

Radiological Toolbox User's Manual

August 31, 2006

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ABSTRACT

A toolbox of radiological data has been assembled to provide users access to physical, chemical, anatomical, physiological and mathematical data relevant to the radiation protection of workers and member of the public. The software runs on a PC and provides, through a single graphical interface, quick access to contemporary radiation protection data and the means to extract these data for further use in computations and analysis. The numerical data, for the most part, are stored within databases in SI units. However, the user can display and extract values in non-SI units. This second release of the toolbox includes additional computational capabilities and numerical data of general interest. The toolbox was developed for the U.S. Nuclear Regulatory Commission.

1. INTRODUCTION

The Radiological Toolbox, hereafter referred to as the Rad Toolbox or simply toolbox, was developed for the U.S. Nuclear Regulatory Commission (NRC). This computer application provides access to physical, chemical, anatomical, physiological and mathematical data (and models) relevant to the protection of workers and the public from exposures to ionizing radiation. A graphical interface enables viewing of the data and the means to extract data for further use in computations and analysis. The numerical data, for the most part, are stored in SI units. However the user can display and extract the data using non-SI units. The data are stored in Microsoft Access databases and in flat ASCII files. This second release of the toolbox features additional computational capabilities and numerical data of interest. The following data elements are included:

- Biological Data
 - Biokinetic Models and Bioassay Data
 - Composition of Tissues
 - ICRP 72 Organ Masses Values and ICRP 89 Reference Values
 - Radiation Health Effects
- Nuclear Decay Data – ICRP 38 (ICRP 1983) and JAERI (Endo 1999, 2001)
 - Energy-Intensity Data
 - Decay Chains: Tables and Graphic
- Dose Coefficients
 - Internal Irradiation
 - Radiation workers - ICRP Publications 30 and 68 (ICRP 1978, 1994)
 - Members of the public – ICRP Publication 72 (ICRP 1996a)
 - External Irradiation – Federal Guidance Report 12 (EPA 1993)
 - Submersion, immersion, ground plane, and soil
- Early Inhalation: Absorbed-Dose Coefficients for Deterministic Effects
 - User-Specified Integration Periods
- Element Data
 - Radiation Interaction Coefficients
 - Alpha and electron range and stopping power data
 - Photon interaction cross-sections and build-up coefficients
 - Photon and neutron kerma
 - Atomic Masses
- Material Data
 - Interaction Coefficients (see coefficients listed for elements)
 - Composition of Materials
- Public Exposure Data
 - Natural Background Radiation Dose
 - Radionuclides in Materials and Devices
 - Medical Exposures
- Dose Coefficients for Photon and Neutron Fields – ICRP Publication 74 (ICRP 1996b)
 - Operational Quantities
 - Organ Doses for Various Exposure Geometries
- Supplemental Data
 - SI Units and Conversion Factors
 - Formulas
 - Web References
 - DOE Dose Range Graphic
 - A1/A2 Transport Package Values (10 CFR Part 71)

For the most part, the Rad Toolbox accesses numerical databases and converts the requested values to the units specified by the users. Computational modules are included to calculate inhalation dose coefficients for deterministic effects over the time period specified by the user and to compute radiation interaction coefficients for materials based on their elemental composition. Additional computational capability has been included in this release to enable calculation of radiation interaction coefficients for a material of user-defined elemental composition, the activity of members of decay chains at user-specified times, and the doses for a user-specified mixture of radionuclides. Additional information has also been included, e.g., information on the excretion and retention of selected radionuclides in workers. The software's help files provide access to textual information on topics ranging from those of a general nature to the details of models describing the fate of radionuclides in the body. Two new help facilities provide online access to an index of the toolbox and to the portable document file (pdf) of this manual.

1.1 Release Notes

This is the second general release of the toolbox. Some minor restructuring of the information content of the toolbox was undertaken with inclusion of additional information and enhancements suggested by users. Of particular note is the additional computational capability provided in this release.

1.1.1 Software Installation

The toolbox is installed by running the distributed set-up module TB_SETUP. During installation the system may report messages for which the 'ignore' option is the appropriate response. The installation will place a menu item on Windows' *Start/Programs* menu. Clicking on that item will invoke the software to display the screen in Fig. 1. In Fig. 1, the column of buttons on the left provide access to different data within the folders to the right. The software can be removed from the computer by clicking on *My Computer/Control Panel/Add/Remove Programs* and selecting "remove this software."

To view this document within the Rad Toolbox, Adobe Reader® software should reside on the computer and files with extension pdf registered to be opened by that software. Adobe Reader® 7.0 can be downloaded from <http://www.adobe.com/downloads/>.

1.1.2 Known Bugs in Version 2.0

There remains one known "bug" in this release:

In some instances, the graphical display of the decay chain associated with the parent radionuclide may contain artifacts, e.g., as in the Am-242m chain. However, the software should not crash as the chain is assembled. Caution: The decay chain graphics have not been tested for all potential parent nuclides.

1.2 Support

If you encounter any problems running the Rad Toolbox, please contact Andrea Sjoreen (sjoreenal@ornl.gov or 865-574-5333) at Oak Ridge National Laboratory. If you have technical questions or comments, please contact Keith Eckerman (eckermankf@ornl.gov or 865-574-6251) at Oak Ridge National Laboratory. Comments on style, usability, and other features that might be useful additions are appreciated.

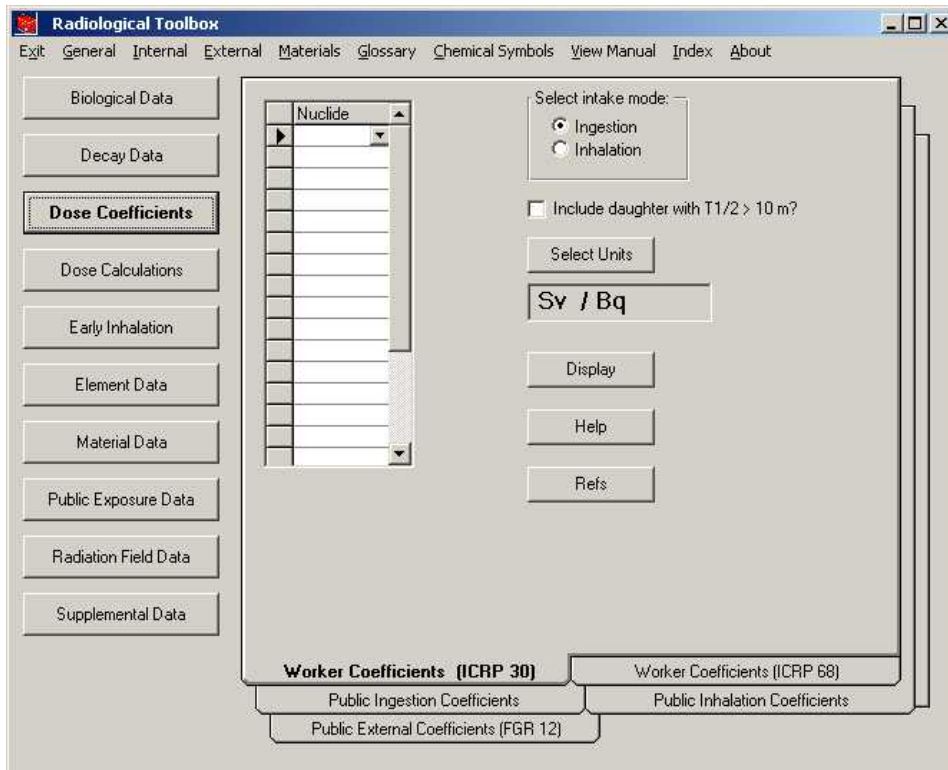


Fig. 1. Rad Toolbox initial screen.

2. TOOLBOX CONTENT

When the toolbox is initiated, the screen of Fig. 1 appears. For the discussion below, the column of buttons on the left side of the screen is said to refer to different *sections* of the toolbox, and the structure on the right to *folders*. Note these terms do not refer to database structures but are only used to facilitate the discussion. The headings of Sect. 2.2 – 2.11 below correspond to the names of sections of the toolbox as indicated in Fig. 1.

2.1 Menu and Help Items

The menu bar at the top of the screen (see Fig. 1) allows access to the software help files in addition to other standard functions. The menu items are:

Exit – leave the toolbox

General

Internal

Coefficients

Biokinetic Models

GI Model

Bladder Model

Lung Model

Systemic Model

External – Dose Coefficients

Nuclide Coefficients

Field Coefficients

Materials

Glossary

Dosimetric Glossary

Absorber Glossary

Chemical Symbols

View Manual – Display pdf of this manual

Index – Display an index of the toolbox contents

About – Display toolbox version, acknowledgments, and system info.

2.2 Biological Data

The *Biological Data* section (Fig. 2) of the toolbox contains data on the following:

Biokinetic Models

Bioassay Data

Composition of Tissues

Organ Masses

ICRP 89 Reference Values

Radiation Health Effects

These data are displayed in tables many of which can be exported to Excel. The biokinetic models are from ICRP Publications 68 (ICRP 1994) and 72 (ICRP 1996a). Urinary and fecal excretion data and retention data in the bioassay data collection were calculated using DCAL (Eckerman *et al* 2006) for a limited set of radionuclides based on the models of Publication 68. The information on the compositions of tissues is from Coursey *et al.* (2001). The organ mass data are from Publication 72. An extensive set of reference values from ICRP Publication 89 (2002) as well as information on the deterministic (Abrahamson *et al.* 1989, Scott 2004) and stochastic health effects (BEIR 2006) of ionizing radiation have been included in this release.

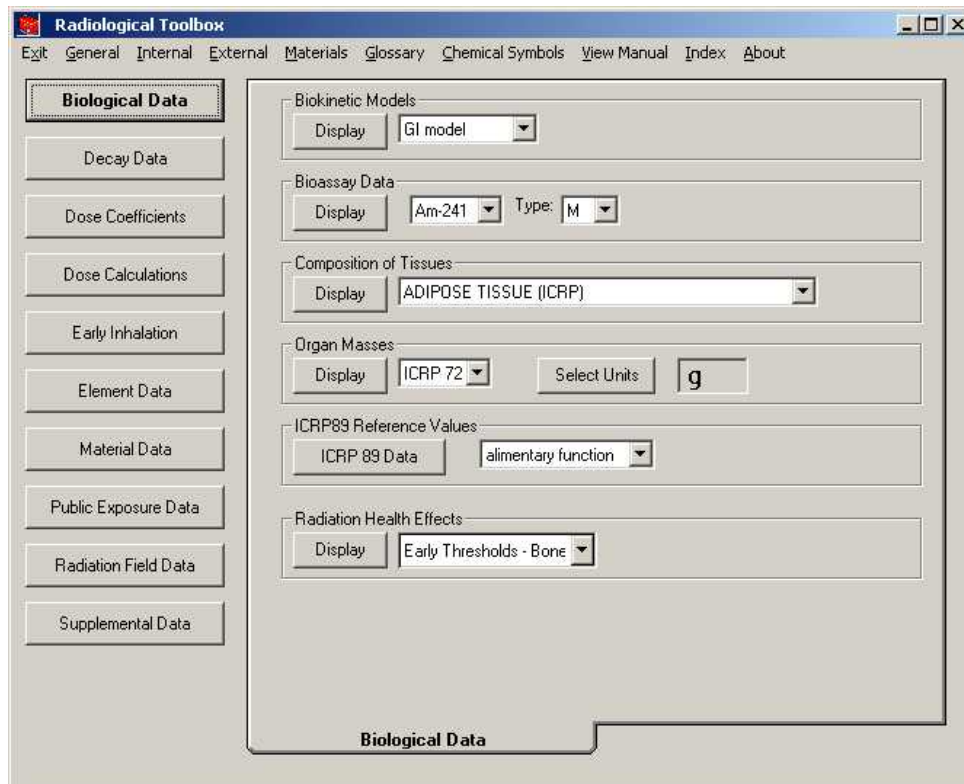


Fig. 2. The initial screen for biological data.

2.3 Decay Data

The *Decay Data* section (Fig. 3) of the toolbox provides detailed data on the energy and intensities of the radiations emitted during nuclear transformations (decays). Two sets of data are included: the first from ICRP Publication 38 (ICRP 1983) and the second from a compilation by the Japan Atomic Energy Research Institute (JAERI) (Endo *et al.* 1999; Endo and Yamaguchi 2001). The data are in the format of the file structure of Eckerman *et al.* (1994).

Information on the energy and intensity of the emitted radiations are displayed in separate tables for alpha particles, beta transitions (average energy), photons, and mono-energetic electrons. The type of radiation is identified in each table and its associated code, the variable *ICODE* – as defined by Eckerman *et al.* (1994), is displayed. The beta table contains information on both $\beta+$ and $\beta-$ transitions; however, the plotted spectrum includes all beta transitions. X-rays, gamma rays, and annihilation quanta are included in the photon table with their assigned *ICODE*. The data for internal conversion and Auger electrons are included in the mono-energetic electron table. The caption of each table lists the number of radiations of the indicated type emitted in the decay processes.

The activity of the selected radionuclide (including its radioactive daughter products) can be calculated by selecting *Activity* as the data type, entering the time of interest, and pressing *Display*. The calculation assumes a unit activity of the radionuclide (the parent in the case of a chain) at time 0. The displayed results can then be scaled by a user-specified value. This feature is discussed further in Sect. 3.4.

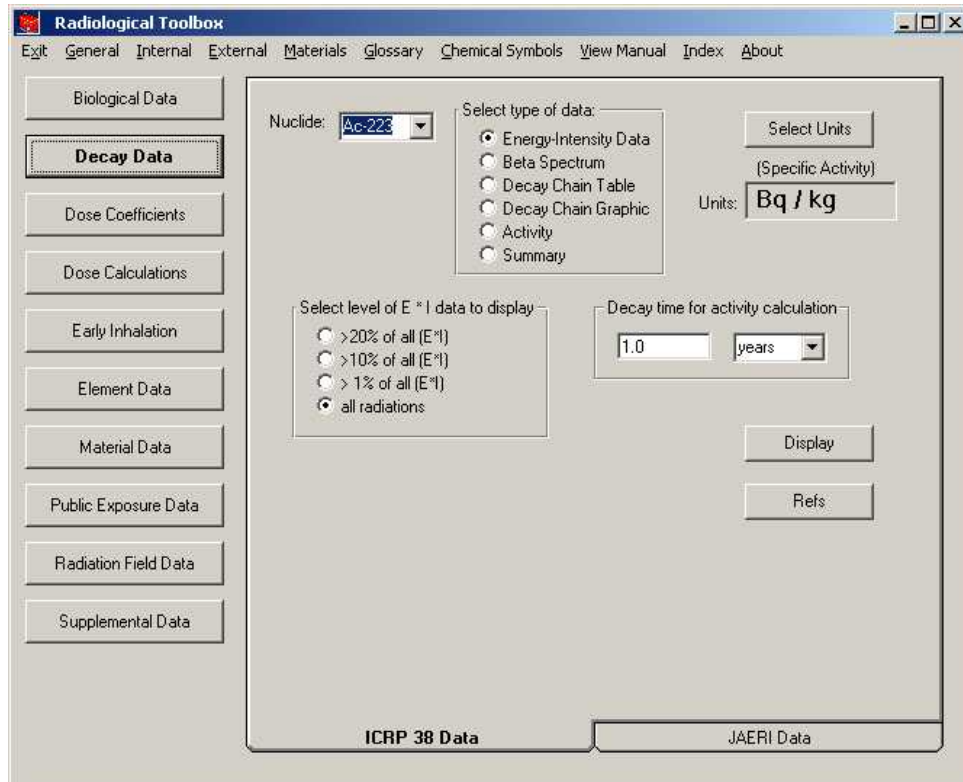


Fig. 3. The initial screen for decay data.

All tables of energy-intensity data are sorted by increasing energy of the emitted radiation. The tables include all the radiations without regard to the potential significance. It is possible to specify a fractional energy cutoff in percent thus limiting the tables to those radiations that contribute more than the percent cutoff to the total emitted energy. For example, a cutoff of 1% would result in the table containing only radiations contributing more than 1% to the total energy for that radiation type. It is possible to sort the data by increasing intensity (yield) or by energy (the default sort variable) by clicking on the column heading. Each table may be separately exported to Excel. (When the *Export* button is pressed only the displayed table is exported.)

The beta spectrum is displayed as a graph, but the spectrum is exported as a tabulation of the number of electrons $Y(E) dE$ emitted with energy between E and $E+dE$ as a function of energy E . That is, as a differential energy spectrum.

The decay chain table includes the specific activity, half-life, decay mode, and identification of radioactive daughters with their branching fractions. The *Summary* option provides for the radionuclide a summary of the emission of each radiation type (alpha, electrons, photons, etc.), its specific activity (default units are Bq/kg), and, in the case of a photon emitter, the gamma constant. This table can not be exported.

The decay chain graphic includes half-lives and branching fractions (Fig. 4). The stable end product of the chain is included in the graphic but it is not included in the decay chain table. The graphic can not be exported.

The decay data summary contains half-life, decay mode, specific activity, total emitted energy, gamma constant, and a summary table of the four radiation types.

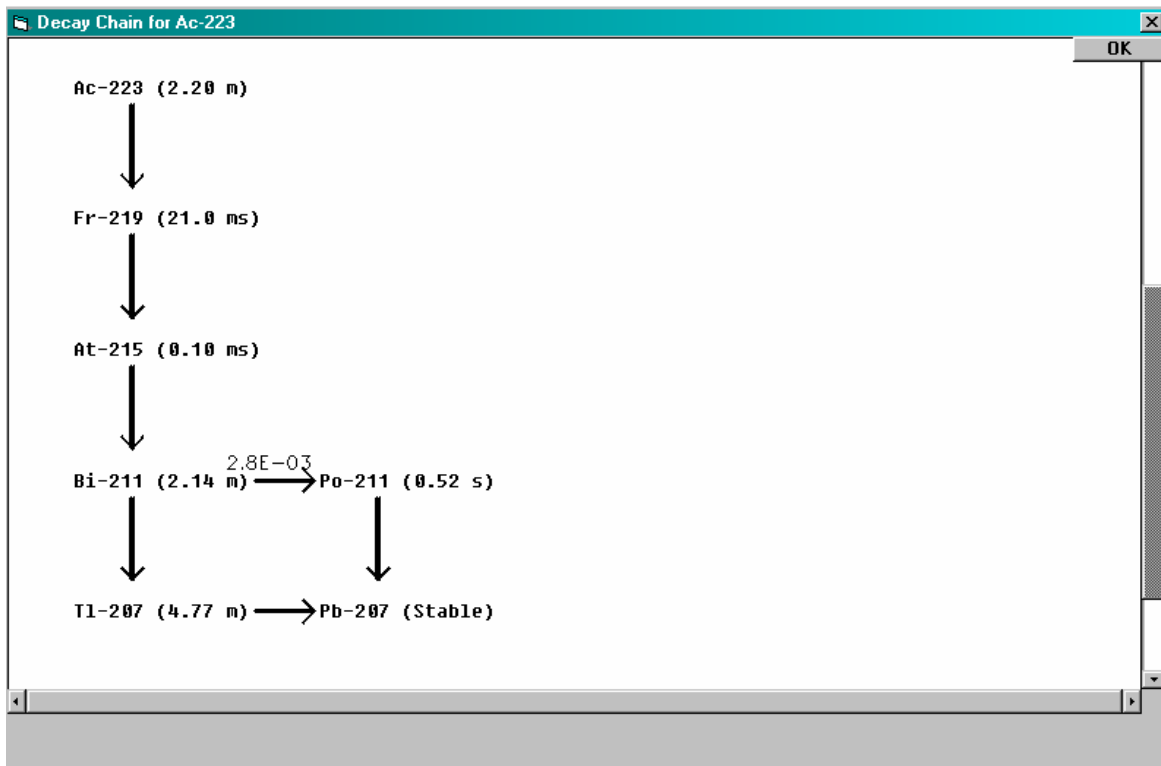


Fig. 4. An example of a decay chain plot.

2.4 Dose Coefficients

The *Dose Coefficients* section (Fig. 5) of the toolbox provides access to five sets of nuclide-specific dose coefficients. They are: external dose rate coefficients for 826 radionuclides from Federal Guidance Report 12 (EPA 1993), the committed dose coefficients for inhalation and ingestion intakes of 738 radionuclides by workers in ICRP Publications 30 and 68 (ICRP 1978; 1994), and age-dependent committed dose coefficients for the inhalation and ingestion intakes of 738 radionuclides¹ by members of the public (six ages at intake) in ICRP Publication 72 (ICRP 1996a). The coefficients corresponding to ICRP Publications 68 and 72 were extracted, with permission, from the ICRP CD (ICRP 2001). The coefficients corresponding to ICRP Publication 30 were available in data files at ORNL. For each set of coefficients it is possible to display up to 20 nuclides at a time for a chosen route of exposure or intake. The displayed table can be exported to an Excel spreadsheet. The default units used are the SI units, i.e., the units of the original data. However, the user may specify non-SI units for display and export.

Coefficients are displayed for the organ equivalent dose and the effective dose for each radionuclide selected. For exposure to radionuclide contamination outside the body, the coefficients are for the adult as considered in Federal Guidance Report 12 (EPA 1993). For inhalation intakes of radionuclides the dose coefficients are displayed for all particulate absorption types (or clearance class in the ICRP 30 data set) and for gases and vapors, if applicable. For ingestion intakes, the coefficients for all chemical forms, characterized by the f_1 value defining the fractional absorption from gastrointestinal (GI) tract, are shown for the selected radionuclide. The absorption type or class, f_1 value, and half-life are included in the display and in tables exported to Excel.

¹ The numbers of nuclides differ between Federal Guidance Report 12 and ICRP Publications 30, 68, and 72 as the latter set of publications do not consider the intake of radionuclides of half-life less than 10 minutes.

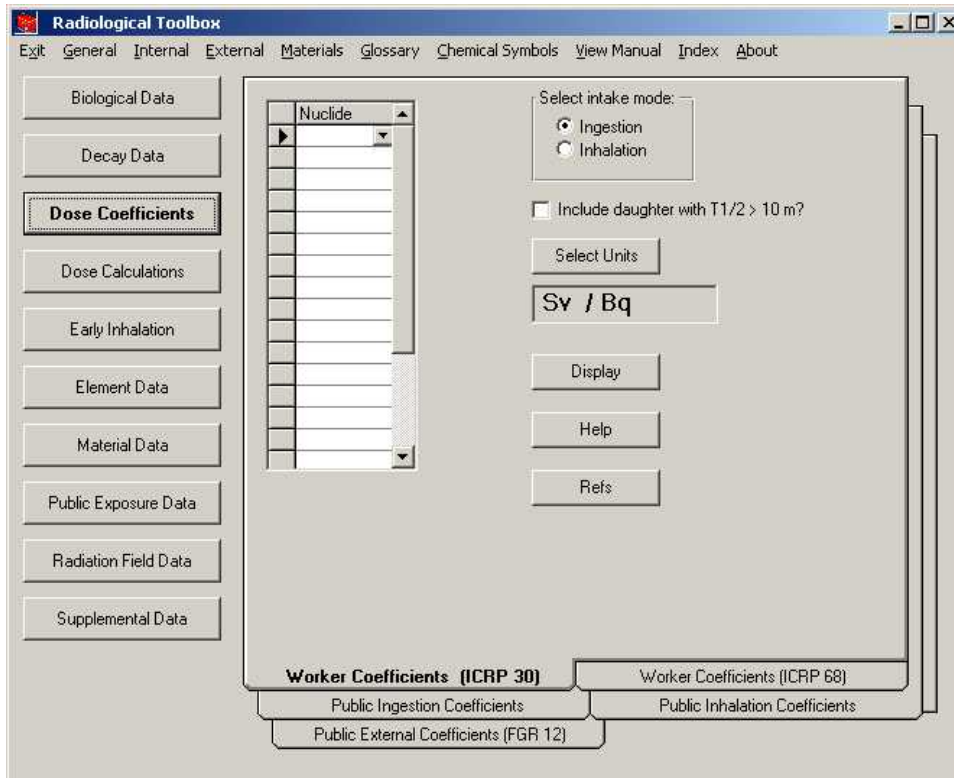


Fig. 5. The initial screen for dose coefficient data.

Note that the set of nuclides selected for display and the selected units for the coefficients ‘stick’ across the dose coefficient data sets. That is, once a set of nuclides or units has been specified, this request applies to all dose coefficients to be displayed until the user changes the request. If inhalation and ingestion coefficients are not available for a nuclide initially specified in the external coefficient folder the nuclide is ignored.

2.5 Dose Calculations

The *Dose Calculations* section (Fig. 6) was developed for this release of the toolbox to enable rather simple numerical calculations of dose for a mixture of radionuclides. The user selects the folder with the appropriate dose coefficients and then identifies the nuclides and their activity. The mixture can consist of up to 20 radionuclides. In the case of external exposure the dose coefficients are uniquely identified by the route of exposure and the radionuclide. Thus it is possible to include the total dose for the mixture in the table. This is not the situation for the intake of radionuclide where multiple coefficients exist for a nuclide due to different chemical forms. Thus for inhalation and ingestion intakes it is not possible to include the total dose in the table but rather the table includes the dose for intake of each chemical form. The user should export the table to Excel, deletes data columns for irrelevant chemical forms, and derive the total dose within Excel.

The *Activity* feature of the *Decay Data* section can be used to derive the activity (and time-integrated activity) of the members of a decay chain. That information can be imported to the *Dose Calculations* section (see *Paste Decay Results* button) and the calculations for the chain displayed. This new feature is discussed further in Sect. 3.4.

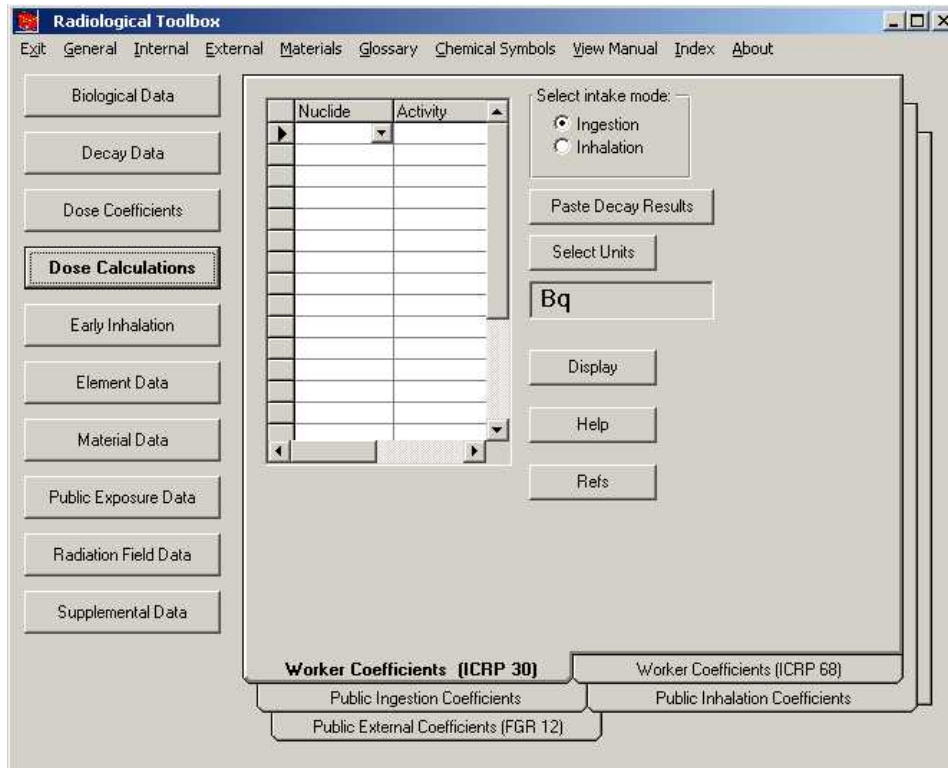


Fig. 6. The initial screen for calculation of dose.

2.6 Early Inhalation

The *Early Inhalation* section (Fig. 7) of the toolbox provides a means to derive inhalation dose coefficients for deterministic health effects (early effects). The coefficients are presented in terms of absorbed dose; separate values are given for radiations of low and high linear energy transfer LET. Appropriate values of the relative biological effectiveness *RBE*, see the suggested values (IAEA 2005) under *Radiation Health Effects* in the *Biological Data* section, can then be applied to the absorbed dose components. Absorbed coefficients for the small intestine, red marrow, lung (mass average), and alveolar interstitial region can be displayed. The coefficients are derived from dosimetric data for the adult archived on the Federal Guidance Report 13 CD (EPA 2000). These data were based on an aerosol characterized by an activity median aerodynamic diameter (AMAD) of 1 μm . The user may specify integration times (up to 20 times) from 1 day to 10 years. The units of these absorbed dose coefficients may be changed and the values exported to Excel.

A complete set of age-specified absorbed dose coefficients for all organs/tissues and either inhalation or ingestion intakes can be obtained using EPA's Acute Dose Calculator. This software can be downloaded from EPA's web site (<http://www.epa.gov/radiation/federal/techdocs.htm#adc>).

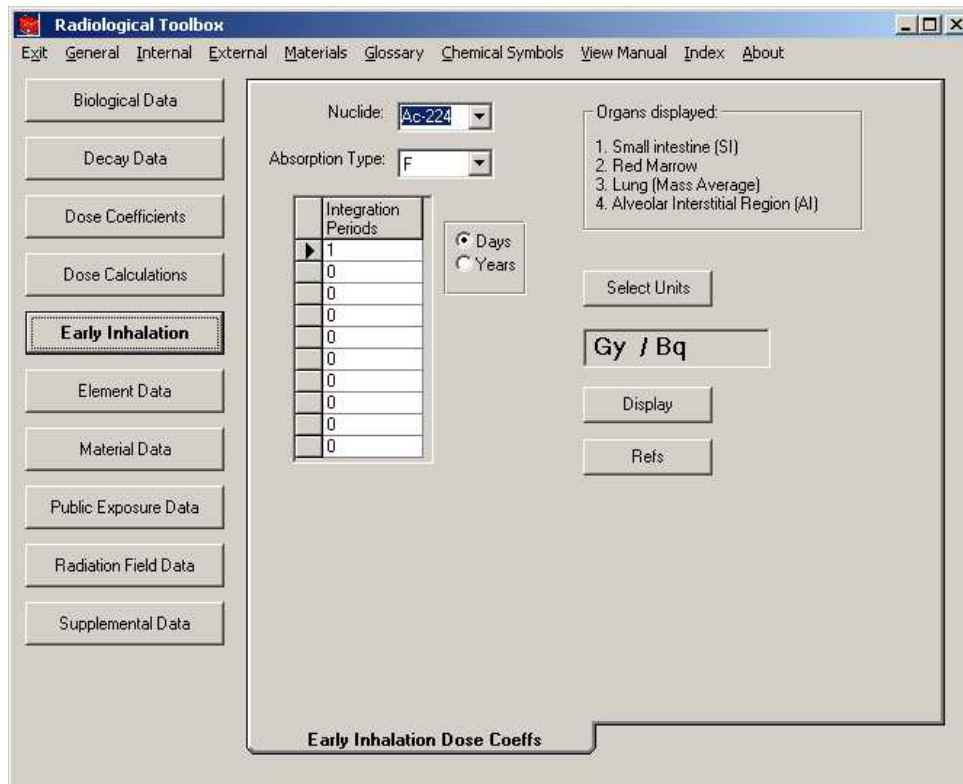


Fig. 7. The initial screen for absorbed dose coefficients for early effects.

2.6 Element Data

The *Element Data* section of the toolbox provides access to interaction coefficients for alpha, electron, photon and neutron radiations by element (Fig. 8). The user may select the type of data (coefficient) for display and its units. Once the data table (Fig. 9.) is displayed, the data may be plotted (Fig. 10) as a function of energy, by double clicking on the data column of interest. The entire table may be exported to Excel. Coefficients are not available for every element or for each radiation type. The photon cross section, alpha, and electron data are from Berger *et al.* (1999, 2005). The parameters of the geometric progression (GP) form of the build-up factor (Harima *et al.* 1991) are from ANSI Standard 6.4 (1991). The user can display the parameter values or a table of the buildup factors for photon of energy between 0.015 and 15 MeV at distances ranging from 0.5 to 60 mean free paths (MFP). The *Photon Buildup* folder contains a graphic of the equation for the GP build-up factor. The kerma coefficients (photon and neutron) were taken from KERMAL, RSICC package DLC-143 [Howerton (1986a and 1986b)].

The *Element Data* section also provides access to atomic mass and isotopic abundance data. These data, which can be exported to Excel, are from Coursey *et al.* (2001). Stable, primordial, and cosmogenic radioactive isotopes are marked with a colored background. This information was abstracted from the 16th edition of the *Chart of the Nuclides* (Baum *et al.* 2002).

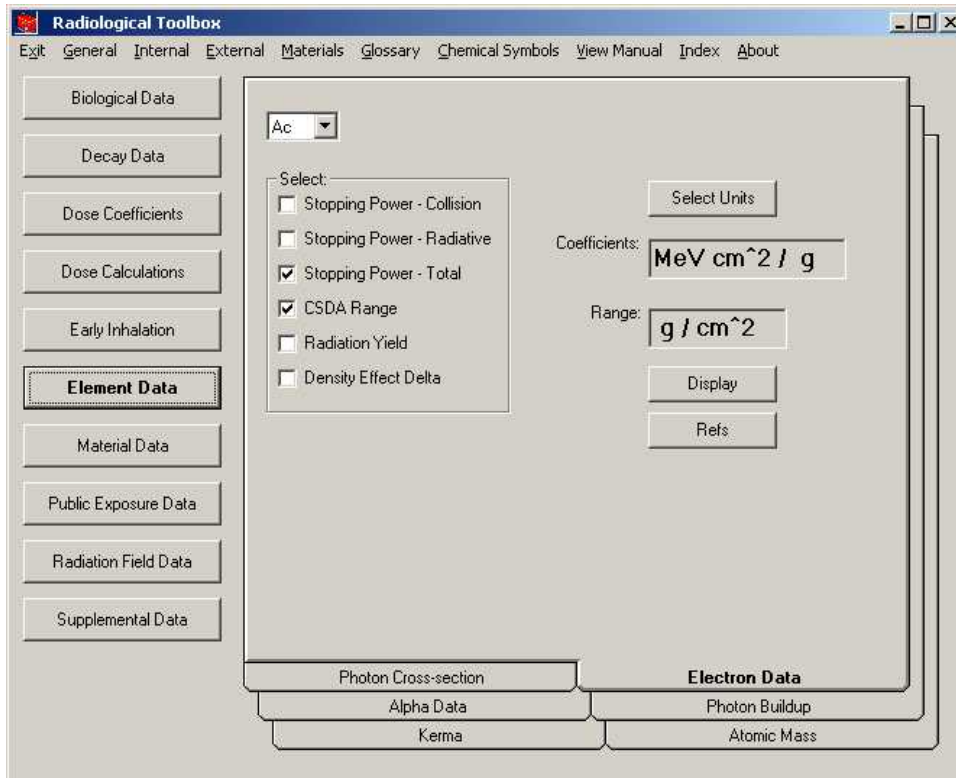


Fig. 8. The initial screen for element data section.

Kinetic Energy (MeV)	Stopping Power - Total (MeV cm ² /g)	CSDA Range (g/cm ²)
1.00E-02	8.30E+00	8.47E-04
1.25E-02	7.26E+00	1.17E-03
1.50E-02	6.48E+00	1.54E-03
1.75E-02	5.88E+00	1.94E-03
2.00E-02	5.40E+00	2.39E-03
2.50E-02	4.67E+00	3.39E-03
3.00E-02	4.15E+00	4.52E-03
3.50E-02	3.76E+00	5.79E-03
4.00E-02	3.45E+00	7.18E-03
4.50E-02	3.20E+00	8.69E-03
5.00E-02	2.99E+00	1.03E-02
5.50E-02	2.82E+00	1.20E-02
6.00E-02	2.67E+00	1.39E-02
7.00E-02	2.43E+00	1.78E-02
8.00E-02	2.25E+00	2.21E-02
9.00E-02	2.10E+00	2.67E-02
1.00E-01	1.99E+00	3.16E-02
1.25E-01	1.77E+00	4.50E-02
1.50E-01	1.62E+00	5.98E-02
1.75E-01	1.51E+00	7.58E-02
2.00E-01	1.43E+00	9.29E-02
2.50E-01	1.32E+00	1.29E-01
3.00E-01	1.25E+00	1.68E-01
3.50E-01	1.20E+00	2.09E-01
4.00E-01	1.17E+00	2.52E-01
4.50E-01	1.15E+00	2.95E-01
5.00E-01	1.13E+00	3.39E-01
5.50E-01	1.12E+00	3.83E-01
6.00E-01	1.12E+00	4.28E-01

Fig. 9. An example of a data table for actinium (Ac)

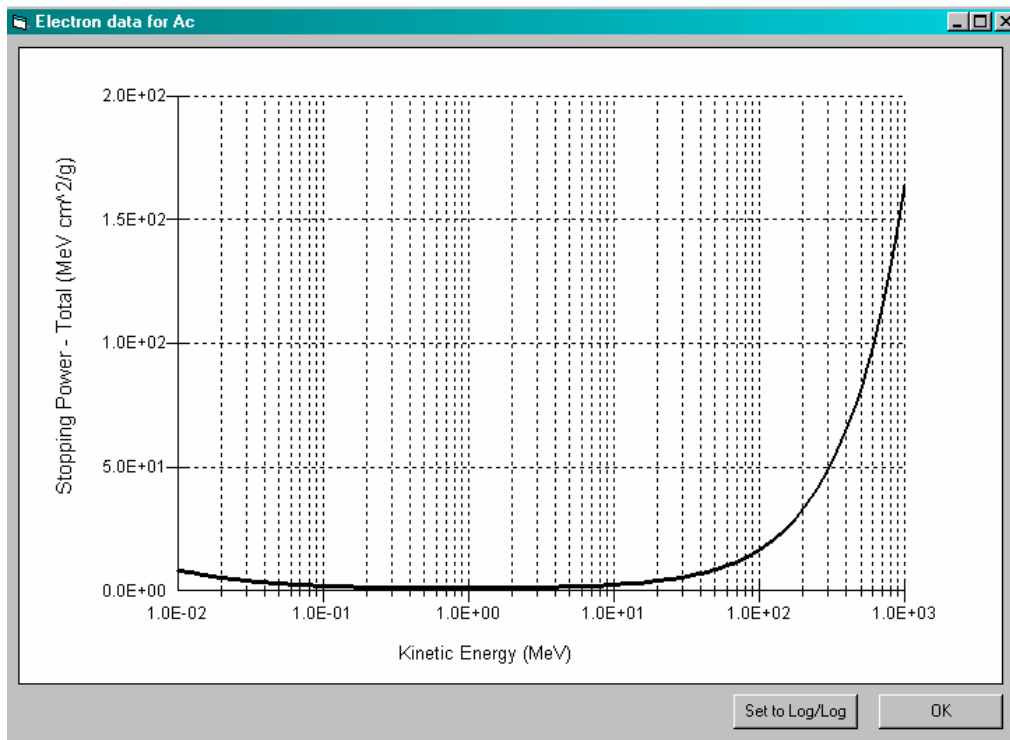


Fig. 10. An example of a data plot for actinium (Ac).

2.7 Material Data

The *Material Data* section (Fig. 11) provides access to various radiological properties of materials. Interaction and kerma coefficients for the materials are derived using the elemental compositions specified by Coursey *et al.* (2001) (originally published as Coplen 2001; Rosman and Taylor 1998; and Audi and Wapstra 1995). Thus, the material definitions in the kerma references (Howerton, 1986a, 1986b) are not used. Since kerma values were only available for element of atomic numbers less than 30, only materials composed of these elements are considered. In computing the coefficients for neutrons, the isotopes of the composition were assumed to be either the natural occurring isotope or the most abundant isotope of the element. These data may be exported to Excel spreadsheets.

Photon build-up factors (geometric progression GP form) are derived for materials using procedures outlined by Sidhu *et al.* (1999, 2000). These procedures enable estimates of the parameters of the GP form for the mixture based on the parameters for the 23 elements specified in the ANSI standard (ANSI, 1964). The parameters of the GP form or a table of the build-up factors for photon of energy between 0.015 and 15 MeV at distance ranging from 0.5 to 60 mean-free paths (MFP) can be displayed and exported to Excel.

Provisions are included in this release to enable the user to define a material and calculate its interaction coefficients. See Sect. 3.5 for an illustration of this feature.

2.9 Public Exposure Data

The *Public Exposure Data* section (Fig. 12) contains data such as:

- Natural Background Radiation*
- Background Radiation in the Body*
- Radionuclides in Materials*
- Radionuclides in Devices*
- Primordial Radionuclides*
- Typical Exposures during Medical Procedures*

The annual dose from natural background radiation in the United States and radionuclides in the body are from Report 94 of the National Council on Radiation Protection and Measurement (NCRP 1988). Information on radionuclides in material and the primordial radionuclides are from the Radiation Information Network (ISU 2003). The information on radionuclides in devices is from a report of the International Atomic Energy Agency (IAEA 2003). The typical exposures during medical procedures are from the DOE Dose Range Graphic (the graphic is included in the toolbox – see *Supplemental Data* section).

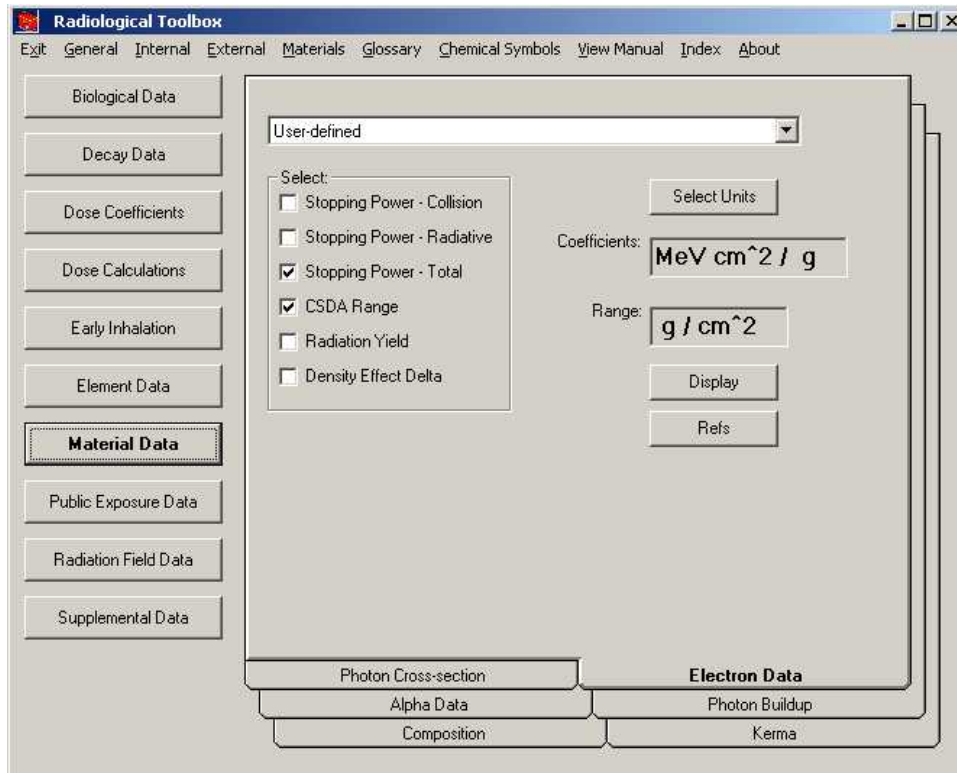


Fig. 11. The initial screen for material data.

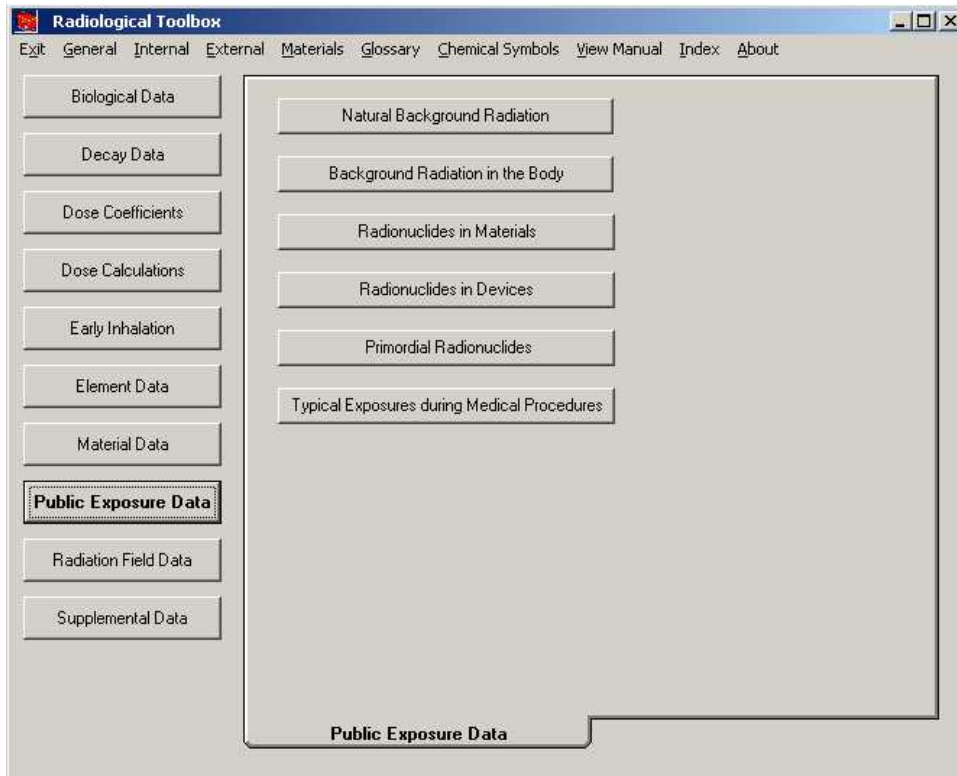


Fig. 12. The initial screen for public exposure data.

2.10 Radiation Field Data

The *Radiation Field Data* section (Fig. 13) provides access to conversion coefficients for the operational quantities and organ dose coefficients for mono-energetic neutron and photon radiation fields. These data, compiled by a joint task group of ICRP and International Commission on Radiological Units (ICRU), were abstracted from ICRP Publication 74 (ICRP 1977b). Organ dose coefficients are available for antero-posterior, postero-anterior, left-lateral, right-lateral, rotational, and isotropic exposure geometries. Graphics defining these geometries are displayed on the folder. Once a table of coefficients is displayed, the user may plot any data column by double-clicking on the column heading of the column. The entire table may be exported to Excel.

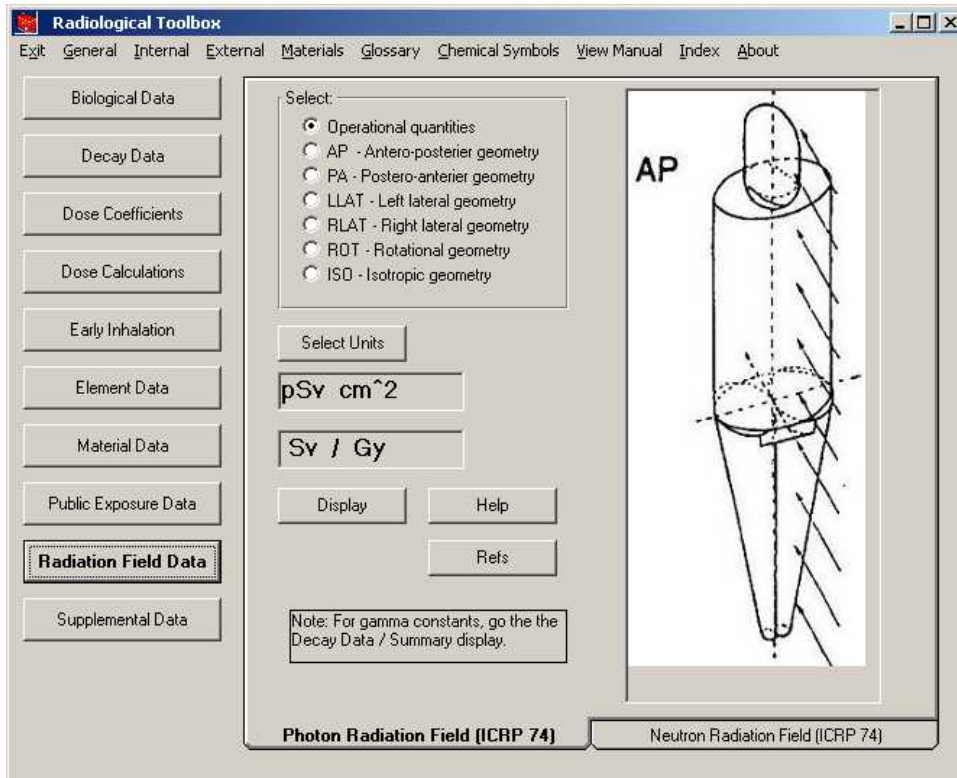


Fig. 13. The initial screen for conversion coefficients for radiation fields.

2.11 Supplemental Data

The *Supplemental Data* section (Fig. 14) provides access to other radiation and health physics data. This section includes:

- SI Units*
- Physical Constants*
- Conversion Factors*
- Formulae*
- Web Pages*
- DOE Dose Range*
- Transport Package Regulations*

The *Physical Constants* and *Conversion Factors* may be exported to the clipboard by right-clicking on the value. A simple web browser is available to view the web links. The discussion of SI units is abstracted from Baum, *et al.* (2002). The physical constants and conversion factors are from Lide (1997). The formula or equations are from various sources. The *DOE Dose Ranges* graphic was compiled by the DOE Office of Science to provide an “orders of magnitude” sense of radiation doses range from NCRP’s “Negligible Dose” to those of cancer radiotherapy. The graphic can be viewed in either SI or conventional units.

The transport package regulation consists of the A_1 and A_2 values for radionuclides from Appendix A of 10 CFR Part 71 (FR 2004). The values are given in both TBq (10^{12} Bq) and Ci. The A_1 value is the maximum activity of a special form of the radionuclide permitted in a Type A package. The A_2 value is the maximum activity of a radionuclide, other than in a special form, that is permitted in a Type A package. A Type A package is defined as a package complying with DOE regulations in 49 CFR Part 173.

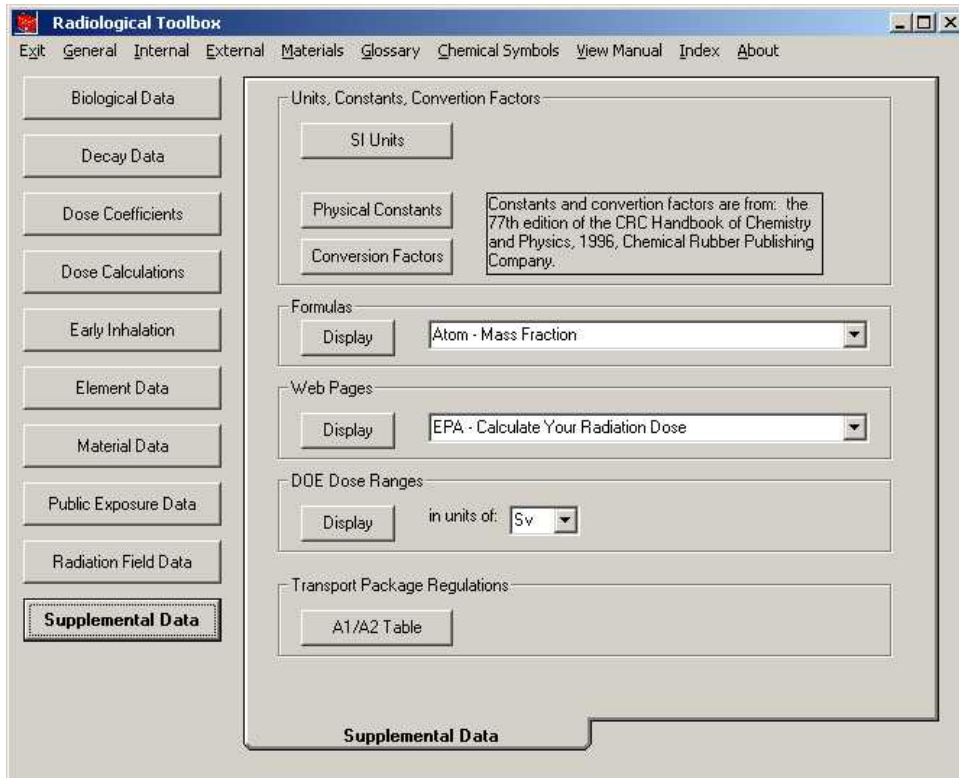


Fig. 14. The initial screen for supplemental data.

3.0 HOW TO ACCESS RAD TOOLBOX FEATURES

This section describes the use of some of the Rad Toolbox features.

3.1 How to Use the Dose Coefficient Nuclide Input Grid

Dose coefficients can be requested for up to 20 radionuclides in a single query by either typing in the radionuclide name or select it from the choice list. The user can navigate the choice list by typing the first few characters of the selected name and then pressing *Enter*. If an invalid name (either misspelled or a radionuclide not in the database) is entered, an error message is displayed and that entry must be corrected or changed to a blank to continue. Always enter a name in the top cell of the list, but blank cells may exist between filled cells. The table displayed will not necessarily have the radionuclides in the order that they were entered.

3.2 How to Use the Nuclide, Element, and Material Choice Lists

For choice lists where a single item is to be selected, either type in the item name or select it from the choice list. The user can navigate the choice list by typing the first few characters of the selected name. If an invalid name is provided (either from misspelling or specifying an item not included in that database) an error message is displayed and the entry must be corrected to continue.

3.3 How to Export Data

The export of data from the Rad Toolbox is possible only if Microsoft Excel has been installed. An Export button is available on each table that may be exported. The first time the Export button is pressed, a new Excel file is opened. The data in the displayed table are copied to the first sheet of the Excel file. If the Excel file remains open then additional exported data tables will be copied to the same sheet as the previously exported data. The new data will be positioned next to the previous data, with one blank column in between. If the Excel file, is closed then the next request to export a data table results in a new Excel file be opened. The Rad Toolbox will not export data to an existing Excel file.

3.4 How to Use the Activity Feature in Dose Calculations for a Decay Chain

As an example, consider a calculation of the external dose rate one week post the deposition of pure Ra-226 on the ground surface. The *Activity* feature of the *Decay Data* section can be used to compute the activity and time-integrated activity (s) or nuclear transformation of each chain members over a user-specified time (d) period. Fig. 15 shows such values. The activity data is selected by clicking on its column heading and pressing the *Copy* button.

	Nuclide	Activity	Integrated Activity (sec)
▶	Ra-226	1.00E+00	6.05E+05
	Rn-222	7.19E-01	2.62E+05
	Po-218	7.19E-01	2.62E+05
	Pb-214	7.18E-01	2.60E+05
	At-218	1.44E-04	5.24E+01
	Bi-214	7.17E-01	2.59E+05
	Po-214	7.17E-01	2.59E+05
	Pb-210	2.55E-04	5.60E+01
	Bi-210	7.08E-05	1.18E+01
	Po-210	6.80E-07	8.77E-02

Fig. 15. Activity and integrated activity at day 7 for Ra-226 chain.

The user then goes to the *Dose Calculations* section, selects the *Public External Coefficients* folder, presses the *Paste Decay Results* button, and selects *Ground Surface* as the exposure mode. Pressing *Display* provides a table of the contribution to dose of each chain member as seen in Fig. 16. Note the members of the chain may not be listed in the order of the decay chain; see Fig. 15. To show the total column in Fig. 16, the display has been scrolled to the right. The values under the total column represent the dose rate (Sv/s) at day 7 post the initial deposition of 1 Bq/m² of pure Ra-226. This table can be exported to Excel.

Nuclide	Po-218	Ra-226	Rn-222	Total
Adrenals	1.97E-24	3.79E-22	2.27E-25	8.67E-16
Bladder Wall	2.06E-24	4.02E-22	2.47E-25	9.75E-16
Bone Surface	3.11E-24	9.62E-22	3.94E-25	1.37E-15
Brain	2.06E-24	3.92E-22	2.42E-25	9.32E-16
Breast	2.27E-24	4.61E-22	2.71E-25	1.02E-15
Esophagus	1.88E-24	3.48E-22	2.18E-25	8.51E-16
Stomach Wall	2.08E-24	4.06E-22	2.41E-25	9.39E-16
Small Intestine Wall	2.04E-24	3.81E-22	2.35E-25	9.31E-16
Upper Large Intestine Wall	2.06E-24	3.93E-22	2.40E-25	9.39E-16
Lower Large Intestine Wall	2.13E-24	3.93E-22	2.44E-25	9.60E-16
Kidneys	2.10E-24	4.04E-22	2.43E-25	9.54E-16
Liver	2.08E-24	4.05E-22	2.42E-25	9.39E-16
Lungs	2.17E-24	4.29E-22	2.57E-25	9.83E-16
Muscle	2.36E-24	4.61E-22	2.78E-25	1.06E-15
Ovaries	2.01E-24	3.83E-22	2.57E-25	9.02E-16
Pancreas	1.92E-24	3.68E-22	2.22E-25	8.88E-16
Red Marrow	2.22E-24	4.21E-22	2.59E-25	1.00E-15
Skin	2.99E-24	5.75E-22	3.54E-25	8.60E-15
Spleen	2.10E-24	4.10E-22	2.42E-25	9.39E-16
Testes	2.38E-24	4.70E-22	2.82E-25	1.06E-15
Thymus	2.00E-24	3.89E-22	2.47E-25	9.32E-16
Thyroid	2.25E-24	4.29E-22	2.69E-25	9.62E-16
Uterus	2.02E-24	3.84E-22	2.35E-25	9.17E-16
Effective (ICRP 26)	2.27E-24	4.56E-22	2.69E-25	1.02E-15
Effective (ICRP 60)	2.21E-24	4.32E-22	2.60E-25	1.07E-15

Fig. 16. The dose rate at day 7 post a deposition of 1 Bq/m² of pure Ra-226.

Had the integrated activity (s) been pasted into the dose calculations the resultant numerical values would represent the dose (Sv) over the seven days for an initial deposition of 1 Bq/m² of Ra-226. However the display would have indicated dose rate (Sv/s) not dose (Sv). The user must keep in mind the nature of the calculations being undertaken.

3.5. How to Define a Material and Calculate its Interaction Coefficients

As an example, consider a calculation of the electron interaction coefficients for the user-defined material *silly cement*. *Silly cement* consists of H, C, and Cl in mass fractions 0.06, 0.54, and 0.40, respectively. When the *Material Data* section is displayed the pull down menu of materials defaults to “User-defined.” Clicking the *Display* button brings up the input screen to define the material. The completed input screen for *silly cement* is shown in Fig. 17. Press the *Exit* button to compute and display the table of interaction coefficients for *silly cement*. The input screen includes a note which must be followed for proper closure of the data input.

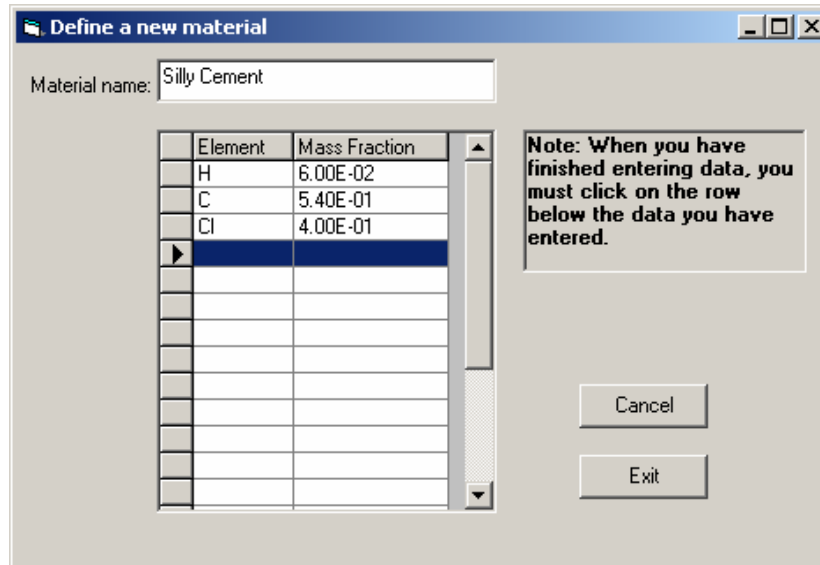


Fig. 17. Input screen for user-defined material.

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