            break;

        default:break;
    }
}

three_d_slab_help()
{
    switch (point) {
        case 0 :help_screen ("x-side length:");
            break;
        case 1 :help_screen ("y-side length:");
            break;
        case 2 :help_screen ("thickness:");
            break;
        case 4 :help_screen ("source density:");
            break;
        case 5 :help_screen ("relative error:");
            break;
        case 6 :help_screen ("skin depth:");
            break;
        case 7 :help_screen ("air gap thickness:");
            break;
        case 8 :
        case 9 :help_screen ("covering material:");
            break;

        default:break;
    }
}

```

Appendix D

```
    }  
}  
  
/*****/  
  
msg_screen(str)  
char str[];  
{  
    long loop;  
   strupr(str);  
    save_back_ground(21,8,22,74);  
    window(21,8,22,74,WINDOW_COL);  
    _setbkcolor(4);  
    _settextcolor(7);  
    _settextposition (21,10);  
    _outtext(str);  
    for ( loop = 0; loop < DELAY; loop++) { /* delay */  
    }  
    restore_back_ground( 21,8,22,74 );  
    _setbkcolor(0);  
    _settextcolor(7);  
}
```

PROGRAM MODULE SPHERE.C

```

#include <stdlib.h>
#include <stdio.h>
#include <graph.h>
#include "varglob.h"
#include "varskin.h"

#define NO_OF_FIELDS 8 /*number of input fields */
#define STRING_SIZE 9
#define BELL 7
#define READ_COL 66 /*the column from which the input will be read*/
#define SPACE_CHAR 32
#define FIRST_LINE 4 /*first line of input */
#define NULL_CH 0
#define DELAY 1000000

extern VARSKIN_DATA_TYPE varskin_data; /* definition in varskin.h file */
extern get_all_string(int field_no); /*in CYLIN.c file*/
extern msg_screen (char *str); /*in CYLIN.c file*/
extern float xninty[6];
extern file_exist; /*in dataread.c file */
extern char data_array[12][9]; /*in dataread.c file */

char diameter[9], time_exp[9], dens[9], relerr[9], dmax1[9],
    airgap[9], tc[9], dc[9];
extern int point;
char input_string[NO_OF_FIELDS][STRING_SIZE];
extern char c;

sphere_input()
{
    int true = 1;
    int row, col, field_no, f, invalid_dmax, iteration;
    long loop;
    float real_value[NO_OF_FIELDS];
    char ans;

    field_no = NO_OF_FIELDS;
    row = 2;
    col = 8;
    for (loop = 0; loop < NO_OF_FIELDS; loop++) { /*initializing strings*/
        input_string[loop][0] = 0;
    }
    if (file_exist) {
        strcpy (input_string[0], data_array[0]);
        strcpy (input_string[1], data_array[10]);
        strcpy (input_string[2], data_array[3]);
        strcpy (input_string[3], data_array[4]);
    }

```

Appendix D

```

        strcpy ( input_string[4], data_array[5]);
        strcpy ( input_string[5], data_array[9]);
        strcpy ( input_string[6], data_array[6]);
        strcpy ( input_string[7], data_array[7]);

    }

    _clearscreen ( _GCLEARSCREEN);
    _settextposition( 1, (80 - strlen("SPHERICAL SOURCE GEOMETRY"))/2);
    printf("SPHERICAL SOURCE GEOMETRY");
    _settextposition (row += 2, col);
    printf ("Enter the sphere diameter in micrometers      : ");
    _settextposition (row += 2, col);
    printf ("Enter the exposure time in minutes           : ");
    _settextposition (row += 2, col);
    printf ("Enter the source material density in g/cm ^ 3      : ");
    _settextposition (row += 2, col);
    printf ("Enter the relative error                          : ");
    _settextposition (row += 2, col);
    printf ("Enter the skin density thickness in mg/cm ^ 2        : ");
    _settextposition (row += 2, col);
    printf ("Enter the air gap thickness in mm                    : ");
    _settextposition (row += 2, col);
    printf ("Enter the thickness of material between the source and : ");
    _settextposition (row += 1, col);
    printf (" skin (protective clothing) in mm");
    _settextposition (row += 1, col);
    printf ("Enter the density of the covering material in g/cm ^ 3  : ");

    row = 2;
    if (file_exist) {
        for ( loop = 0; loop < NO_OF_FIELDS ; loop++) {
            _settextposition (row += 2, READ_COL);
            printf ("%s",input_string[loop]);
        }
    }

    while (true) {
        _settextposition (22,8); /* to clear the confirmation line*/
        printf ("");
        get_all_string (field_no); /* reads inputs as strings*/
        for ( loop = 0; loop < NO_OF_FIELDS; loop++) { /*convert string
            to real number*/
            real_value[loop] = atof(input_string[loop]);
        }

        if ( real_value[0] < 1.0 ) { /*validate input for diameter */
            c = 0; /*initialize the input character*/

```

```

    point = 0;
    putchar(BELL);
    msg_screen ("The diameter must be at least 1 micrometer.");
    continue;
}

if ( real_value[1] < 0 ) { /*validate input for time_exp */
    c = 0; /*initialize the input character*/
    point = 1;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the exposure time");
    continue;
}
if ( real_value[2] <= 0 ) { /*validate input for dens */
    c = 0; /*initialize the input character*/
    point = 2;
    putchar(BELL);
    msg_screen ("Enter a positive value for the source density ");
    continue;
}
if ( real_value[3] < 0 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 3;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the relative error");
    continue;
}
if ( real_value[3] >= 1 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 3;
    putchar(BELL);
    msg_screen ("The relative error must be less than 1");
    continue;
}

if ( real_value[4] < 0 ) { /*validate input for dmax1 */
    c = 0; /*initialize the input character*/
    point = 4;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the skin density thickness");
    continue;
}
if ( real_value[5] < 0 ) { /*validate input for airgap */
    c = 0; /*initialize the input character*/
    point = 5;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the air gap thickness");
    continue;
}

```

Appendix D

```

    }
    if ( real_value[6] < 0 ) { /*validate input for tc */
        c = 0; /*initialize the input character*/
        point = 6;
        putchar(BELL);
        msg_screen ("Enter a non-negative value for the cover material thickness ");
        continue;
    }
    if ( real_value[7] < 0 ) { /*validate input for dmax */
        c = 0; /*initialize the input character*/
        point = 7;
        putchar(BELL);
        msg_screen ("Enter a non-negative value for the cover material density ");
        continue;
    }
    f = varskin_data.number_of_nuclide;
    invalid_dmax = 0;
    _setbkcolor(2);
    _settextcolor(0);
    _settextposition ( 25,12);
    _outtext("          FINAL CONFIRMATION FOR INPUT DATA ....");
    _setbkcolor(0);
    _settextcolor(7);

    _settextposition (22,8);
    putchar(BELL);
    printf ("Are all entries correct (Y/N) ? "); /*confirmation*/
    ans = getche();
    if ( (ans == 'N') || (ans == 'n') ) {
        c = 0; /*initialize the input character*/
        continue;
    }
    if ( (ans == 'Y') || (ans == 'y') ) {
        true = 0; /*input is complete */
        c = 0; /*initialize the input character*/
        point = 0;
        _clearscreen ( _GCLEARSCREEN);
    }
}

strcpy ( data_array[0], input_string[0]);
strcpy ( data_array[10], input_string[1]);
strcpy ( data_array[3], input_string[2]);
strcpy ( data_array[4], input_string[3]);
strcpy ( data_array[5], input_string[4]);
strcpy ( data_array[9], input_string[5]);
strcpy ( data_array[6], input_string[6]);
strcpy ( data_array[7], input_string[7]);

strcpy ( diameter , input_string[0]);

```

```
strcpy ( time_exp , input_string[1]);  
strcpy ( dens , input_string[2]);  
strcpy ( relerr , input_string[3]);  
strcpy ( dmax1 , input_string[4]);  
strcpy ( airgap , input_string[5]);  
strcpy ( tc , input_string[6]);  
strcpy ( dc , input_string[7]);
```

```
}
```

Appendix D

PROGRAM SLAB.C

```
#include <stdlib.h>
#include <stdio.h>
#include <graph.h>
#include "varglob.h"
#include "varskin.h"

#define NO_OF_FIELDS 10 /*number of input fields */
#define STRING_SIZE 9
#define BELL 7
#define READ_COL 66 /*the column from which the input will be read*/
#define SPACE_CHAR 32
#define FIRST_LINE 4 /*first line of input */
#define NULL_CH 0
#define DELAY 1000000

extern VARSKIN_DATA_TYPE varskin_data; /* definition in varskin.h file */
extern get_all_string(int field_no); /*in CYLIN.c file*/
extern msg_screen (char *str); /*in CYLIN.c file*/
extern float xninty[6];
extern file_exist; /*in dataread.c file */
extern char data_array[12][9]; /*in dataread.c file */

char x_length[9], y_length[9], dth1[9], time_exp[9], dens[9], relerr[9],
      dmax1[9], airgap[9], tc[9], dc[9] ;
extern int point ;
char input_string[NO_OF_FIELDS][STRING_SIZE];
extern char c ;

slab_input()
{
    int true = 1;
    int row, col, field_no, f, invalid_dmax, iteration ;
    long loop;
    float real_value[NO_OF_FIELDS];
    char ans;

    field_no = NO_OF_FIELDS;
    row = 2;
    col = 8;
    for (loop = 0; loop < NO_OF_FIELDS; loop++) { /*initializing strings*/
        input_string[loop][0] = 0;
    }
    if (file_exist) {
        strcpy ( input_string[0], data_array[1]);
        strcpy ( input_string[1], data_array[2]);
        strcpy ( input_string[2], data_array[8]);
    }
}
```



```

strcpy ( input_string[3], data_array[10]);
strcpy ( input_string[4], data_array[3]);
strcpy ( input_string[5], data_array[4]);
strcpy ( input_string[6], data_array[5]);
strcpy ( input_string[7], data_array[9]);
strcpy ( input_string[8], data_array[6]);
strcpy ( input_string[9], data_array[7]);

}

_clearscreen ( _GCLEARSCREEN);
_settextposition ( 1, (80 - strlen("3-D SLAB GEOMETRY"))/2);
printf("3-D SLAB GEOMETRY");
_settextposition (row += 2, col);
printf ("Enter the X-side length in micrometers      :");
_settextposition (row += 2, col);
printf ("Enter the Y-side length in micrometers      :");
_settextposition (row += 2, col);
printf ("Enter the slab thickness in micrometers     :");
_settextposition (row += 2, col);
printf ("Enter the exposure time in minutes          :");
_settextposition (row += 2, col);
printf ("Enter the source material density in g/cm ^ 3 :");
_settextposition (row += 2, col);
printf ("Enter the relative error                      :");
_settextposition (row += 2, col);
printf ("Enter the skin density thickness in mg/cm ^ 2 :");
_settextposition (row += 2, col);
printf ("Enter the air gap thickness in mm              :");
_settextposition (row += 2, col);
printf ("Enter the thickness of material between the source and :");
_settextposition (row += 1, col);
printf ("  skin (protective clothing) in mm");
_settextposition (row += 1, col);
printf ("Enter the density of covering material in g/cm ^ 3 :");

row = 2;
if (file_exist) {
    for ( loop = 0; loop < NO_OF_FIELDS ; loop++) {
        _settextposition (row += 2, READ_COL);
        printf ("%s",input_string[loop]);
    }
}

while (true) {
    _settextposition (24,8); /* to clear the confirmation line*/
    printf ("");
    get_all_string (field_no); /* reads inputs as strings*/

```

Appendix D

```
for ( loop = 0; loop < NO_OF_FIELDS; loop++ ) { /*convert string
    to real number*/
    real_value[loop] = atof(input_string[loop]);
}

if ( real_value[0] < 1.0 ) { /*validate input for x_length */
    c = 0; /*initialize the input character*/
    point = 0;
    putchar(BELL);
    msg_screen ("The X-side length must be at least 1 micrometer.");
    continue;
}

if ( real_value[1] < 1.0 ) { /*validate input for y_length */
    c = 0; /*initialize the input character*/
    point = 1;
    putchar(BELL);
    msg_screen ("The Y-side length must be at least 1 micrometer.");
    continue;
}

if ( real_value[2] < 1.0 ) { /*validate input for thickness */
    c = 0; /*initialize the input character*/
    point = 2;
    putchar(BELL);
    msg_screen ("The disk thickness must be at least 1 micrometer.");
    continue;
}

if ( real_value[3] < 0 ) { /*validate input for time_exp */
    c = 0; /*initialize the input character*/
    point = 3;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the exposure time");
    continue;
}

if ( real_value[4] <= 0 ) { /*validate input for dens */
    c = 0; /*initialize the input character*/
    point = 4;
    putchar(BELL);
    msg_screen ("The source density must be greater than 0 ");
    continue;
}

if ( real_value[5] < 0 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 5;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the relative error");
    continue;
}
```

```

if ( real_value[5] >= 1 ) { /*validate input for relerr */
    c = 0; /*initialize the input character*/
    point = 5;
    putchar(BELL);
    msg_screen ("The relative error must be less than 1");
    continue;
}

if ( real_value[6] < 0 ) { /*validate input for dmax1 */
    c = 0; /*initialize the input character*/
    point = 6;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the skin density thickness");
    continue;
}

if ( real_value[7] < 0 ) { /*validate input for airgap */
    c = 0; /*initialize the input character*/
    point = 7;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the air gap thickness");
    continue;
}

if ( real_value[8] < 0 ) { /*validate input for tc */
    c = 0; /*initialize the input character*/
    point = 8;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the material thickness ");
    continue;
}

if ( real_value[9] < 0 ) { /*validate input for dmax */
    c = 0; /*initialize the input character*/
    point = 9;
    putchar(BELL);
    msg_screen ("Enter a non-negative value for the material density ");
    continue;
}

f = varskin_data.number_of_nuclide;
invalid_dmax = 0;
_setbkcolor(2);
_settextcolor(0);
_settextposition ( 25,12);
_outtext("      FINAL CONFIRMATION FOR INPUT DATA .... ");
_setbkcolor(0);
_settextcolor(7);

_settextposition (24,8);
putchar(BELL);

```

Appendix D

```
printf("Are all entries correct (Y/N) ? ");/*confirmation*/
ans = getche();
if ( (ans == 'N') || (ans == 'n')) {
    c = 0; /*initialize the input character*/
    continue;
}
if ( (ans == 'Y') || (ans == 'y')) {
    true = 0; /*input is complete */
    c = 0; /*initialize the input character*/
    point = 0;
    _clearscreen ( _GCLEARSCREEN);
}
}
```

```
strcpy ( data_array[1], input_string[0]);
strcpy ( data_array[2], input_string[1]);
strcpy ( data_array[8], input_string[2]);
strcpy ( data_array[10], input_string[3]);
strcpy ( data_array[3], input_string[4]);
strcpy ( data_array[4], input_string[5]);
strcpy ( data_array[5], input_string[6]);
strcpy ( data_array[9], input_string[7]);
strcpy ( data_array[6], input_string[8]);
strcpy ( data_array[7], input_string[9]);
```

```
strcpy ( x_length , input_string[0]);
strcpy ( y_length , input_string[1]);
strcpy ( dth1 , input_string[2]);
strcpy ( time_exp , input_string[3]);
strcpy ( dens , input_string[4]);
strcpy ( relerr , input_string[5]);
strcpy ( dmax1 , input_string[6]);
strcpy ( airgap , input_string[7]);
strcpy ( tc , input_string[8]);
strcpy ( dc , input_string[9]);
```

```
}
```

PROGRAM MODULE GAMMA.C

```

#include <graph.h>
#include <stdio.h>
#include <math.h>
#include "varglob.h"
#include "varskin.h"

#define STRING_SIZE 9
#define BELL 7

extern VARSKIN_DATA_TYPE varskin_data; /* definition in varskin.h file */

extern window( int window_row1, int window_col1, int window_row2, int window_col2, char attr);
/* in select0.c file */
extern float geavg[6], gfac[6];
extern int selected_source_type; /* indicates sourcetype selected;
    decalred in src.c file */
extern char diameter[9], dth1[9], time_exp[9], dens[9], relerr[9], dmax1[9],
    airgap[9], tc[9], x_length[9], y_length[9], dc[9];
char gamma_answer[] = "nnnnnn";

gamma()
{
    int loop;
    double diam, dth, xl, yl, air, dimax;
    diam = atof(diameter);
    dth = atof(dth1);
    xl = atof(x_length);
    yl = atof(y_length);
    air = atof(airgap);
    if (selected_source_type == 0)
    {
        dimax = 0.;
    }
    if (selected_source_type == 1)
    {
        dimax = diam;
    }
    if (selected_source_type == 2)
    {
        if (diam >= dth)
        {
            dimax = diam;
        }
        else
        {
            dimax = dth;
        }
    }
}

```

Appendix D

```

    }
    if (selected_source_type == 3)
    {
        dimax = diam;
    }
    if (selected_source_type == 4)
    {
        if (xl >= dth && xl >= yl)
        {
            dimax = xl;
        }
        if (yl >= dth && yl >= xl)
        {
            dimax = yl;
        }

        if (dth >= yl && dth >= xl)
        {
            dimax = dth;
        }
    }
    for (loop = 0; loop < varskin_data.number_of_nuclide; loop++) {
        if (geavg[loop] > 0 && dimax <= 1000. && air <= 50.)
        {
            gamma_screen();
            break;
        }
    }

    for (loop = 0; loop < varskin_data.number_of_nuclide; loop++) {
        if (geavg[loop] > 0 && dimax <= 1000. && air <= 50.)
        {
            gamma_input(loop);
        }
    }
}

```

```

gamma_screen()
{
    int j,row,col,len;
    char line[60];
    char str[] = "GAMMA DOSE MODEL.";

    char headline[] = "SIMPLIFIED GAMMA DOSE MODEL";
    char c=0;
    FILE *infile;
    line[0] = 0;
}

```

```

_setbkcolor(4);
_settextcolor(7);
window(6,10,21,72,WINDOW_COL);
_settextposition ( 6, (80 - strlen(headline))/2);
_outtext(headline);
row = 7;
col = 12;

if( (infile = fopen( "help.txt", "rt")) == NULL ) {
    _settextposition ( 12,12);
    _outtext ( "!!! Can't open help.txt file" );
}
else {
    do {
        if (feof(infile)) {
            _settextposition ( 12,12);
            _outtext ( "!!! help is not available in help.txt" );
            break;
        }
        fgets(line,60,infile);

    }
    while (!strstr(line, str) );
    fgets(line,60,infile);
    do {
        if (feof(infile)) break;
        _settextposition ( ++row, col);
        _outtext(line);
        fgets(line,60,infile);

    }
    while (!strstr(line, str));
    fclose(infile);
}

_setbkcolor(0);
_settextcolor(7);

}

gamma_input(i)
int i;
{
    _settextposition ( 23,12);
    printf ("                ");
    putchar(BELL);
    do {
        _settextposition ( 23,12);

```

Appendix D

```
    printf("Do you want the gamma dose to be calculated for %s (Y/N)? ",  
          varskin_data.nuclide_data[i].nuclide_name);  
    gamma_answer[i] = getche();  
}  
while ( (gamma_answer[i] != 'n') && (gamma_answer[i] != 'N') &&  
        (gamma_answer[i] != 'y') && (gamma_answer[i] != 'Y'));  
}
```


PROGRAM MODULE OUTPUT.C

```

#include <graph.h>
#include <stdio.h>
#include "varskin.h"

extern VARSKIN_DATA_TYPE varskin_data; /* definition in varskin.h file */
extern float ebeta[6], xninty[6], byield[6], fbeta[6][30];
extern float geavg[6], gfac[6];
extern char gamma_answer[6];
extern char vol_answer;
extern char data_array[12][9]; /* in dataread.c file */

char diameter[9], x_length[9], y_length[9], dth1[9], dens[9], relerr[9],
    dmax1[9], tc[9], dc[9], airgap[9], thskin[9], time_exp[9];
extern int isource; /* indicates distributed source or not, declared in
    varmain.c file */
extern int selected_source_type; /* indicates sourcetype selected
    declared in src.c file */

float ss[6];
int geo, f=0;
char name[6][8];

data_output()
{
    int i, j, n, c, loop, loc;
    FILE *outfile;

    if( (outfile = fopen( "output.dat", "w")) == NULL ) {
        _clearscreen(_GCLEARSCREEN);
        _settextposition(23,10);
        perror("Can't create the output file");
        exit( 1 );
    }
    f = varskin_data.number_of_nuclide;
    geo = selected_source_type;
    for ( loop = 0; loop < f; loop++ ) {
        ss[loop] = varskin_data.nuclide_data[loop].nuclide_strength;
        strcpy(&name[loop][0], varskin_data.nuclide_data[loop].nuclide_name);
    }
    /****** For point and Disc source *****/
    if ( (selected_source_type == 0) || (selected_source_type == 1) ) {
        strcpy ( dmax1 , thskin);
        strcpy (dth1 , "0");
        strcpy (dens , "0");
    }
    _clearscreen ( _GCLEARSCREEN );
    _settextposition ( 20,10);

```

Appendix D

```
for ( loop = 0 ; loop < 12 ; loop++ ) {
    if ( data_array[loop][0] == 0 ) {
        strcpy (data_array[loop],"0");
    }
    fprintf (outfile, "%s\n",data_array[loop]);
}

fprintf (outfile, "%d \n%d",geo,f);
fprintf (outfile, "\n%c", vol_answer);
fprintf (outfile, "\n%d", isource);
for ( i = 0; i < varskin_data.number_of_nuclide ; i++ ) {
    fprintf (outfile, "\n%c",gamma_answer[i]);

    fprintf (outfile,"\n%s %8.4f %8.4f %8.4f",
        name[i], ebeta[i], xninty[i], byield[i]);
    for ( j = 0; j < 3; j++ ) {
        fprintf(outfile,"\n ");
    }
    for ( c = 0; c < 10; c++ ) {
        loc = 10*j + c;
        fprintf (outfile,"%7.4f ", fbeta[i][loc]);
    }
    fprintf (outfile, "\n%8.4f %8.4f",geavg[i],gfacs[i]);
    fprintf(outfile,"\n%f",ss[i]);

}
printf("Output is written to the file OUTPUT.DAT");
fclose(outfile);
}
```

PROGRAM MODULE HELP.C

```

#include <stdlib.h>
#include <graph.h>
#include <stdio.h>
#include "varglob.h"
#include <malloc.h>

extern save_back_ground( int top_row,int left_col, int bottom_row, int right_col);
extern restore_back_ground ( int top_row,int left_col, int bottom_row, int right_col);
extern memory_copy( char far *source, char far *dest, int bytes_in_a_line );
extern window( int window_row1, int window_col1, int window_row2, int window_col2, char attr);
/* in select0.c file */

help_screen(str)
char str[];
{
    int i,j,k,row,col,len;
    char line[60];
    char headline[]=" Help Screen for ";
    char c=0;
    FILE *infile;
    j = k = 0;
   strupr(str);
    line[0] = 0;
    _setbkcolor(4);
    _settextcolor(7);
    save_back_ground(6,10,21,72);
    window(6,10,21,72,WINDOW_COL);
    strcat (headline , str);
    _settextposition ( 6, (80 - strlen(headline))/2);
    _outtext(headline);
    row = 7;
    col = 12;
    do {
        if( (infile = fopen( "help.txt", "rt")) == NULL ) {
            _settextposition ( 12,12);
            _outtext ( "!!! Can't open help.txt file" );
        }
        else {
            do {
                if (feof(infile)) {
                    _settextposition ( 12,12);
                    _outtext ( "!!! help is not available in help.txt" );
                    break;
                }
            }
            fgets(line,60,infile);
        }
    }
}

```

Appendix D

```

while (!strstr(line, str) );
fgets(line,60,infile);
do {
    if (feof(infile)) break;
    if ( row == 19) {
        j = 0;
        _settextposition ( 21, col);
        _outtext("Press <ESC> to return, <PgDn> for next page... ");
    }
    do {
        c = getch();
        if (c==0) {
            c=getch();
            if (c==PGDN_KEY) {
                j = 1;
            }
            else {
                j = 0;
            }
        }
    }
    while ((c != ESCAPE_KEY) && !j);
    if (c == ESCAPE_KEY) {
        break;
    }
    if (j) {
        row = 7;
        window(8,10,21,72,WINDOW_COL);
    }

    _settextposition ( ++row, col);
    _outtext(line);
    fgets(line,60,infile);

}
while (!strstr(line, str));
fclose(infile);
}

if (j) {
    _settextposition ( 21, col);
    _outtext("Press <ESC> to return, <PgUp> for previous page... ");
    do {
        c = getch();
        if (c==0) {
            c=getch();
            if (c==PGUP_KEY) {
                k = 1;
            }
        }
    }
}

```

```

        else {
            k = 0;
        }
    }
}
while ((c != ESCAPE_KEY) && !k);
    if (c == ESCAPE_KEY) {
        break;
    }
    if (k) {
        row = 7;
        window(8,10,21,72,WINDOW_COL);
        continue;
    }
}

_settextposition ( 21, col);
_outtext("Strike <ESC> to return ....");

while (c != ESCAPE_KEY) {
    c = getch();
}
break;
}
while (1);
restore_back_ground( 6,10,21,72 );
_setbkcolor(0);
_settextcolor(7);
}

```

APPENDIX E

TEXT OF SADDE Mod 2 CODE

APPENDIX E

TEXT OF SADDE Mod 2 CODE

\$LARGE

```

    program saddle
c Modified by JSD on 22 June 199, and 6 Oct 1992
    dimension eb(150),spec(30,150),comp(1500),x(1000),phi(1000)
    real xx90(1000),f(1000),b(150),c(150),d(150),by(30)
    dimension xr(30),fit(30),spec1(150),spec2(150),eele(30),yele(30)
    character*1 answ
    CHARACTER*6 NUCLIDE,nucnew
    character*80 deck(30,20),dtemp
    LOGICAL*4 EXXT
c
    data xr/0.,.01,.02,.03,.04,.05,.10,.15,.20,.25,.30,.35,.40,.45,
1 .50,.55,.60,.65,.70,.75,.80,.85,.90,.95,1.0,1.1,1.2,1.4,1.6,1.8/
c
    n = 150
    iwt = 1
    nz = 8
    niso = 1
    ntot = 0
    byield = 0.
    emax = 0.
    write(*,*) ' Please enter the isotope (or mixture) name (6 charact
&ers)'
    read(*,1)nucnew
1    format(a6)
    write(*,*) ' Are multiple isotopes to be included? [y/n]'
    read(*,'(a)')answ
    if(answ.eq.'y'.or.answ.eq.'Y')then
49    write(*,*) ' Enter the total number of isotopes:'
        read(*,*)niso
        if(niso.gt.30)then
            write(*,*) ' The number of isotopes must be less than 30'
            go to 49
        endif
    endif
    do 502 j=1,niso
c+1
        write(*,10000)j

```

Appendix E

```
10000 format(' Data for isotope number ',i2)
      write(*,10001)
10001 format(/ Enter the number of decay paths for this ',
      & 'radionuclide: ', $)
48 read(*,*)mod
   if(mod.gt.20)then
      write(*,*)' The number of decay paths must be less than 20'
      go to 48
   endif
   write(*,10002)
10002 format(' Enter the ATOMIC NUMBER of the transition (daughter) ',
      & 'nucleus: ', $)
   read(*,*)z
   write(*,10003)
10003 format(' Enter the ATOMIC MASS of the parent nucleus: ', $)
   read(*,*)a
   if(niso.gt.1)then
      write(*,10004)
10004 format(' Enter the weighting factor for the radionuclide: ', $)
   read(*,*)wt
   else
      wt=1.
   endif
   write(deck(j,1),'(i2,f7.1,f9.3,e9.2,3i6)')mod,z,a,wt,n,iwt,nz
   do 50 i = 2,mod+1
      write(*,10005)i-1
10005 format(' Decay Path Number ',i2)
      write(*,10006)
10006 format(/ Enter the endpoint (maximum) beta energy in MeV: ', $)
      read(*,*)em
      write(*,10007)
10007 format(/ Enter the fractional Yield: ', $)
      read(*,*)yld
      write(*,10008)
10008 format(/ Enter the forbiddenness: ', $)
      read(*,*)nf
      byield = byield + yld*wt
      if(em.gt.emax)then
         emax=em
         jmax = j
      endif
      write(deck(j,i),'(2f8.4,i6)')em,yld,nf
50 continue
   by(j) = byield
   byield = 0.
```

C

C Add internal conversion and Auger electrons

```

C
  write(*,10009)
10009 format(/ ' Enter the number of internal conversion and Auger ',
  & / ' electrons for this radionuclide: ', $)
  read(*,*)nele
  ntot = ntot+nele
  if(ntot.gt.30)then
    write(*,10011)
10011 format(/ ' The TOTAL number of electrons in a run must be less ',
  & 'than 30.', /, ' Please re-start Sadde Mod 2')
    go to 552
  endif
  if(nele.eq.0)go to 502
  do 502 i = ntot-nele+1,ntot
6161 write(*,10010)i-ntot+nele
10010 format(/ ' Enter the energy in MeV for electron number ',i2,' : '
  & , $)
  read(*,*)eele(i)
  if(eele(i).le.0.)then
    write(*,20001)
20001 format(/ ' The electron energy must be greater than 0.')
    go to 6161
  endif
  write(*,10012)i-ntot+nele
10012 format(/ ' Enter the fractional yield for electron number ',i2,
  & ' : ', $)
  read(*,*)yele(i)
  if(yele(i).le.0.)then
    write(*,20002)
20002 format(/ ' The yield must be greater than 0. Restart this entry')
    go to 6161
  endif
  byield = byield + yele(i)
502 continue
445 if(answ.eq.'y'.or.answ.eq.'Y')then
c
c modify decks to account for emax
c
  do 444 j = 1,niso
  if(j.eq.jmax)go to 444
  read(deck(j,1),'(i2,f7.1,f9.3,e9.2,3i6)')mod,z,a,wt,n,iwt,nz
  mod = mod+1
  write(deck(j,1),'(i2,f7.1,f9.3,e9.2,3i6)')mod,z,a,wt,n,iwt,nz
  do 55 i=mod+1,3,-1
    deck(j,i)=deck(j,i-1)

```

Appendix E

```
55      continue
      write(deck(j,2),'(f8.4)')emax
444 continue
c
c rank decks in order of decreasing endpoint energies
c
  do 563 j = 1,niso
    read(deck(j,1),'(i2,f7.1,f9.3,e9.2,3i6)')mod,z,a,wt,n,iwt,nz
    if(mod.ge.2)then
561 nswap = 0
      do 562 i = 2,mod
        read(deck(j,i),'(f8.4)')e1
        read(deck(j,i+1),'(f8.4)')e2
        if(e1.lt.e2)then
          dtemp = deck(j,i+1)
          deck(j,i+1) = deck(j,i)
          deck(j,i) = dtemp
          nswap = 1
        endif
562 continue
      if(nswap.ne.0)goto561
    endif
563 continue
c
  do 564 j=1,niso
    call beta(j,eb,spec,deck)
    byield = byield + by(j)
564 continue
565   do 57 i = 1,n
     do 566 j = 1,niso
       spec1(i) = spec1(i) + by(j)*spec(j,i)/byield
566   continue
57   continue
  else
c
c single isotope - reorder deck
c
    byield = by(1)
    if(mod.ge.2)then
571 nswap = 0
      do 572 i = 2,mod
        read(deck(1,i),'(f8.4)')e1
        read(deck(1,i+1),'(f8.4)')e2
        if(e1.lt.e2)then
          dtemp = deck(1,i+1)
          deck(1,i+1) = deck(1,i)
```

```

        deck(1,i) = dtemp
        nswap = 1
        endif
572 continue
    if(nswap.ne.0)goto571
    endif
c
    call beta(1,eb,spec,deck)
    do 477 i=1,150
        spec1(i) = spec(1,i)
477 continue
    endif
C
C Monoenergetic electrons
c Re-order electrons by decreasing energies
1561 nswap = 0
    do 5621 i = 1,ntot-1
        if(eele(i).lt.eele(i+1))then
            tempe = eele(i+1)
            tempy = yelee(i+1)
            eele(i+1) = eele(i)
            yelee(i+1) = yelee(i)
            eele(i) = tempe
            yelee(i) = tempy
            nswap = 1
        endif
5621 continue
    if(nswap.ne.0)goto1561
C
    IF (ntot.gt.0)then
        do 244 i=1,ntot
            if(eele(i).gt.emax)then
C Generate new spectrum with larger EMAX
                call spline(149,eb,spec1,b,c,d)
                anorm = eele(i) / emax
                do 245 ii=1,149
                    eb(ii)=eb(ii)*anorm
                    a=eb(ii)
                    spec2(ii)=slvsp(149,a,eb,spec1,b,c,d)
                    if (a.gt.emax)spec2(ii)=0.
                    if (spec2(ii).lt.0.)spec2(ii)=0.
245 continue
                    do 248 ij=1,150
                        spec1(ij)=spec2(ij)
248 spec2(ij)=0.
C Set new EMAX

```

Appendix E

```
    emax = eele(i)
    endif
C Modify beta spectrum
    edif=eb(10)-eb(9)
    do 247 j=1,149
        if(eb(j).ge.eele(i))then
            spec1(j)=spec1(j)+yele(i)/edif
            go to 244
        endif
        if(j.eq.149)spec1(149)=spec1(149)+yele(i)/edif
247    continue
244    continue
        ENDIF
249    m = 149
c
    write(*,*)' generating beta spectrum'
c
c to save beta spectrum for verification
c
    open(4,file='spectrum',status='unknown')
    do 199 i=1,150
        write(4,*)eb(i),spec1(i)
199    continue
    close(4)
c
200 call spline(m,eb,spec1,b,c,d)
c
    do 250 i = 1,1500
        comp(i) = 0.0
250    continue
c
    de = emax/1500.
    eav = 0.0
c
    do 300 i=1,1500
        a=de*(float(i)-0.5)
        ans=slvsp(m,a,eb,spec1,b,c,d)
        if (ans.lt.0.)then
            ans=0.
        else
            e1 = e1 + ans*a
            Y1 = Y1 + ans
        endif
300    comp(i) = ans
        eav = e1/y1
c
```

```

400 write(*,*)' starting to generate distribution functions'
c
  iter = 150
c
  call sadd(iter,comp,emax,eav,x,phi)
c
  etot=0.
c
  delx = x(iter)/float(iter)
c
  do 500 i=1,iter
    etot=etot+phi(i)*x(i)*x(i)
500 continue
  etot = etot*eav*4.*3.14159*delx
c
  sfrac=0.
c
  do 600 i=1,iter
    sfrac=sfrac+eav*phi(i)*4.*3.1415*x(i)*x(i)*delx/etot
    if (sfrac.ge.0.9) goto 610
600 continue
c
610 x90 = x(i)
c
c
  do 700 i=1,iter
    f(i) = 4.*3.14159265*x(i)*x(i)*x90*phi(i)
    xx90(i) = x(i)/x90
700 continue
c
  i=1
  j=1
c
705 if (xr(i).lt.xx90(1)) then
  fit(i)=f(1)+(f(2)-f(1))*(xr(i)-xx90(1))/(xx90(2)-xx90(1))
  i=i+1
  goto 705
endif
c
710 if (xx90(j).eq.xr(i)) then
  fit(i)=f(j)
  i=i+1
  j=j+1
  goto 800
endif
  if (xx90(j).gt.xr(i)) then

```

Appendix E

```
fit(i)=f(j-1)+(f(j)-f(j-1))*(xr(i)-xx90(j-1))/(xx90(j)-xx90(j-1))
i=i+1
else
j=j+1
endif
800 if (i.le.30) goto 710
c
INQUIRE(FILE='BETADATA.DAT',EXIST=EXXT)
IF ( EXXT ) GOTO 549
553 WRITE(*,*)'DATA FILE BETADATA.DAT IS'
WRITE(*,*)'NOT ACCESIBLE'
GOTO 552
549 OPEN(21, FILE='BETADATA.DAT',STATUS='OLD')
DO 1115 INUC=1,100
READ(21,111)NUCLIDE
111 FORMAT(4X,A6)
IF( NUCLIDE .EQ. nucnew ) then
print*, ' This is a duplicate nuclide.'
print*, ' Program Terminated'
print*, ' BETADATA.DAT was not altered'
close(21)
stop
endif
IF( NUCLIDE .EQ. 'ENDOFF' ) then
if(inuc.gt.100)then
print*, ' BETADATA.DAT contains too many isotopes'
print*, ' Please delete one or more isotopes and restart'
print*, ' this program'
go to 552
endif
backspace(21)
write(21,111)nucnew
if(byield.lt.10.)then
write(21,900)eav,x90,byield
elseif(byield.lt.100.)then
write(21,9001)eav,x90,byield
else
write(21,9002)eav,x90,byield
endif
write(21,901)(fit(j),j=1,30)
write(21,902)
write(21,903)
GO TO 904
900 format(4x,3f8.4)
9001 format(4x,3f8.3)
9002 format(4x,3f8.2)
```

```

901 format(4x,10f7.4,/,4x,10f7.4,/,4x,10f7.4)
902 format('  0.0  0.0')
903 format(' ENDOFI')
      ELSE
      do kkk=1,5
      READ(21,900)
      enddo
      ENDIF
1115 CONTINUE
904 write(*,*)' ave energy is ...',eav
      write(*,*)' x90 distance is..',x90
      write(*,*)' yield is .....',byield
      write(*,901)(fit(j),j=1,30)
      print*, ' BETADATA.DAT has been updated'
      close(21)
552 stop
      end
c *****
      SUBROUTINE BETA(JNOW,EB1,SPEC1,INPUT)

C *****
C
C This program generates beta-particle energy spectra based on the
C following input data:
C
C  MOD  = NUMBER OF MODES OF DECAY
C  EMAX = ENDPOINT ENERGY FOR BETA SPECTRA (MeV)
C  YLD  = YIELD (MODE PROBABILITY PER DISINTEGRATION)
C  Z    = ATOMIC NUMBER OF RADIONUCLIDE
C  A    = ATOMIC MASS NUMBER OF RADIONUCLIDE
C  NF   = STATE OF FORBIDDENNESS (0,1,2,3)
C  NZ   = FACTOR N IN EXPRESSION  $ZETA = (1/2)^{(1/NZ)}$ . SUCCESSIVE
C         ENERGIES (LOG SPACING) VARY BY FACTOR ZETA. (SUGGEST NZ=6)
C  N    = NUMBER OF STEPS AT WHICH SPECTRUM IS EVALUATED
C  IWT  = 1 FOR EQUAL ENERGY SPACING, 2 FOR LOG SPACING
C
C
C The following auxiliary subprograms are required:
C
C  SUBROUTINES SPECT, NORMAL, INTWT
C  FUNCTIONS  GAMMA, FERMI, SHAPE
C
C Output is in two columns:
C
C  1. Energy in units of  $mc^2$ 
C  2. Energy spectrum in units of  $(mc^2)^{-1}$ 

```

Appendix E

```
C
C Input data (NON-FORMATTED)
C
C CARD 1: MOD,Z,A,N,IWT,NZ
C CARD 2: EMAX,YLD,NF
C CARD 3: Additional cards if MOD > 1, in
C order of decreasing EMAX.
C
C *****

IMPLICIT REAL*8(A-H,O-Z)
COMMON /VALS/E(300),Y(300)
COMMON /CONST/EMC2,PI,ALPH,V0,W0,Z,A,NF,N,EMAX
COMMON /CMN1/IWTEAVG
DIMENSION SPEC(150)
REAL*4 SPEC1(30,150),EB1(150)
CHARACTER*80 INPUT(30,20)

C *****

20 FORMAT(2E12.4)

C ***** READ FIRST TWO DATA CARDS

READ(INPUT(jnow,1),'(I2,F7.1,F9.3,9x,3I6)')MOD,Z,A,N,IWT,NZ
READ(INPUT(jnow,2),'(2F8.4,I6)') EMAX,YLD,NF
write(*,*)emax,yld,nf
C ***** INITIALIZE SPECTRUM

DO 30 I=1,N
30 SPEC(I) = 0.D0

C ***** INITIALIZE CONSTANTS

IF (NZ.LT.3) NZ = 3
ZN = REAL(NZ)
ZT = (0.5D0)**(1.D0/ZN)
PI = DACOS(-1.D0)
EMC2 = .5110034D0
ALPH=0.0072973503D0
V0 = 1.13D0*(ALPH**2)*(Z**(4.D0/3.D0))
W0 = EMAX/EMC2 + 1.D0

C ***** SET UP LOG ENERGY SCALE

IF (IWTEQ.2) THEN
```



```

15  U = EMAX*ZT**(N-1)/EMC2
    IF (U.LT.V0) THEN
      N = N-1
      GO TO 15
    ENDIF
    NTOT = N
    DO 10 I = 1,N
      E(I) = EMAX*ZT**(N-I)/EMC2
10  CONTINUE
    ENDIF

C ***** SET UP LINEAR ENERGY SCALE

    IF (IWTEQ.1) THEN
      NTOT = N
      E(N) = EMAX/EMC2
      E(1) = V0
      CALL INTWT(1,N,E,Y)
    ENDIF

C ***** EVALUATE NORMALIZED SPECTRUM

C ***** CALCULATIONS FOR FIRST MODE

    CALL SPECT
    CALL NORMAL
    DO 31 I=1,N
      SPEC(I) = Y(I)*YLD
31  CONTINUE
    IF(MOD.EQ.1) GO TO 41

C ***** CALCULATIONS FOR ADDITIONAL MODES

    DO 40 J=2,MOD
      READ(INPUT(jnow,J+1),'(2F8.4,I6)') EMAX,YLD,NF
      write(*,*)emax,yld,nf
      W0 = EMAX/EMC2 + 1.D0
50  IF(E(N).GT.EMAX/EMC2) THEN
      N = N-1
      GO TO 50
    ENDIF
    CALL SPECT
    CALL NORMAL
    DO 60 K = 1,N
      SPEC(K) = SPEC(K) + Y(K)*YLD
60  CONTINUE

```

Appendix E

```
40 CONTINUE
41 IF(IWTEQ.1) NSTRT = 2
   IF(IWTEQ.2) NSTRT = 1
80 DO 12 I=NSTRT,NTOT
   EB1(I-1)=E(I)*EMC2
   SPEC1(jnow,I-1)=SPEC(I)/EMC2
12 CONTINUE
   RETURN
   END
```

C *****

SUBROUTINE SPECT

```
IMPLICIT REAL*8(A-H,O-Z)
COMMON /VALS/E(300),Y(300)
COMMON /CONST/EMC2,PI,ALPH,V0,W0,Z,A,NFN,EMAX
DO 15 I=1,N
  W=E(I)+1.D0
  IF(E(I).GT.V0) THEN
    Y(I) = FERMI(W-V0)*(((W-V0)**2-1.D0)**0.5D0)*(W-V0)*((W0-W)**2)
    Y(I) = Y(I)*SHAPE(W)
  ELSE
    Y(I) = 0.D0
  ENDIF
15 CONTINUE
  RETURN
  END
```

C *****

SUBROUTINE NORMAL

```
IMPLICIT REAL*8(A-H,O-Z)
COMMON /VALS/E(300),Y(300)
COMMON /CONST/EMC2,PI,ALPH,V0,W0,Z,A,NFN,EMAX
COMMON /CMN1/IWT,N,E,V
DIMENSION V(300)
CALL INTWT(IWT,N,E,V)
FF = 0.D0
GG = 0.D0
DO 35 I=1,N
  FF = FF + Y(I)*V(I)
  GG = GG + Y(I)*V(I)*E(I)
35 CONTINUE
  IF(IWTEQ.2) THEN
```

```

      FF = FF + Y(1)*(E(1)-V0)/2.D0
      GG = GG + Y(1)*E(1)*(E(1)-V0)/2.D0
    ENDIF
      FF = FF + Y(N)*(EMAX/EMC2-E(N))/2.D0
      GG = GG + Y(N)*E(N)*(EMAX/EMC2-E(N))/2.D0
    DO 40 I = 1,N
      Y(I) = Y(I)/FF
40 CONTINUE
      EAVG = EMC2*GG/FF
      RETURN
    END

```

C *****

DOUBLE PRECISION FUNCTION GAMMA(X)

```

      IMPLICIT REAL*8(A-H,O-Z)
      B1 = -.577191652D0
      B2 = .988205891D0
      B3 = -.897056937D0
      B4 = .918206857D0
      B5 = -.756704078D0
      B6 = .482199394D0
      B7 = -.193527818D0
      B8 = .035868343D0
      Z = 1.D0
10 IF(X.GE.2.D0) THEN
      Z = Z*(X-1.D0)
      X = X-1.D0
      GOTO 10
    ENDIF
      Y = X-1.D0
      Y2=Y*Y
      Y4=Y2*Y2
      GAMMA=Z*(1.D0+B1*Y+B2*Y2+B3*Y*Y2+B4*Y4+B5*Y*Y4+B6*Y4*Y2+B7*Y4*Y2*Y
&+B8*Y4*Y4)
    END

```

C *****

DOUBLE PRECISION FUNCTION FERMI(W)

```

*   Revised 2 Jul 86
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /CONST/EMC2,PI,ALPH,V0,W0,Z,A,NFN,EMAX
      S=(1.D0-(ALPH*Z)**2)**0.5D0-1.D0

```

Appendix E

```

R=((1.123D0*A**(1.D0/3.D0))-(0.941D0*A**(-1.D0/3.D0)))
P=(1.D0+S/2.D0)/((ABS(GAMMA(3.D0+2.D0*S)))**2)
B=R**(2.D0*S)
B1=(ALPH*Z)**2+0.25D0
V=(ALPH*Z*W)/((W**2-1.D0)**0.5D0)
G = 2.D0*V*PI
IF(W0.LT.20.0) G = G/(1.D0-DEXP(-2.D0*V*PI))
D=G*(((B1*(W**2))-0.25D0)**S)
FERMI = P*B*D
END

```

C *****

DOUBLE PRECISION FUNCTION SHAPE(W)

```

IMPLICIT REAL*8(A-H,O-Z)
COMMON /CONST/EMC2,PI,ALPH,V0,W0,Z,A,NFN,EMAX
GOTO(1,2,3)NF
GOTO 10
3 SN=(W**2-1.D0)**3+(W0-W)**6+7.D0*(W**2-1.D0)*((W0-W)**2)
&*((W**2-1.D0)+(W0-W)**2)
GO TO 14
2 SN=(W**2-1.D0)**2+(W0-W)**4+(10.D0/3.D0)*(W**2-1.D0)*((W0-W)
&)**2)
GO TO 14
1 SN=(W**2-1.D0)+(W0-W)**2
GO TO 14
10 SN=1.D00
14 SHAPE = SN
END

```

C *****

SUBROUTINE INTWT(IWT,NWT,WTAB,WATES)

```

C IWT=1,EQUALLY SPACED POINTS
C IWT=2,SUCCESSIVELY MULTIPLICATED SPACED POINTS
C NWT---NUMBER OF ENTRIES
C WTAB---ABSCISSA LIST FOR WHICH INTEGRATION WEIGHTS ARE DETERMINED
C WATES--LIST OF INTEGRATION WEIGHTS TO BE DETERMINED
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION WTAB(300),WATES(300)
WTA=NWT
WTAB1 = WTAB(1)
WTABN = WTAB(NWT)
IF(NWT-2)10,20,20

```

```

10 WATES(1)=0.D0
   GO TO 199
20 IF(IWT-2)30,40,40
30 WTDEL=DABS(WTABN-WTAB1)/(WTA-1.D0)
   GO TO 50
40 WTDEL=DABS(DLOG(WTABN/WTAB1))/(WTA-1.D0)
   WTAB1=DLOG(WTAB1)
   DO 48 I=2,NWT
   WTAB(I)=DEXP(WTAB1+(I-1)*WTDEL)
48 CONTINUE
   GO TO 60
50 DO 55 I=1,NWT
   WTAB(I)=WTAB1+(I-1)*WTDEL
55 CONTINUE
60 NWTB=(WTA/2.+1)
   NWTB=(WTA/2.-1)
   NWTC=(WTA/4.+1)
   NWTD=(WTA/4.-1)
   IF (NWT-2) 199,65,70
65 WATES(1) = WTDEL/2.D0
   WATES(2) = WATES(1)
   GO TO 199
70 WATES(1)=WTDEL/3.D0
   WTC=WATES(1)
   WATES(NWT)=WATES(1)
   DO 80 I=1,NWTB
   WATES(I+1)=WTDEL+WTC
   INDX=NWT-I
   WATES(INDX)=WTDEL+WTC
   WTC=-WTC
80 CONTINUE
   WTD=1.D0/24.D0
   IF(NWTC-NWTD)100,100,90
90 WTD=-WTD
100 IF(NWTA-NWTB)140,140,110
110 WATES(NWTB)=WATES(NWTB)-WTD*WTDEL
   WATES(NWTB+1)=WATES(NWTB+1)+5.D0*WTD*WTDEL
   WATES(NWTB+3)=WATES(NWTB)
   WATES(NWTB+2)=WATES(NWTB+1)
140 IF (IWTEQ.2) THEN
   DO 160 I = 1,NWT
   WATES(I) = WATES(I)*WTAB(I)
160 CONTINUE
   ENDIF
199 RETURN
   END

```

Appendix E

```

C
C*****
SUBROUTINE SPLINE(M,X,Y,B,C,D)
  INTEGER N,M
  REAL X(M),Y(M),B(M),C(M),D(M)
C
  N=M
  NM1=N-1
  IF(N.LT.2) RETURN
  IF(N.LT.3) GO TO 50
C
  D(1)=X(2)-X(1)
  C(2)=(Y(2)-Y(1))/D(1)
  DO 10 I=2,NM1
    D(I)=X(I+1)-X(I)
    B(I)=2.*(D(I-1)+D(I))
    C(I+1)=(Y(I+1)-Y(I))/D(I)
    C(I)=C(I+1)-C(I)
10  CONTINUE
C
  B(1)=-1.*D(1)
  B(N)=-1.*D(N-1)
  C(1)=0.
  C(N)=0.
  IF (N.EQ.3) GO TO 15
  C(1)=C(3)/(X(4)-X(2)) - C(2)/(X(3)-X(1))
  C(N)=C(N-1)/(X(N)-X(N-2)) - C(N-2)/(X(N-1)-X(N-3))
  C(1)=C(1)*D(1)**2/(X(4)-X(1))
  C(N)=-C(N)*D(N-1)**2/(X(N)-X(N-3))
C
15  DO 20 I=2,N
    T=D(I-1)/B(I-1)
    B(I)=B(I)-T*D(I-1)
    C(I)=C(I)-T*C(I-1)
20  CONTINUE
C
  C(N)=C(N)/B(N)
  DO 30 IB=1,NM1
    I=N-IB
    C(I)=(C(I)-D(I)*C(I+1))/B(I)
30  CONTINUE
C
  B(N)=(Y(N)-Y(NM1))/D(NM1)+D(NM1)*(C(NM1)+2.*C(N))
  DO 40 I=1,NM1
    B(I)=(Y(I+1)-Y(I))/D(I)-D(I)*(C(I+1)+2.*C(I))
    D(I)=(C(I+1)-C(I))/D(I)

```

```

      C(I)=3.*C(I)
40    CONTINUE
      C(N)=3.*C(N)
      D(N)=D(N-1)
      RETURN
C
50    B(I)=(Y(2)-Y(1))/(X(2)-X(1))
      C(1)=0.
      D(1)=0.
      B(2)=B(1)
      C(2)=0.
      D(2)=0.
      RETURN
      END
C
C *****
C
      REAL FUNCTION SLVSP(M,A,X,Y,B,C,D)
      INTEGER N,M
      REAL A,X(M),Y(M),B(M),C(M),D(M)
C
C THIS SUBROUTINE EVALUATES THE CUBIC SPLINE FUNCTION
C
      INTEGER I,J,K
      REAL DX
      DATA I/1/
      N=M
      IF(I.GE.N)I=1
      IF(A.LT.X(I)) GO TO 10
      IF(A.LE.X(I+1)) GO TO 30
C
10    I=1
      J=N+1
20    K=(I+J)/2
      IF(A.LT.X(K))J=K
      IF(A.GE.X(K))I=K
      IF(J.GT.I+1) GO TO 20
C
30    DX=A-X(I)
      SLVSP=Y(I)+DX*(B(I)+DX*(C(I)+DX*D(I)))
      RETURN
      END
      SUBROUTINE SADD(ITER,RN,EMAX,EAV,X,PHI)
C
c NOV. 1985
c Written by SD MILLER to calculate scaled absorbed-dose

```

Appendix E

```
c distributons for beta spectra.
c
c
c Modified Dec. 1987 by SD MILLER to work with betacomp.f
c routine for complex beta emmitters.
c
c
c   dimension rn(1500),temp(1000),X(1000),PHI(1000)
c   dimension range(40),energy(40)
c
c   data energy /.010,.015,.020,.025,.030,.035,.040,.045,
1 .050,.055,.060,.065,.070,.075,.080,.085,.090,.095,.10,
2 .15,.20,.25,.30,.35,.40,.45,.50,.60,.70,.80,.90,1.00,
3 1.5,2.0,3.0,4.0,5.0,6.0,7.0,8.0/
c
c   data range /.00024,.00050,.00083,.00124,.00171,.00225,
1 .00285,.00351,.00422,.00499,.00580,.00667,.00759,.00855,
2 .00956,.0106,.0117,.0128,.0140,.0276,.0440,.0625,.0826,
3 .104,.126,.150,.174,.223,.273,.325,.377,.430,.696,.961,
4 1.49,2.00,2.50,2.99,3.47,3.95/
c
c Compute maximum electron range based on maximum beta energy
c
c   jj=1
c
c   5   if (emax.lt.energy(1)) then
c       xmax=emax*range(1)/energy(1)
c       goto 100
c   endif
c
c   10  if (energy(jj).eq.emax) then
c       xmax=range(jj)
c       jj=jj+1
c       goto 100
c   endif
c   if (energy(jj).gt.emax) then
c       xmax=range(jj-1)+(range(jj)-range(jj-1))
c       1   *(emax-energy(jj-1))/(energy(jj)-energy(jj-1))
c       goto 100
c   else
c       jj=jj+1
c   endif
c   goto 10
100 continue
c
c   delx = xmax/float(iter)
```



```

    dele = emax/float(iter)
c
c step through each energy in the beta spectra until EMAX.
c
    do 199 i=1,iter
199     temp(i) = 0.
c
c pick an energy
c
    write(*,*)
c
    do 299 k=1,iter
c
    e = dele*(float(k)-0.5)
    prob = 0.
        do 298 m = 1,10
            prob = prob + rn( (k-1)*10 + m)
298     continue
        prob = 0.1*prob
c
c normalize the phi function before use
c
    write(*,398)k,iter
398 format(' + on iteration',i4,' of',i4)
    sum = 0.
c
    do 399 i=1,iter
    xs = float(i)*delx
c
    imax = i
    adder = spends(e,xs)
    if(adder.eq.0.0)then
        goto400
    else
c
    sum = sum + adder*delx*3.14159*4.*xs*xs
    endif
c
399 continue
c
400 if (sum.ne.0.) then
    do 499 i=1,imax
        xs = float(i)*delx
        temp(i) = temp(i) + dele*spends(e,xs)*prob*e/sum
499 continue
    endif

```

Appendix E

```
c
299 continue
c
  do 599 i=1,iter
    x(i) = float(i)*delx
    phi(i) = temp(i)/eav
599 continue
c
c
  return
end
c
c *****
c
c REAL FUNCTION SPENS(ENERGY,DISTANCE)
C
C THIS FUNCTION CALCULATES PHI OF A MONOENERGETIC ELECTRON USING DATA
C FROM THE SPENSER TABLES. PHI IS THE FRACTION OF THE TOTAL ENERGY
C DEPOSITED AT "DISTANCE" PER UNIT MASS. PHI IS CALCULATED KNOWING THE
C INITIAL ELECTON ENERGY AND THE DISTANCE FROM THE SOURCE TO THE DOSE
C POINT
C WRITTEN BY WD REECE DEC 1987. Modified by JS Durham October 1991.
C
  DIMENSION E(20),FX90(13),F(13,20)
  DIMENSION EUP(20),X90T(20)
  DIMENSION B(13,20),C(13,20),D(13,20),B1(20),C1(20),D1(20)
C
  COMMON /COMSPLI/ B,C,D,B1,C1,D1
C
  DATA E/4.,2.,1.,0.7,0.4,0.2,0.1,0.05,0.03,0.025,0.02,0.015,
&0.01,0.005,0.002,0.001,0.0005,0.0002,0.0001,0.00005/
  DATA EUP/0.,0.0001,0.0002,0.0005,0.001,0.002,0.005,
&0.010,0.015,0.02,0.025,0.03,0.05,1.,2.,4.,7,1.,2.,4./
  DATA X90T/0.,.0000003,.0000005,.0000018,0.0000049,0.000016,
&0.000071,0.00021,0.00044,0.00075,0.00107,0.00140,0.00318,0.0106,
&0.0334,0.096,.207,.328,.74,1.57/
C
  DATA FX90/0.,.1,2.,3.,4.,5.,6.,7.,8.,9,1.,1.1,1.15/
  DATA F/0.75,.75,.76,.78,.80,.83,.89,.99,1.09,1.13,.97,.45,.12,
&0.68,.69,.71,.74,.78,.84,0.92,1.04,1.16,1.20,1.00,.47,.18,
&0.61,.62,.65,.70,.76,.85,0.95,1.08,1.22,1.29,1.03,.49,.20,
&0.57,.59,.62,.68,.75,.85,0.96,1.10,1.25,1.31,1.04,.50,.21,
&0.52,.54,.58,.65,.73,.84,0.98,1.13,1.30,1.37,1.06,.51,.22,
&0.48,.50,.55,.62,.72,.84,1.00,1.20,1.35,1.39,1.09,.51,.22,
&0.45,.47,.53,.61,.71,.85,1.01,1.19,1.37,1.42,1.11,.50,.22,
&0.43,.45,.51,.59,.71,.86,1.03,1.21,1.37,1.41,1.13,.49,.20,
```

```

&0.34,.53,.62,.69,.90,1.04,1.12,1.23,1.23,1.02,.73,.43,.29,
&0.43,.46,.52,.61,.73,.87,1.04,1.22,1.35,1.40,1.14,.46,.17,
&0.52,.55,.60,.72,.82,1.07,1.17,1.25,1.22,1.00,.72,.42,.29,
&0.50,.51,.61,.72,.91,1.12,1.18,1.20,1.16,.96,.69,.43,.30,
&0.40,.51,.60,.69,.90,1.08,1.14,1.21,1.22,1.01,.72,.44,.30,
&0.44,.49,.61,.74,.85,1.09,1.23,1.25,1.17,.95,.66,.41,.30,
&0.24,.51,.63,.81,.95,1.12,1.25,1.22,1.08,.86,.61,.37,.27,
&0.19,.53,.73,.78,1.05,1.21,1.25,1.17,1.00,.77,.55,.36,.28,
&0.27,.69,.88,1.01,1.08,1.16,1.17,1.07,.88,.67,.47,.31,.25,
&0.43,.72,1.03,1.21,1.25,1.20,1.05,.88,.71,.54,.39,.28,.23,
&0.51,.85,1.13,1.29,1.25,1.13,.99,.81,.63,.48,.36,.26,.22,
&0.59,1.01,1.25,1.32,1.23,1.11,.91,.71,.54,.42,.33,.25,.21/
C
DATA IFIRST/0/
C
IF(IFIRST.EQ.0)THEN
DO 100 J = 1,20
100 CALL SPLIN2D(13,J,FX90,FB,C,D)
CALL SPLINE(20,EUP,X90T,B1,C1,D1)
IFIRST = 1
ENDIF
C
C FIND FRACTION OF X90 DISTANCE
C
IF (ENERGY.LT.0.00005) THEN
C
C ENERGY IS LESS THAN 0.05 KEV
C
SPENS=0.0
RETURN
ENDIF
C
DO 10 I=2,20
IF(ENERGY.GE.E(I))GOTO15
10 CONTINUE
15 DELE=(ENERGY-E(I-1))/(E(I)-E(I-1))
DS = SLVSP(20,ENERGY,EUP,X90T,B1,C1,D1)
FRACTION=DISTANCE/DS
DX90=1.0/DS
FACT = DX90/FRACTION
C
16 IF(FRACTION.GE.1.17)THEN
SPENS=0.
RETURN
ELSE
IF(FRACTION.GE. 1.15 )THEN

```

Appendix E

```

C
C FRACTION IS BETWEEN 1.15 AND 1.17
C
  SPENS=(F(13,I-1)+DELE*(F(13,I)-F(13,I-1)))*(1.17-FRACTION)*50.
  SPENS=SPENS/(4.0*3.14159)
  SPENS=SPENS*DX90*FACT*FACT
  RETURN
ENDIF

C
21 SPENS=(1.-DELE)*SLVSP2D(13,I-1,FRACTION,FX90,FB,C,D)
  & + DELE*SLVSP2D(13,I,FRACTION,FX90,FB,C,D)
  SPENS=SPENS*DX90*FACT*FACT/(4.0*3.14159)
C
  RETURN
ENDIF
END
C*****
SUBROUTINE SPLIN2D(M,IE,X,Y,B,C,D)
  INTEGER N,M
  REAL X(13),Y(13,20),B(13,20),C(13,20),D(13,20)
  INTEGER NM1,IB,I
  REAL T
C
  N=M
  NM1=N-1
  IF(N.LT.2) RETURN
  IF(N.LT.3) GO TO 50
C
  D(1,IE)=X(2)-X(1)
  C(2,IE)=(Y(2,IE)-Y(1,IE))/D(1,IE)
  DO 10 I=2,NM1
    D(I,IE)=X(I+1)-X(I)
    B(I,IE)=2.*(D(I-1,IE)+D(I,IE))
    C(I+1,IE)=(Y(I+1,IE)-Y(I,IE))/D(I,IE)
    C(I,IE)=C(I+1,IE)-C(I,IE)
10 CONTINUE
C
  B(1,IE)=-1.*D(1,IE)
  B(N,IE)=-1.*D(N-1,IE)
  C(1,IE)=0.
  C(N,IE)=0.
  IF (N.EQ.3) GO TO 15
  C(1,IE)=C(3,IE)/(X(4)-X(2)) - C(2,IE)/(X(3)-X(1))
  C(N,IE)=C(N-1,IE)/(X(N)-X(N-2)) - C(N-2,IE)/(X(N-1)-X(N-3))
  C(1,IE)=C(1,IE)*D(1,IE)**2/(X(4)-X(1))
  C(N,IE)=-C(N,IE)*D(N-1,IE)**2/(X(N)-X(N-3))

```

```

C
15 DO 20 I=2,N
    T=D(I-1,IE)/B(I-1,IE)
    B(I,IE)=B(I,IE)-T*D(I-1,IE)
    C(I,IE)=C(I,IE)-T*C(I-1,IE)
20 CONTINUE
C
    C(N,IE)=C(N,IE)/B(N,IE)
    DO 30 IB=1,NM1
        I=N-IB
        C(I,IE)=(C(I,IE)-D(I,IE)*C(I+1,IE))/B(I,IE)
30 CONTINUE
C
    B(N,IE)=(Y(N,IE)-Y(NM1,IE))/D(NM1,IE)+D(NM1,IE)*(C(NM1,IE)+
&      2.*C(N,IE))
    DO 40 I=1,NM1
        B(I,IE)=(Y(I+1,IE)-Y(I,IE))/D(I,IE)-D(I,IE)*(C(I+1,IE)+
&      2.*C(I,IE))
        D(I,IE)=(C(I+1,IE)-C(I,IE))/D(I,IE)
        C(I,IE)=3.*C(I,IE)
40 CONTINUE
    C(N,IE)=3.*C(N,IE)
    D(N,IE)=D(N-1,IE)
    RETURN
C
50 B(1,IE)=(Y(2,IE)-Y(1,IE))/(X(2)-X(1))
    C(1,IE)=0.
    D(1,IE)=0.
    B(2,IE)=B(1,IE)
    C(2,IE)=0.
    D(2,IE)=0.
    RETURN
    END
C
C *****
C
C REAL FUNCTION SLVSP2D(M,IE,U,X,Y,B,C,D)
    INTEGER N,M
    REAL U,X(13),Y(13,20),B(13,20),C(13,20),D(13,20)
C
C THIS SUBROUTINE EVALUATES THE CUBIC SPLINE FUNCTION
C
C INTEGER I,J,K
    REAL DX
    DATA I/1/
    N=M

```

Appendix E

```
      IF(I.GE.N)I=1
      IF(U.LT.X(I)) GO TO 10
      IF(U.LE.X(I+1)) GO TO 30
C
10    I=1
      J=N+1
20    K=(I+J)/2
      IF(U.LT.X(K))J=K
      IF(U.GE.X(K))I=K
      IF(J.GT.I+1) GO TO 20
C
C EVALUATE SPLINE
C
30    DX=U-X(I)
      SLVSP2D=Y(I,IE)+DX*(B(I,IE)+DX*(C(I,IE)+DX*D(I,IE)))
      RETURN
      END
```

DISTRIBUTION

No. of
Copies

OFFSITE

J. M. Bell
Division of Radiation Protection &
Emergency Preparedness
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555

A. K. Roecklein
Radiation Protection & Health
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

W. D. Reece
Texas A&M University
Department of Nuclear Engineering, Room 129
College Station, TX 77843-3133

ONSITE

50 Pacific Northwest Laboratory

G. Akabani
J. S. Durham (39)
R. D. Stewart
W. E. Wilson
Health Physics Department Library
Publishing Coordination (2)
Technical Report Files (5)

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202		U. S. NUCLEAR REGULATORY COMMISSION					
BIBLIOGRAPHIC DATA SHEET (See instructions on the reverse)		1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Num- bers, if any.) NUREG/CR-5873 PNL-7913					
2. TITLE AND SUBTITLE VARSKIN MOD2 and SADDE MOD2: Computer Codes for Assessing Skin Dose from Skin Contamination		3. DATE REPORT PUBLISHED <table border="1"> <tr> <td>MONTH</td> <td>YEAR</td> </tr> <tr> <td>December</td> <td>1992</td> </tr> </table>		MONTH	YEAR	December	1992
MONTH	YEAR						
December	1992						
5. AUTHOR(S) J.S. Durham		4. FIN OR GRANT NUMBER L1543					
6. TYPE OF REPORT		7. PERIOD COVERED (Inclusive Dates)					
8. PERFORMING ORGANIZATION - NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.) Pacific Northwest Laboratory Richland, WA 99352							
9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.) Division of Regulatory Applications Office of Nuclear Regulatory Research U.S. Nuclear Regulatory Commission Washington, DC 20555							
10. SUPPLEMENTARY NOTES							
11. ABSTRACT (200 words or less) <p>The computer code VARSKIN has been modified to calculate dose to skin from three-dimensional sources, sources separated from the skin by layers of protective clothing, and gamma dose from certain radionuclides. A correction for backscatter has also been incorporated for certain geometries. This document describes the new code, VARSKIN MOD2, including installation and operation instructions, provides detailed descriptions of the models used, and suggests methods for avoiding misuse of the code. The input data file for VARSKIN MOD2 has been modified to reflect current physical data, to include the contribution to dose from internal conversion and Auger electrons, and to reflect a correction for low-energy electrons.</p> <p>In addition, the computer code SADDE: Scaled Absorbed Dose Distribution Evaluator has been modified to allow the generation of scaled absorbed dose distributions for mixtures of radionuclides including internal conversion and Auger electrons. This new code, SADDE MOD2, is also described in this document. Instructions for installation and operation of the code and detailed descriptions of the models used in the code are provided.</p>							
12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.) VARSKIN MOD2, SADDE MOD2, computer codes, skin dose, beta dose		13. AVAILABILITY STATEMENT Unlimited					
		14. SECURITY CLASSIFICATION (This Page) Unclassified (This Report) Unclassified					
		15. NUMBER OF PAGES					
		16. PRICE					