USER GUIDE TO THE ICRP CD AND THE DECDATA SOFTWARE

K. F. Eckerman and A. Endo

1. Basic Information About the CD and Software Package

ICRP Publication 107 entitled "Nuclear Decay Data for Dosimetric Calculations" includes a CD that provides electronic files of the unabridged nuclear decay data for 1252 radionuclides of 97 elements. The CD contains the following:

- README.TXT: A file containing information post preparation of the publication
- CONTENT.PDF: A file detailing the content of the CD
- LICENSE.TXT: A file containing the license agreement and a liability statement
- USERGUIDE.PDF: The user guide to the DECDATA software; this document
- ICRP-07 nuclear decay data files:
    - ICRP-07.NDX
    - ICRP-07.RAD
    - ICRP-07.BET
    - ICRP-07.NSF
    - ICRP-07.ACK
- SETUP.EXE: Executable file for installing DECDATA software
- ARCHIVE folder:
    - INPUT folder: EDISTR04 input files for nuclides of the ICRP collection
    - OUTPUT folder: EDISTR04 output files for nuclides of the ICRP collection
    - SOURCE folder: Source code for DECDATA

The software package DECDATA enables viewing the radiological properties of radionuclides of the ICRP collection in a tabular and graphical manner as no detailed tabulations are included in the publication. Data on the yields and energies of the radiations of a user-specified radionuclide can be extracted into ASCII files for subsequent use. DECDATA is intended for use on a personal computer (PC) with Windows operating system.

The CD contains a file, AUTORUN.INF, which invokes SETUP.EXE to install DECDATA when the CD is placed in the CD drive. If this function has been disabled on the computer then, from Explorer, click on SETUP.EXE to install DECDATA. AUTORUN can be bypassed by holding down the shift key when the CD is placed in the drive.

SETUP.EXE is a Windows installation procedure[1] that installs DECDATA and its data files. After the user agrees to the license statement the procedure creates a folder with the default name ICRP07 on the hard drive, installs the software in the folder, and places the DECDATA icon on the desktop. Three additional folders, below the main folder, are created. The decay data files reside in the subfolder DATA, decay scheme drawings for selected files are in the FIGS subfolder, and all output files generated by DECDATA are written to the subfolder OUTPUT. The subfolder REPORT contains documents of potential interest to the user, including this document.

DECDATA is a console application developed using PowerBASIC™ Console Compiler[2] with Perfect Sync, Inc[3] modules Console Tools™ and Graphics Tools™ providing additional functionality. Graphical support is provided by the DPlot Jr[4] module. Documents in the REPORT subfolder can be selected for viewing within DECDATA, as can some of DECDATA output files. This capability depends on the user having associated files with file extensions *pdf* and *txt* with Acrobat Reader[5] and an ASCII editor (such as Microsoft's Notepad), respectively.

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[1] The install package was created using Inno Setup compiler available from http://www.innosetup.com.
[2] PowerBASIC, Inc.; 1978 Tamiami Trail S. #200; Venice, FL 34293. See http://www.powerbasic.com/.
[3] Perfect Sync, Inc. 6511 Franklin Woods Dr., Traverse City, MI. See http://perfectsync.com/.
[4] HydeSoft Computing, Inc., 110 Roseland Drive, Vicksburg, MS 39180. See http:// www.dplot.com/index.htm.
[5] Adobe Acrobat Reader of Adobe Inc. is available from http://www.pdf-2007.com/index.asp.

2. Information on the Nuclear Decay Data Files

The nuclear decay data are embodied in five formatted (hence readable with an ASCII editor) direct-access files, each with the root name ICRP-07. The file ICRP-07.RAD contains the data on the absolute yields (or intensities) and mean[6] or discrete energies of the radiations emitted by the 1252 nuclides of the ICRP-07 collection. This file contains data for all emitted radiations; i.e., no cutoff on the number of radiations has been applied to the data of the electronic files as would be required in printed tabulations.

The file ICRP-07.BET contains the beta spectra for all beta emitters in the collection. EDISTR04 (Dillman 1980, Endo *et al.* 2005), the software used to compute the energies and yields of the emitted radiations, computes the spectrum for each beta transition to determine the mean beta energy of the transitions and tabulates the composite spectra for all beta transitions of the radionuclide. Only the composite spectra are included in this file.

The file ICRP-07.ACK contains the Auger and Coster-Kronig (CK) electron spectra for selected radionuclides. These discrete emissions were collected into no more than 15 groups for each decay mode in the ICRP-07.RAD file. Hereafter Auger and Coster-Kronig (CK) is denoted as Auger-CK.

The spectra of neutrons emitted during spontaneous fission are contained in the file ICRP-07.NSF. In the ICRP-07 collection, 28 radionuclides decay by spontaneous fission.

To facilitate access to the data in these files, an additional file ICRP-07.NDX was constructed. A brief description of each of these five files is presented below. For convenience, the files are referred to by their file extension, i.e., NDX, RAD, BET, ACK, and NSF.

<u>Index File: ICRP-07.NDX</u>

The NDX file serves as the entrance into the larger radiation (RAD) and spectral (BET, ACK, and NSF) files. The NDX file contains one record for each nuclide of the collection. Fields of the nuclide record specify the location of the nuclide's records in the RAD, BET, ACK, and NSF files. In addition to these so-called pointers, the record contains fields giving the nuclide's physical half-life, decay mode (e.g., alpha or beta), identity of progeny (daughters), fraction of the nuclear transformations forming each daughter (so-called branching fraction), the total energies emitted by alpha, electron, and photon emissions (including electrons and photons accompanying spontaneous fission), and other supportive data. A full description of the NDX records is given in Table 1.

The records of the index file have been sorted by the nuclide field, making it possible for user-developed software to locate the record for a radionuclide of interest using a binary search algorithm. While the purpose of the NDX file is to provide entrance into the other data files, it is of considerable utility in its own right. For example, DECDATA constructs the decay chain headed by a radionuclide from information in the NDX file – this is discussed further below.

Both the radioactive and stable daughter nuclei and their branching fractions are included in the file. The Tantulum-180m daughter, formed in 0.3% of the decays of Hf-180m is indicated here as stable as in NUBASE2003 (Audi *et al*. 2003). In the NDX file, daughter nuclei with a zero record pointer (Record-i of Table 1) are stable. A list of the radionuclides of the ICRP-07 collection is contained in the REPORT folder (ICRP_Nuclides.TXT).

<u>Radiation File: ICRP-07.RAD</u>

The records of the RAD file contain the data on the energy and yield of each radiation emitted in nuclear transformations of the radionuclide. No cutoff is applied to the number of radiations in this file. The fields of the RAD records are described in Table 2. The first record (header record) of a nuclide in the file contains the name of the nuclide, its half-life, and the number of data records for each radiation that follow. The fields of the data record are: (1) an integer code (ICODE) that identifies the radiation type; (2) the absolute yield of the radiation (i.e.,

[6] Mean values are reported for beta particles, Auger and Coster-Kronig electron groups, and the radiations emitted during spontaneous fission – fission fragments, neutrons, and delayed beta emission.

number per nuclear transformation); (3) the unique or average energy of the radiation; and (4) a two-character mnemonic denoting the radiation type. The ICODE and the mnemonic are defined in Table 3. The nuclide record in the NDX file includes a field, Pointer-1 of Table 1, which contains the record number of header record of the nuclide in the RAD file, a so-called pointer.

The data records for the nuclides are ordered by radiation type, the order of ICODE, and by increasing energy. The radiations group are:

- Photons- ICODE 1-3: x ray, γ ray, annihilation photons, and prompt and delayed photons of spontaneous fission
- Beta particles- ICODE 4-5: mean energy of each beta transition
- Monoenergetic electrons- ICODE 6-7: internal conversion and Auger-CK electrons
- Alpha particles- ICODE 8
- Alpha recoil nuclei- ICODE 9
- Fission fragments- ICODE 10
- Neutrons- ICODE 11

The records of each group are sorted by increasing energy. This sorting facilitates interpolation in an energy-dependent function, e.g., the energy-dependent specific absorbed fraction data for the radiation type. The mnemonic can be used to identify a particular radiation type within its group (for example, annihilation photons, delayed gamma rays, etc.).

Beta Spectra File: ICRP-07.BET

The BET file contains the beta spectrum for each beta emitter of the ICRP-07 collection. The spectral data are tabulated on a fixed logarithmic-type energy grid. For each nuclide, the header record gives the name of the nuclide and the number of data records that follow. The fields of the data records contain the electron energy E (MeV) and the number of electrons emitted per nuclear transformation with energy between E and $E + dE$. The structure of the records of the BET file is given in Table 4. A field of the nuclide record in the NDX file, Pointer-2 of Table 1, contains the record number of the nuclide's header record in the BET file.

Auger-CK Electron Spectra File: ICRP-07.ACK

For 136 selected nuclides, detailed Auger-CK electron spectra are contained in the ACK file. These emissions were collapsed into no more than 15 groups for each decay mode in the RAD file. The maximum number of discrete electrons in the spectrum of a radionuclide is 3015 in the case of Hg-195m and Hg-197m. The fields of the header record contain the name of the nuclide and the number of data records that follow. The fields of the data records contain the electron energy E (eV), the yield (number of electrons of that energy per nuclear transformation), and an identification of the orbital transition. The data records have been sorted by increasing electron energy. The format of the records is given in Table 5. A list of the nuclides, for which detailed spectra are included in the ACK file, is contained in the REPORT folder (AugerList.TXT). A field of the nuclide record in the NDX file, Pointer-3 of Table 1, contains the record number of the nuclide's header record in the ACK file.

Neutron Spectra File: ICRP-07.NSF

The NSF file contains the spectra of neutrons emitted by radionuclides undergoing spontaneous fission. In the ICRP-07 collection, 28 radionuclies decay by spontaneous fission. For each nuclide, the header record gives the name of the nuclide, the branching fraction for spontaneous fission, and the number of data records that follow. The fields of data records define a neutron energy bin (a lower and upper energy are given) and the number of neutrons per nuclear transformation in that energy bin. The format of the records of the NSF file is given in Table 6. A field of the nuclide record in the NDX file, Pointer-4 of Table 1, contains the record number of the nuclide's header record in the NSF file.

Table 1. Structure of Records in ICRP-07.NDX File		
Field	**Format**[a)]	**Description**
Record 1[b)]		
First	I4	Record number of first data record
Last	I4	Record number of last data record
Data Records (First, ..., Last)[c)]		
Nuclide	A7	Name of nuclide (parent); e.g., Am-241, Tc-99m
Half-life	A8	Half-life of nuclide
Units	A2	Half-life units: μs - microsecond, ms - millisecond, s – second, m – minute, d - day, and y – year
Decay Mode	A8	A denotes alpha, B- beta minus, B+ beta plus, EC electron capture, IT internal transition, and SF spontaneous fission
Pointer-1	I7	Location of nuclide in ICRP-07.RAD file
Pointer-2	I7	Location of nuclide in ICRP-07.BET file
Pointer-3	I7	Location of nuclide in ICRP-07.ACK file
Pointer-4	I6	Location of nuclide in ICRP-07.NSF file
The next block of three fields is repeated for radioactive daughter *i*, *i* = 1 to 4.		
Daughter-*i*	A7	Name of daughter nuclide *i*
Record-*i*	I6	Location of daughter *i* in ICRP-07.NDX file
Branch-*i*	E11.0	Branching fraction to daughter *i*
E-alpha	E7.0	Energy of alpha emissions (MeV/nt)
E-electron	E8.0	Energy of electrons, including beta (MeV/nt)
E-photon	E8.0	Energy of photon emission (MeV/nt)
Number-1	I4	Number of photon of energy less than 10 keV per nt
Number-2	I4	Number of photons of energy greater than 10 keV per nt
Number-3	I4	Number of beta transitions per nt
Number-4	I5	Number of monoenergetic electrons per nt
Number-5	I4	Number of alpha transitions per nt
AMU	E11.0	Atomic mass of radionuclide (Audi *et al*. 2003)
Γ_{10}	E10.0	Air kerma-rate constant (Gy-m^2 (Bq s)$^{-1}$)
K_{air}	E9.0	Air kerma coefficient (Gy-m^2 (Bq s)$^{-1}$)

[a)]The format is expressed in FORTRAN notation, e.g., A8 denotes an alphanumic field of length 8, I5 an integer field of length 5, and E11.0 a real numeric field of length 11.
[b)]FORTRAN Format(2I4)
[c)]FORTRAN Format (A7,A8,A2,A8,3I7,I6,1X,3(A7,I6,E11.0,1X),A7,I6,E11.0,F7.0,2F8.0,3I4,I5,I4, E11.0,E10.0,E9.0)

Table 2. Structure of Records in ICRP-07.RAD File

Field	Format	Description
Nuclide Record		
Nuclide	A7	Nuclide name; e.g., Tc-99m
$T_{1/2}$	E11.0	Physical half-life of nuclide
Time unit	A2	Units of $T_{1/2}$, see Table 1
N	I9	Number of data records
Data Record (1, …, N)		
ICODE	A2	Radiation type (see Table 3)
Yield	E12.0	Yield of the radiation (/nt)
Energy	E12.0	Energy of the radiation (MeV)
JCODE	A3	Mnemonic (see Table 3)

Table 3. Description of ICODE Variable

ICODE	Mnemonic For ICODE	Description
1	G	Gamma rays
	PG	Prompt gamma rays*
	DG	Delayed gamma rays*
2	X	X rays
3	AQ	Annihilation photons
4	B+	Beta + particles
5	B-	Beta – particles
	BD	Delayed beta particles*
6	IE	IC electrons
7	AE	Auger electrons
8	A	Alpha particles
9	AR	Alpha recoil nuclei
10	FF	Fission fragments
11	N	Neutrons

∗Prompt and delayed radiations of spontaneous fission.

Table 4. Structure of Records in ICRP-07.BET File

Field	Format	Description
Nuclide Record		
Nuclide	A7	Nuclide name; e.g., Tc-99m
N	I10	Number of data records
Data Record (1, …, N)		
Energy	F7.0	Energy grid point (MeV)
Number	E10.0	Number of beta particles per MeV per nuclear transformation at this energy

Table 5. Structure of Records in ICRP-07.ACK File

Field	Format	Description
Nuclide Record		
Nuclide	A7	Nuclide name; e.g., I-123
$T_{1/2}$	A17	Half-life with its units
N	I8	Number of discrete electron lines
Data Record (1, …, N)		
Yield	E11.0	Number of electrons per nt at this energy
Energy	E12.0	Electron energy (eV)
Transition	A9	Identification of atomic transition; e.g., L1 M2 M3

Table 6. Structure of Records in ICRP-07.NSF File

Field	Format	Description
Nuclide Record		
Nuclide	A7	Nuclide name; e.g., Cf-252
BF	E13.0	SF branching fraction
N	I9	Number of neutron energy bins
Data Record (1, …, N)		
Energy-1	E8.0	Lower energy (MeV)
Energy-2	E9.0	Upper energy (MeV)
Yield	E12.0	Number of neutrons per nt in bin

3. Air Kerma for Ideal Point Source

A field of the nuclide record in the NDX file contains the quantity air kerma as a measure of the radiation field in the vicinity of a point source of the radionuclides. Kerma, an acronym for the kinetic energy released per unit mass, is the kinetic energy of charged particles liberated by photon and neutron interactions per unit mass.

3.1 Air Kerma-Rate Constant

The nuclide record in the NDX file has a field containing the air-kerma rate constant. This constant, a characteristic of a radionuclide, is defined in terms of an ideal point source. The International Commission on Radiation Units and Measurements (ICRU 1998) defined the constant as $\Gamma_\delta = l^2 \dot{K}_\delta / A$ where $\dot{K}_\delta$ is the air kerma rate due to photons of energy greater than δ at a distance *l* in vacuum from a point source of the radionuclide of activity *A*. The photons referred to include gamma rays, characteristic x rays, and inner bremsstrahlung; the latter is not addressed in the ICRP-07 collection because of its low yield and energy. Annihilation photons, included in the tabulated emissions, are not included in the definition of the constant as they would not be present for an ideal point source in a vacuum. In a source of finite size, attenuation and scattering occur, and external bremsstrahlung can be produced. In addition, any medium between the source and the point of measurement will give rise to absorption and scattering, external bremsstrahlung, and annihilation photons. In many cases, these processes can substantially influence the observed kerma rate. The constant, as defined, is given by

$$\Gamma_\delta = \frac{1}{4\pi} \sum_i (\mu_k / \rho)_i \, Y_i \, E_i \tag{1}$$

where $(\mu_k/\rho)_i$ is the mass energy-transfer coefficient in air for photons of energy E_i emitted by the nuclide with yield Y_i. The mass energy-transfer coefficients used to derive the tabulated values are from Shultis and Faw (1999). The value of δ was 10 keV. The air kerma-rate constant is the SI equivalent of the quantity referred to as the specific gamma constant.

3.2. Point Source Air-Kerma Coefficient

As noted above, the air kerma-rate constant does not consider annihilation photons associated with positron emission and the neutrons and photons accompanying spontaneous fission. To address these radiations, the air-kerma coefficient $K_{\mathrm{air},\delta}$ for a hypothetical point source is defined as

$$K_{air,\delta} = \frac{1}{4\pi} \left[\sum_i (\mu_k / \rho)_i \, Y_i \, E_i + \sum_i Y(E_i , E_{i+1}) \, \bar{k}(E_i , E_{I+1}) \right] \tag{2}$$

and is included on the nuclide record in the NDX file. The first summation in the right hand side Eqn 2 extends over all photons of energy greater than δ, including annihilation photons arising from position emission and the delayed and prompt gamma-rays accompanying spontaneous fission. The second summation in Eqn 2 is the contribution to air kerma of neutrons accompanying spontaneous fission with yield $Y(E_i , E_{i+1})$ per nuclear transformation and $\bar{k}(E_i , E_{i+1})$ denotes the value of the neutron air kerma coefficient (Chadwick *et al.* 1999) averaged over the energies E_i to E_{i+1}. Only neutrons of energy greater than δ (10 keV) are considered. The constant and the coefficient are numerically equal except in the cases of positron emission or spontaneous fission decay. The cautionary statements above regarding the air kerma-rate constant and the observed kerma rate for a real source in air are applicable to the coefficient.

4. Basic Operation and Features of the DECDATA Software

DECDATA can be invoked by clicking on its desktop icon. To access the records for a radionuclide of interest the user clicks on the chemical symbol of the element in the periodic table. Displayed in the lower right corner of the screen is the name of the element corresponding to the chemical symbol over which the mouse cursor is currently located (the cursor is not shown in Fig. 1). If the ICRP-07 collection contains no radioisotopes of the element (as for He, Li, B, Md, No, and Lr) then the phrase "No Data" appears in the lower right corner of the display. If the mouse is clicked (left click) while over an element then a list box of the radioisotopes of the element in the collection (see Fig. 2) is displayed. If only a single radioisotope of the element is included in the collection, then clicking on that element results in the display of the summary information for the radioisotope – hydrogen is the only such case. After a radioisotope of the element is selected from the list box of multiple isotopes, e.g., Cf-252, the software displays the physical half-life, decay mode, specific activity, and radioactive progeny of the radionuclide followed by a summary tabulation of its emissions as shown in Fig. 3. Graphical display of the decay scheme of 333 radionuclides were published earlier (Eckerman and Endo 2008) and these graphics are included here in the FIGS folder. A message is displayed as seen in Fig. 3 when the graphic exists for the selected radionuclide.

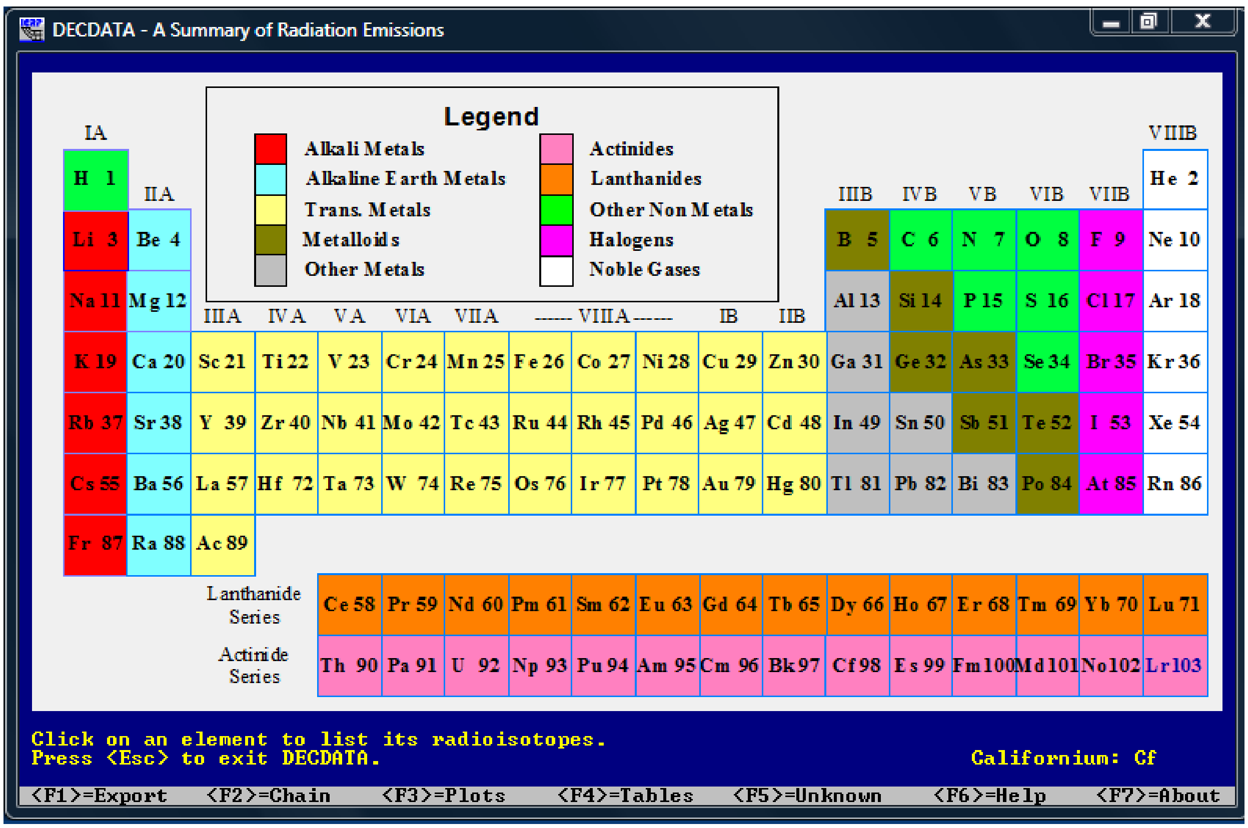


Fig. 1. DECDATA's interface for selecting radioisotopes of the elements in ICRP-07.

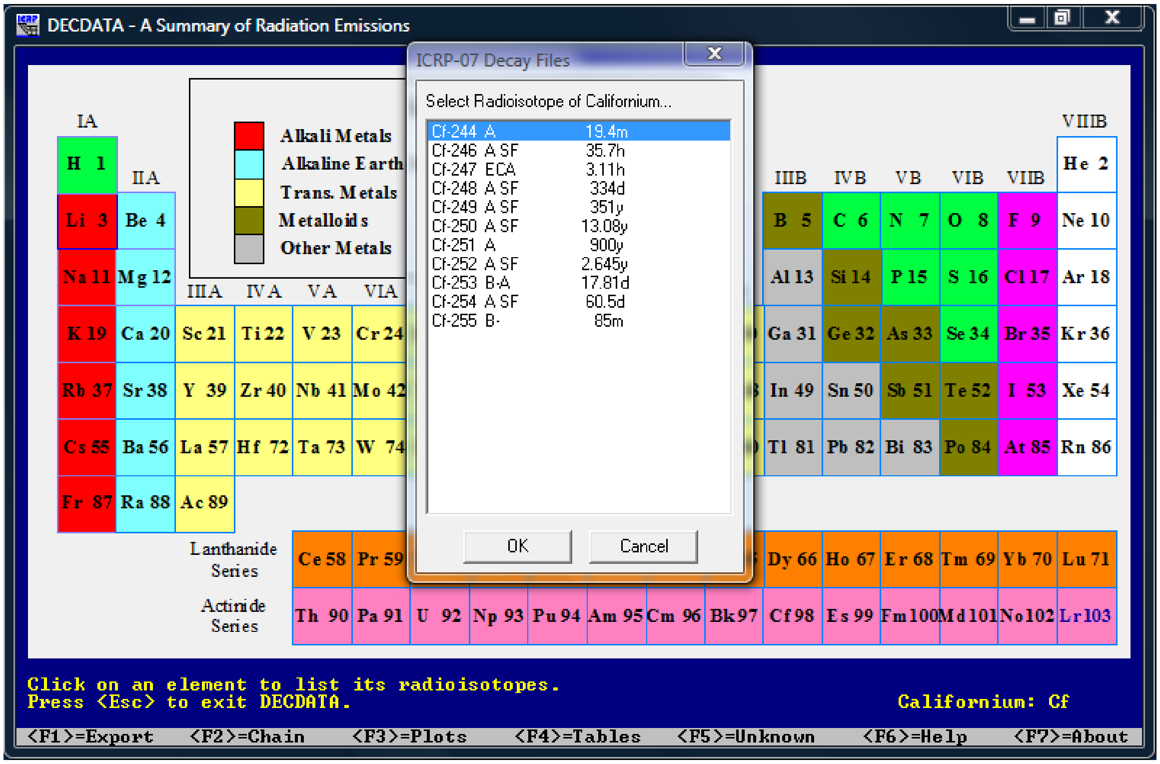


Fig. 2. Menu to select a radioisotope of the selected element.

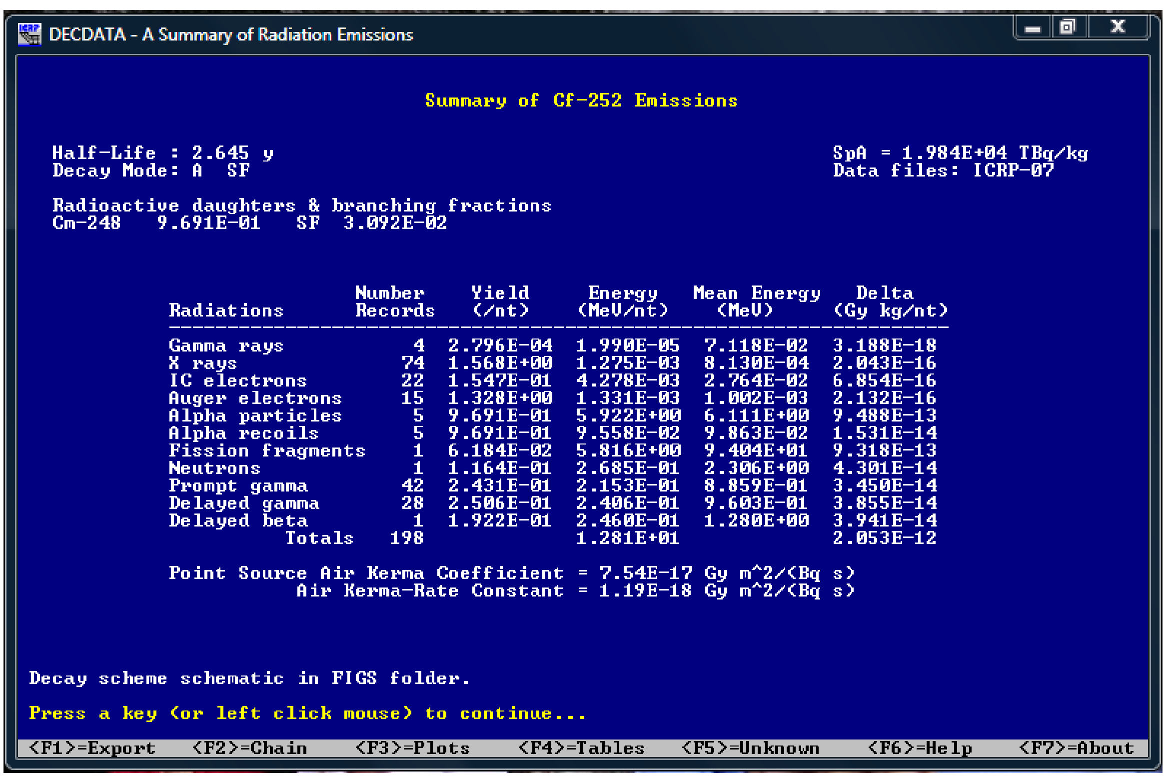


Fig. 3. Summary display of the Cf-252 emissions.

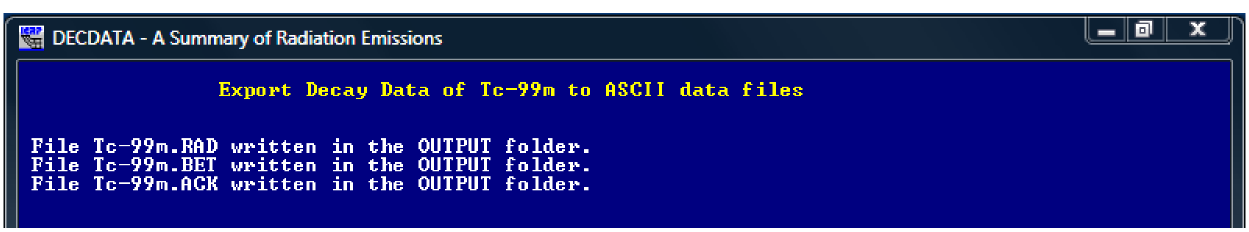
The summary reports the number of records of each radiation type in the RAD file, the yield or number per nuclear transformation (nt), the total emitted energy (MeV per nt), the mean (average) emitted energy (MeV), and the equilibrium absorbed dose quantity Δ (Gy kg nt^{-1}). For brevity, nuclear transformation (Bq s) is abbreviated as nt in the display. The 14 radiation groups of the summary table are listed as: Gamma rays, X rays, Annh photons, Beta+, Beta-, IC electrons, Auger electrons, Alpha particles, Alpha recoil, Fission fragments, Neutrons, Prompt gamma, Delayed gamma, and Delayed beta. In the event photons of energy greater than 10 keV are emitted, the air kerma-rate constant and air kerma coefficient for a point source are displayed. The latter quantity includes for positron emitters the contributions from annihilation photons and for spontaneous fission the contributions from the neutron and the prompt and delayed gamma radiations.

The last line of the display delineates actions assigned to the function keys F1 through F7. These keys can be pressed at any time. The first three keys act on the displayed nuclide while the other keys are not specific to a nuclide. The key assignments are summarized below and described in more detail in the paragraphs that follow.

Function Key	Action
F1	Export to ASCII files the nuclear decay data for the displayed nuclide
F2	Show the decay chain headed by the displayed nuclide and tabulate the cumulative energy associated with the chain members
F3	Graphically display the beta and neutron spectra (continuous) and line spectra for the discrete energies of alpha particles, IC electrons, Auger-CK electrons, and photon radiations
F4	List the radionuclides in the collection sorted by: a) atomic number, b) half-life, c) total emitted energy, d) alpha emitters, e) beta emitters, f) internal transition (IT), g) spontaneous fission, h) principal alpha emission, i) principal beta transition, j) principal photon emission, k) nuclides with detailed Auger-CK spectra
F5	Given an alpha or photon emission of known energy, a search of the RAD file is carried out in an attempt to identify a radionuclide in the ICRP-07 which emits such a radiation
F6	Display documents in the REPORT folder
F7	Display the usual software credit screen

F1 key: Export nuclide data

If the F1 key is pressed while the summary information for a radionuclide is displayed, then the nuclear decay data for the nuclide is extracted from the data files and written to ASCII files in the OUTPUT folder. In the case where the data from Tc-99m is to be extracted the following files are created:



The names of the output files are constructed from the nuclide name with the file extension being the extension of the ICRP-07 file from which the data were extracted. In each output file, the second line of the file is the header record of the nuclide in the file from which the data are extracted. A partial listing of the Tc-99m.RAD file follows.

```
File: Tc-99m.RAD for Tc-99m
Tc-99m       6.015h       143
T1/2 = 6.015h Decay Mode: ITB-
Radiations of each type listed in increasing energy
Number of photon radiations: 86
Number of beta radiations: 3
Number of monoenergetic electron radiations: 54
ICODE  Y (/nt) E(MeV) Mnemonic
START RADIATION RECORDS
2 5.49690E+00 7.87678E-06  X
 / / / / / / / / / / / / / /
 : : : : : : : : : : : : : :
 / / / / / / / / / / / / / /
 1 6.65489E-11 2.17260E-03  G
 2 1.69925E-06 2.23236E-03  X
 / / / / / / / / / / / / / /
 : : : : : : : : : : : : : :
 / / / / / / / / / / / / / /
 1 9.69400E-07 3.22400E-01  G
 5 1.07767E-06 3.01202E-02 B-
 5 2.59439E-05 1.02026E-01 B-
 / / / / / / / / / / / / / /
 : : : : : : : : : : : : : :
 / / / / / / / / / / / / / /
 6 5.99387E-11 3.22400E-01 IE
END RADIATION RECORDS
```

As seen in above listing, the file begins with a few brief comments and then lists, for each radiation type, the number of records in the file. The decay data are bracketed between a start and end delimiter (“START RADIATION RECORDS” and “END RADIATION RECORDS”, respectively). The radiation records are in the format of the RAD file. See Table 2 for the definition of ICODE and the mnemonic.

The records of the Tc-99m.BET file have the same structure as the record in the BET file but are bracketed by start and end delimiters. A few lines from the Tc-99m.bet file are listed below.

```
File: Tc-99m.BET for Tc-99m
Tc-99m        100
Beta Spectrum for Tc-99m
Spectrum is normalized to 1 nt (Bq s)
To normalize to 1 beta, divide by 3.7000E-05
Number of energy points: 100
E(MeV)    P(E)
START RADIATION RECORDS
0.00000 2.319E-04
0.00010 2.318E-04
   ::      ::
0.36000 7.143E-06
0.40000 1.990E-06
0.43618 0.000E+00
END RADIATION RECORDS
```

For selected radionuclides, Tc-99m being one, detailed spectra of the Auger-CK electron emissions are contained in the ACK file. While this level of detail is not necessary in calculations of mean absorbed dose, it is of interest in microdosimetric calculations, e.g., the dose to the cell nucleus from such an emitter incorporated in the cell nucleus. Below is an excerpt from the Tc-99m.ACK file.

```
File: Tc-99m.ACK for Tc-99m
Tc-99m                      968
Auger/Coster-Kronig Spectrum for Tc-99m
Number of electrons: 968
  Y(/nt)       E(eV)   transition
START RADIATION RECORDS
6.57103E-05 3.34000E+00 M1 M4 M5
1.66012E-04 7.28000E+00 M1 M5 M5
7.71672E-08 9.83000E+00 M1 M2 N1
3.19642E-03 1.22200E+01 M2 M3 N4
6.44567E-04 1.23300E+01 M1 M2 N1
7.26819E-03 1.25100E+01 M2 M3 N5
  ::  ::      ::  ::      ::
1.90107E-11 2.20272E+04  K N3 N4
1.90107E-11 2.20275E+04  K N3 N5
1.26734E-11 2.20300E+04  K N3 O1
END RADIATION RECORDS
```

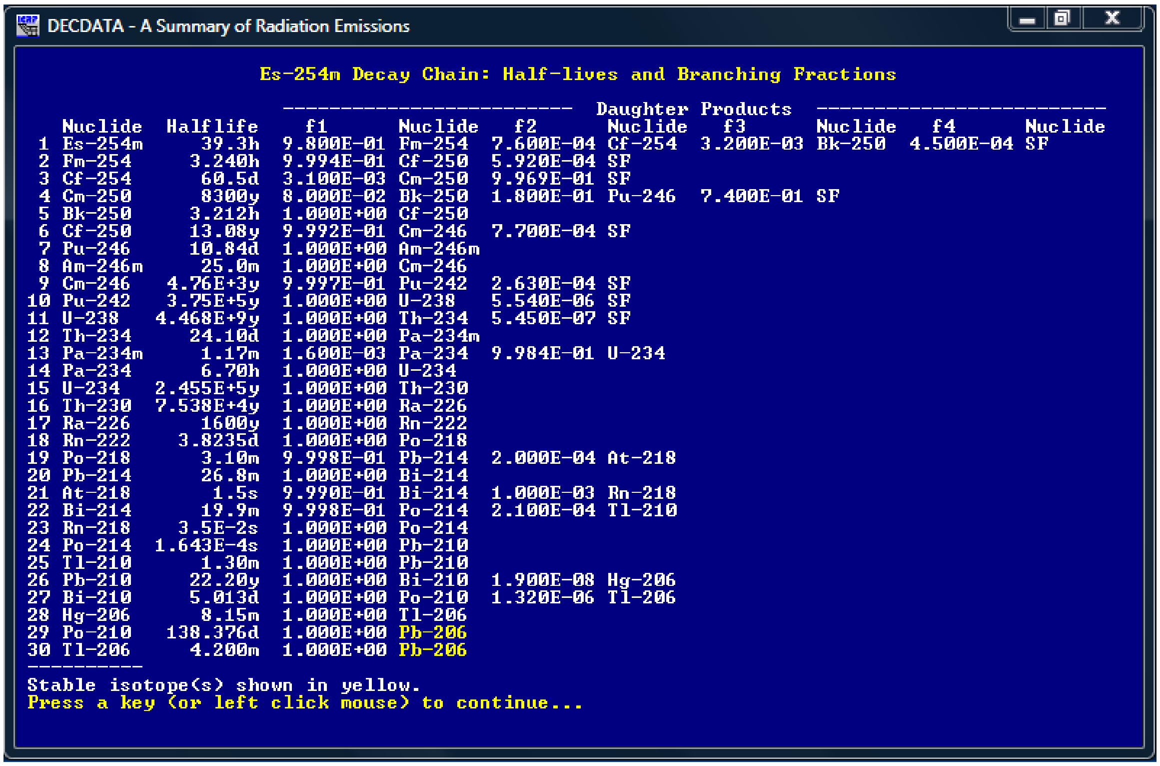
In the case of Tc-99m, the emissions of 968 discrete electrons are tabulated. The unit of the electron energy in this file is eV. In this case the electron energy ranges over four decades.

If decay data for a radionuclide which decays by spontaneous fission, e.g., Cf-252, is requested, a file of the neutron spectra associated with the spontaneous fission process is created. Below is an excerpt from the Cf-252.NSF file.

```
Output File Cf-252.NSF for Cf-252
Cf-252  3.092E-02         52
Neutron Spectra for Cf-252
Number of neutrons per fission - 3.767
Spectrum is normalized to 1 nt (Bq-s)
To normalize to 1 fission, divide by 3.09E-02
To normalize to 1 neutron, divide by 1.1641E-01
Number of energy bins: 52
E1 (MeV) E2 (MeV) Yield (/nt)
START RADIATION RECORDS
4.14E-07 1.00E-06 1.85105E-11
1.00E-06 1.00E-05 1.15581E-09
1.00E-05 5.00E-05 1.27176E-08
5.00E-05 1.00E-04 2.56849E-08
  ::   ::   ::  ::  ::  ::
1.20E+01 1.30E+01 3.82221E-05
1.30E+01 1.40E+01 1.82774E-05
1.40E+01 1.50E+01 8.66434E-06
END RADIATION RECORDS
```

F2 key: Show the decay chain

The decay of some radionuclides results in formation of radioactive nuclei (daughters) and hence a serial decay chain. The F2 key displays the decay chain and is illustrated below for the case of the parent radionuclide Es-254m, the longest chain in the ICRP-07 collection. After selecting Es-254m, its summary display is shown and then pressing F2 results in the display of Fig. 4a. The values under the columns headed by *f1*, *f2*, *f3,* and *f4* denote the fractions of the nuclear transformations of the nuclide in the second column which form the daughter nuclei shown immediately to the right of those fractions. Spontaneous fission, which is a decay mode of several chain members, is denoted as SF in the table. Note that stable nuclei are shown in yellow.


DECDATA - A Summary of Radiation Emissions

Es-254m Decay Chain: Half-lives and Branching Fractions

			Daughter Products							
	Nuclide	Halflife	f1	Nuclide	f2	Nuclide	f3	Nuclide	f4	Nuclide
1	Es-254m	39.3h	9.800E-01	Fm-254	7.600E-04	Cf-254	3.200E-03	Bk-250	4.500E-04	SF
2	Fm-254	3.240h	9.994E-01	Cf-250	5.920E-04	SF				
3	Cf-254	60.5d	3.100E-03	Cm-250	9.969E-01	SF				
4	Cm-250	8300y	8.000E-02	Bk-250	1.800E-01	Pu-246	7.400E-01	SF		
5	Bk-250	3.212h	1.000E+00	Cf-250						
6	Cf-250	13.08y	9.992E-01	Cm-246	7.700E-04	SF				
7	Pu-246	10.84d	1.000E+00	Am-246m						
8	Am-246m	25.0m	1.000E+00	Cm-246						
9	Cm-246	4.76E+3y	9.997E-01	Pu-242	2.630E-04	SF				
10	Pu-242	3.75E+5y	1.000E+00	U-238	5.540E-06	SF				
11	U-238	4.468E+9y	1.000E+00	Th-234	5.450E-07	SF				
12	Th-234	24.10d	1.000E+00	Pa-234m						
13	Pa-234m	1.17m	1.600E-03	Pa-234	9.984E-01	U-234				
14	Pa-234	6.70h	1.000E+00	U-234						
15	U-234	2.455E+5y	1.000E+00	Th-230						
16	Th-230	7.538E+4y	1.000E+00	Ra-226						
17	Ra-226	1600y	1.000E+00	Rn-222						
18	Rn-222	3.8235d	1.000E+00	Po-218						
19	Po-218	3.10m	9.998E-01	Pb-214	2.000E-04	At-218				
20	Pb-214	26.8m	1.000E+00	Bi-214						
21	At-218	1.5s	9.990E-01	Bi-214	1.000E-03	Rn-218				
22	Bi-214	19.9m	9.998E-01	Po-214	2.100E-04	Tl-210				
23	Rn-218	3.5E-2s	1.000E+00	Po-214						
24	Po-214	1.643E-4s	1.000E+00	Pb-210						
25	Tl-210	1.30m	1.000E+00	Pb-210						
26	Pb-210	22.20y	1.000E+00	Bi-210	1.900E-08	Hg-206				
27	Bi-210	5.013d	1.000E+00	Po-210	1.320E-06	Tl-206				
28	Hg-206	8.15m	1.000E+00	Tl-206						
29	Po-210	138.376d	1.000E+00	Pb-206						
30	Tl-206	4.200m	1.000E+00	Pb-206						

Stable isotope(s) shown in yellow.
Press a key (or left click mouse) to continue...

Fig. 4.a. Display of the Es-254m decay chain.

The decay chain information is presented in two screens when the length of the chain is greater than 7 members, as in this case. Upon continuing the display, the additional information provides an evaluation of the potential dosimetric importance of the chain members. Fig. 4.b shows the additional information for the Es-254m chain.

Briefly, DECDATA constructs and displays a table of activities, nuclear transformations, and cumulative energies of emitted alpha, electron, and photon emissions of the chain members over a period of 100 y, assuming a unit activity of the pure parent (e.g., 1 Bq of Es-254m) at time zero. The cumulative energy of alpha, electron (including beta) and photon emissions for the decay series is shown in the right three columns. The length of the chain that accounts for 99% of the total emitted energy over the 100 y time period is calculated for each energy type. For Es-254m the suggestion is made that for dosimetric purposes the chain could be truncated after the sixth member (Cm-250) because the contribution of the rest of the members to the cumulative energy of each radiation type is not significant. Some loss in numerical significance may be evident in these calculations for some decay chains and the guidance concerning truncation is somewhat arbitrary. However, this guidance has proven to be useful when considering the truncation of chains headed by or including long-lived radionuclides. In any event, the user must make the decision regarding truncation of the chain in his application.

DECDATA - A Summary of Radiation Emissions

Es-254m: Activity, Transformations, and Cumulative Energies (MeV) at 100y

	Nuclide	T1/2	A(t)/Ao	nt/Ao(s)	-- Cumulative Energy (MeV) -- Alpha	Electron	Photon
1	Es-254m	39.3h	0.000E+00	2.041E+05	4.246E+03	4.914E+04	9.709E+04
2	Fm-254	3.240h	0.000E+00	2.000E+05	1.464E+06	5.104E+04	9.881E+04
3	Cf-254	60.5d	0.000E+00	1.551E+02	1.464E+06	5.260E+04	1.014E+05
4	Cm-250	8300y	1.262E-12	3.990E-03	1.464E+06	5.260E+04	1.014E+05
5	Bk-250	3.212h	1.010E-13	6.532E+02	1.464E+06	5.279E+04	1.020E+05
6	Cf-250	13.08y	1.683E-06	1.996E+05	2.684E+06	5.484E+04	1.042E+05
7	Pu-246	10.84d	2.272E-13	7.178E-04	2.684E+06	5.484E+04	1.042E+05
8	Am-246m	25.0m	2.272E-13	7.178E-04	2.684E+06	5.484E+04	1.042E+05
9	Cm-246	4.76E+3y	9.093E-07	2.356E+03	2.697E+06	5.486E+04	1.042E+05
10	Pu-242	3.75E+5y	1.379E-10	1.862E-01	2.697E+06	5.486E+04	1.042E+05
11	U-238	4.468E+9y	9.152E-19	8.441E-10	2.697E+06	5.486E+04	1.042E+05
12	Th-234	24.10d	9.132E-19	8.414E-10	2.697E+06	5.486E+04	1.042E+05
13	Pa-234m	1.17m	9.132E-19	8.414E-10	2.697E+06	5.486E+04	1.042E+05
14	Pa-234	6.70h	1.461E-21	1.346E-12	2.697E+06	5.486E+04	1.042E+05
15	U-234	2.455E+5y	7.527E-23	5.693E-14	2.697E+06	5.486E+04	1.042E+05
16	Th-230	7.538E+4y	1.542E-26	4.018E-15	2.697E+06	5.486E+04	1.042E+05
17	Ra-226	1600y	1.197E-28	4.010E-15	2.697E+06	5.486E+04	1.042E+05
18	Rn-222	3.8235d	1.189E-28	4.010E-15	2.697E+06	5.486E+04	1.042E+05
19	Po-218	3.10m	1.193E-28	4.010E-15	2.697E+06	5.486E+04	1.042E+05
20	Pb-214	26.8m	1.189E-28	4.009E-15	2.697E+06	5.486E+04	1.042E+05
21	At-218	1.5s	2.381E-32	8.019E-19	2.697E+06	5.486E+04	1.042E+05
22	Bi-214	19.9m	1.193E-28	4.010E-15	2.697E+06	5.486E+04	1.042E+05
23	Rn-218	3.5E-2s	2.386E-35	8.019E-22	2.697E+06	5.486E+04	1.042E+05
24	Po-214	1.643E-4s	1.189E-28	4.009E-15	2.697E+06	5.486E+04	1.042E+05
25	Tl-210	1.30m	2.512E-32	8.420E-19	2.697E+06	5.486E+04	1.042E+05
26	Pb-210	22.20y	3.965E-29	4.010E-15	2.697E+06	5.486E+04	1.042E+05
27	Bi-210	5.013d	4.005E-29	4.010E-15	2.697E+06	5.486E+04	1.042E+05
28	Hg-206	8.15m	7.504E-37	7.618E-23	2.697E+06	5.486E+04	1.042E+05
29	Po-210	138.376d	3.846E-29	4.010E-15	2.697E+06	5.486E+04	1.042E+05
30	Tl-206	4.200m	5.368E-35	5.369E-21	2.697E+06	5.486E+04	1.042E+05

In dosimetric calculations the Es-254m chain can be truncated at member 6.
Press a key (or left click mouse) to continue...

Fig. 4.b. Summary of emitted energies of the Es-254m chain.

F3 key: Plots of radiation emissions
This function key generates, for the displayed radionuclide, a series of plots of the yield vs. energy of the emitted radiations. In the case of beta emission (negatron and positron) and neutrons the plots are continuous function of energy. For radiations of discrete energy a line plots are generated. Fig. 5 show the generated plots displayed in a cascade manner of the emissions of Cf-252. To expand the plot of interest, click the "maximize" icon in the upper right corner of the plot. The plots of the other radiations can then be selected for viewing by clicking on the "Window" item on DPlotJr's tool bar. You can force DECDATA to display the plots in the maximized manner by creating a file named "DPlotJr.INI" in the ICRP07 folder. The type of axis and their numerical extent can be modified by selecting the options item on DPlot Jr menu. Additional information is available under the help menu.

The neutron spectral data in the NSF file are binned and displayed in two plots evident in Fig. 5, the first being simply the binned spectra (y-axis is the number of neutron per nt with energy within the bin) and the second a lethargy plot (y-axis is the number of neutrons in the bin per nt in lethargy units, i.e., number per nt/ln(E_{i+1}/E_i) where E_{i+1} and E_i are the upper and lower energy bounds of the i^{th} energy bin).

Upon its very first use, DPlotJr may start with its plot window maximized. After resizing the window in the usual Windows manner (dragging the edge and centering) click on Options on the toolbar, select that last item (General) and remove the check mark on "Always start maximized." DplotJr will then start as sized in future applications.

If the ICRP-07.ACK file contains the Auger-CK electron spectrum for the selected radionuclide then the spectrum is also plotted in the cascade. The Auger-CK spectrum of Hg-195m is shown in Fig. 6.

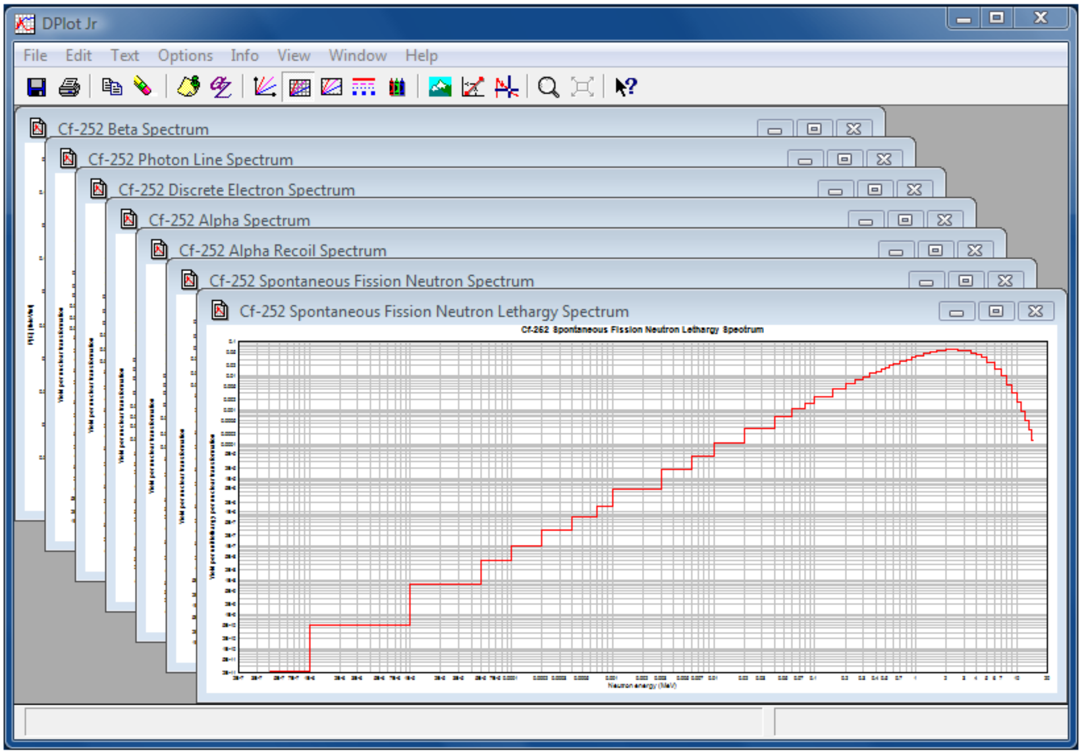


Fig. 5. Cascade plots of Cf-252 emissions.

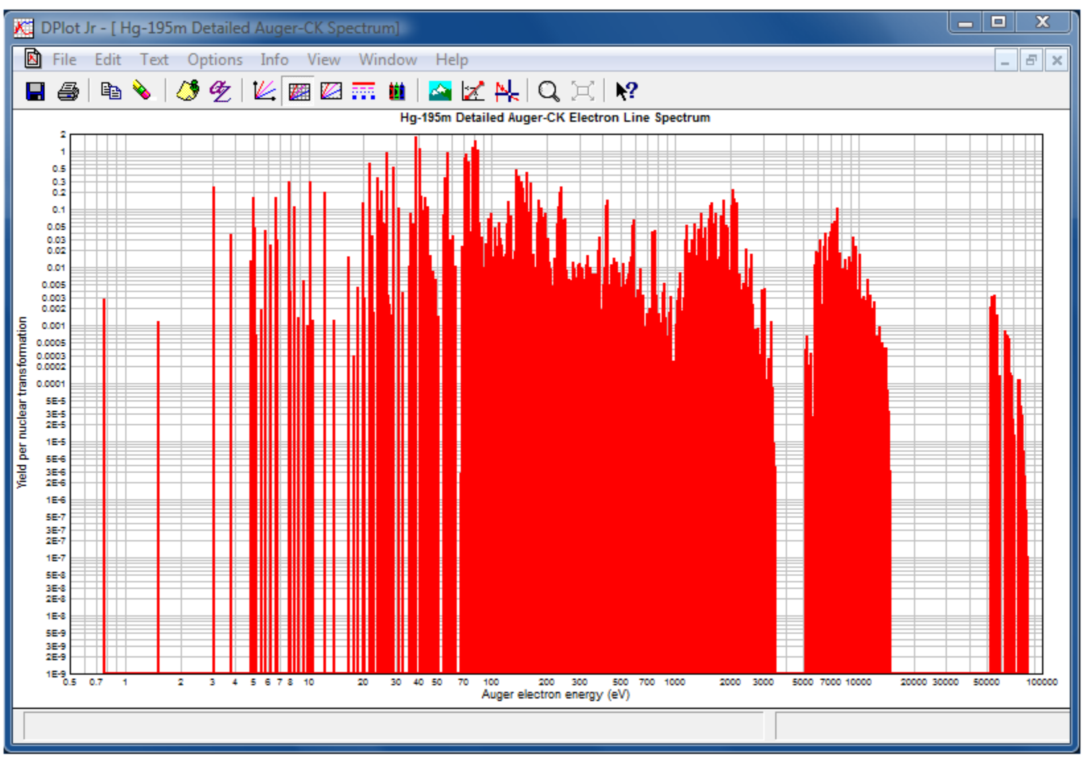


Fig. 6. Detailed Auger and Coster-Kronig electron emissions of Hg-195m.

F4 key: Nuclide lists

The function key F4 displays a menu providing a number of options for sorting and listing the radionuclides in the ICRP-07 collection. In addition, the last two menu items characterize the data files. The actions under this menu are displayed and written to the file NucList-X.TXT, where X corresponds to the index of the user-specified criteria selected from a menu. After the file(s) are constructed DECDATA will open the file using an application registered to open files with the extension TXT. The user is cautioned to be patient while DECDATA constructs the desired information and Windows loads an application to view the file. The menu items are presented below and shown in Fig. 7.

Menu items for sorting and characterizing the radionuclides in ICRP-07

Menu Item	Description
1. Atomic Number(Z)	List nuclides in order of atomic number
2. Physical Half-life	List nuclides by increasing physical half-life
3. Total Emitted Energy	List nuclides by increasing emitted energy
4. Decay by Alpha Emission	List nuclides that undergo alpha decay
5. Decay by Beta– Emission	List nuclides that undergo β^- (negatron) decay
6. Decay by Beta+ Emission	List nuclides that undergo β^+ (positron) decay
7. Decay by Internal Transition	List nuclides that undergo internal transition decay
8. Decay by Spontaneous Fission	List nuclides that undergo spontaneous fission
9. Detailed Auger-CK Spectra	List nuclides in the ACK file
10. Principal Alpha Emission	List nuclides by increasing energy of principal alpha emission
11. Principal Beta Transition	List nuclides by increasing energy of principal beta emission
12. Principal Photon Emission	List nuclides by increasing energy of principal photon emission
13. Air Kerma Constant & Coefficient	Tabulate air kerma-rate constant and coefficient
14. Beta/Electron Skin Dose Coefficient	Compute beta/electron skin dose coefficient
15. Serial Decay Chains	Tabulate serial decay chains
16. Dimensions of ICRP-07 Collection	List dimensions of collection
17. Check Integrity of Installed Files	Verify checksum of ICRP-07 data files.

As the files created by menu items 1 and 9 can be of frequent interest they are included in the REPORT folder as ICRP_Nuclide.TXT and AugerList.TXT, respectively. They can be accessed under the help provisions of the F6 key.

Menu item 14 invokes a calculation of absorbed dose rate to skin (Gy s^{-1} cm^2 Bq^{-1}) resulting from contamination of the skin by radionuclides that undergo beta decay or emit energetic conversion electrons. The absorbed dose calculations is based on the paper by Faw (1992) and is calculated as

$$D_{skin} = 1.602\ 10^{-10} \int_0^\infty P(E)\ R(E)\ dE + \sum_i Y(E_i)\ R(E_i) \tag{3}$$

where $P(E)$ is the number of electrons of energy between E and $E+dE$ emitted per nt as tabulated in the BET file, $Y(E_i)$ is the number of monoenergetic electrons of energy E_i emitted per nt, and $R(E)$ (MeV cm^2 g^{-1}) is the absorbed dose to the skin (averaged over a depth of 5 to 10 mg cm^{-2}) as a function of electron energy expressed in functional form by the parameters of Table 3 of Faw (1992). The integral over the beta spectrum is evaluated by fitting a piecewise cubic hermite interpolation polynomial to the integrand using the PCHIP routines of Fritsch and Carlson (1980).

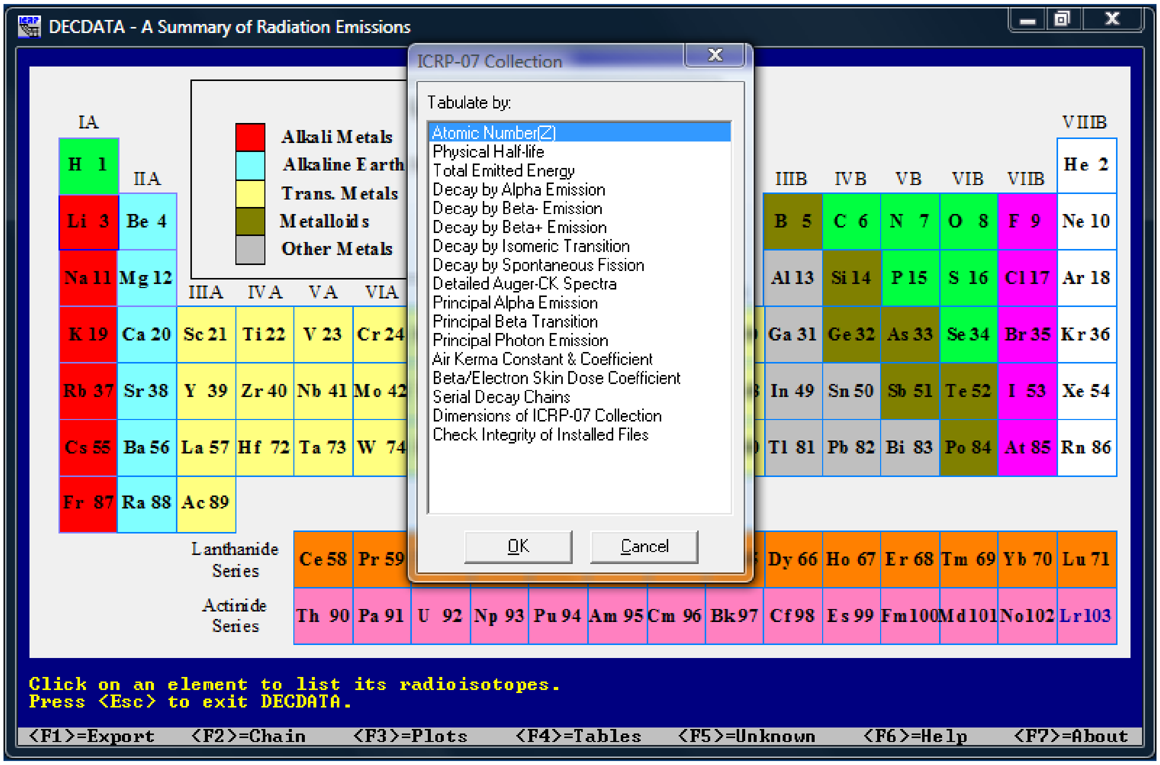
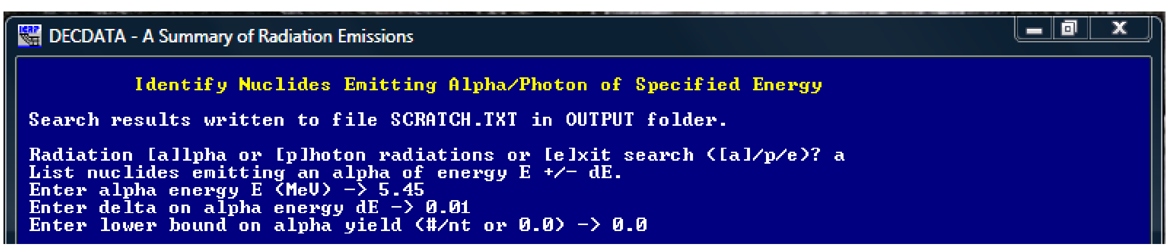


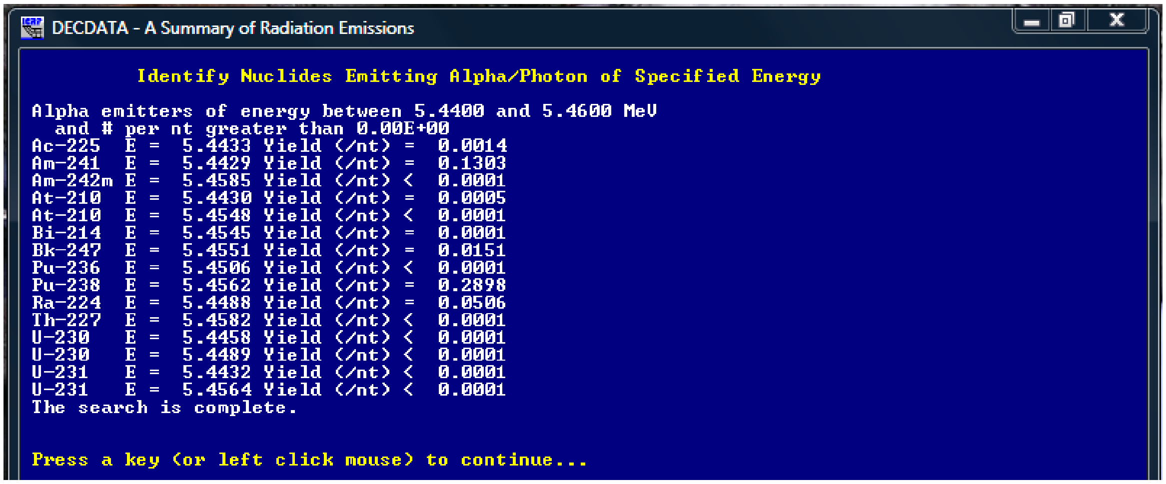
Fig. 7. Menu to characterize the ICRP-07 collection.

F5 key: Identify unknown radionuclide

This function key provides a means to associate an observed alpha particle or photon with a radionuclide in the ICRP-07 collection. For example, assume the emission of an alpha particle of energy 5.45 MeV has been observed. Pressing the F5 key opens a screen within which the user first defines whether the observed radiation is an alpha particle or a photon and then enters the observed energy. In addition to the point-value for the energy, a tolerance (or delta) in energy value and a lower bound on its yield (range from zero to 1.0) is requested as shown below.



A search of the RAD file is performed, as guided by information in the NDX file. The results appear on the screen and are written to the file SCRATCH.TXT in the OUTPUT folder. In this case the screen display is



```
DECDATA - A Summary of Radiation Emissions

          Identify Nuclides Emitting Alpha/Photon of Specified Energy

Alpha emitters of energy between 5.4400 and 5.4600 MeV
  and # per nt greater than 0.00E+00
Ac-225   E =  5.4433 Yield (/nt) =  0.0014
Am-241   E =  5.4429 Yield (/nt) =  0.1303
Am-242m  E =  5.4585 Yield (/nt) <  0.0001
At-210   E =  5.4430 Yield (/nt) =  0.0005
At-210   E =  5.4548 Yield (/nt) <  0.0001
Bi-214   E =  5.4545 Yield (/nt) =  0.0001
Bk-247   E =  5.4551 Yield (/nt) =  0.0151
Pu-236   E =  5.4506 Yield (/nt) <  0.0001
Pu-238   E =  5.4562 Yield (/nt) =  0.2898
Ra-224   E =  5.4488 Yield (/nt) =  0.0506
Th-227   E =  5.4582 Yield (/nt) <  0.0001
U-230    E =  5.4458 Yield (/nt) <  0.0001
U-230    E =  5.4489 Yield (/nt) <  0.0001
U-231    E =  5.4432 Yield (/nt) <  0.0001
U-231    E =  5.4564 Yield (/nt) <  0.0001
The search is complete.

Press a key (or left click mouse) to continue...
```

The search can lead to a substantial number of candidates, particularly for photons, and thus the file SCRATCH.TXT will need to be reviewed. The information on the yield of the radiations within the indicated energy range may be of help in eliminating some candidates. DECDATA will attempt to open the file using the application that has been associated with files with extension TXT, e.g., Microsoft Notepad or an ASCII editor.

F6 key: View files in the REPORT folder

The REPORT folder contains this User Guide, reports produced by the authors (Endo *et al.* 2005, Endo 2005, Endo and Eckerman 2007) during the course of the work creating the decay database, the original EDISTR report of Dillman (1980), and two files created via the F4 key as discussed above. The user can develop and maintain notes on the operation of DECDATA by creating in the REPORT folder a file with an extension registered by the operating system, e.g., using Microsoft NotePad. The file MyNotes.TXT is provided as a template.

F7 key: About

Provides the usual *About* screen associated with current software. The software license, agree to during the installation of DECDATA, can be viewed at this time by pressing the F8 key.

5. Programmer's Notes

The ICRP-07 data files are formatted direct-access files. Each record in these files is of fixed length and includes a carriage return and line feed so that the files are readable when opened with an ASCII editor. The length of the records, less the carriage return and line feed, for each of the ICRP-07 files is listed below.

Length of Records in the Direct-Access Files		
File	**Record Length***	**Number of records**
ICRP-07.NDX	226	1,253
ICRP-07.RAD	29	455,625
ICRP-07.BET	17	111,325
ICRP-07.ACK	32	131,571
ICRP-07.NSF	29	1,484
*Value does not include the carriage return and line feed.		

The number of data records N in the RAD file for a given nuclide is given in the header record for that nuclide in the file but it can also be computed from the nuclide's record in the NDX file as

$$N = \begin{cases} \sum_{1}^{5} \text{Number - i} + \text{Number - 5} \ , & SF \notin \text{Decay Mode} \\ \\ \sum_{1}^{5} \text{Number - i} + \text{Number - 5} + 2 \ , & SF \in \text{Decay Mode} \end{cases}$$

where Number-i refers to the fields of the nuclide record so designated in Table 1. Whether a nuclide decays by spontaneous fission can be determined by parsing its decay mode for the characters "SF" or by noting if the pointer into the NSF file (Pointer-4 of Table 1) is nonzero. The number of alpha transitions, Number-5, enters into the above equation twice since records are included in the RAD file for the kinetic energy of the recoiling nuclei formed in alpha decay as well as the alpha particles themselves. The two additional records for those nuclides undergoing spontaneous fission are those of the mean energies of the fission fragments and neutrons accompanying spontaneous fission.

Records in the RAD file for a particular radiation type emitted by a specific radionuclide can be read as tabulated below. In the table below the fields Pointer-i and Number-i defined in Table 1 of the nuclide's record in the NDX file are denoted by P_i and N_i, respectively. The data records for the radiation type in the RAD file lie between the lower and upper record numbers specified in the last two columns below.

Record Number of Radiations in RAD File			
	Number	**Location of Data Records for Radiation Type**	
Radiation Type	**Records**	**From**	**To**
Photons, E < 10 keV	N_1	$P_1 + 1$	$P_1 + N_1$
Photons, E ≥10 keV	N_2	$P_1 + N_1 + 1$	$P_1 + N_1 + N_2$
Photons, all	N_1+N_2	$P_1 + 1$	$P_1 + N_1 + N_2$
Beta particles	N_3	$P_1 + N_1 + N_2 + 1$	$P_1 + N_1 + N_2 + N_3$
Monoenegetic electrons	N_4	$P_1 + N_1 + N_2 + N_3 + 1$	$P_1 + N_1 + N_2 + N_3 + N_4$
Alpha particles	N_5	$P_1 + N_1 + N_2 + N_3 + N_4 + 1$	$P_1 + N_1 + N_2 + N_3 + N_4 + N_5$
Alpha recoil	N_5	$\mathrm{P_1 + N_1 + N_2 + N_3 + N_4 + N_5 + 1}$	$P_1 + N_1 + N_2 + N_3 + N_4 + 2\ N_5$
Fission fragments[a)]	*1*	$P_1 + N_1 + N_2 + N_3 + N_4 + 2\ N_5 + 1$	$P_1 + N_1 + N_2 + N_3 + N_4 + 2\ N_5 + 1$
Neutrons[a)]	*1*	$P_1 + N_1 + N_2 + N_3 + N_4 + 2\ N_5 + 2$	$P_1 + N_1 + N_2 + N_3 + N_4 + 2\ N_5 + 2$
[a)]Records present only if nuclide undergo spontaneous fission, i.e., $P_4 > 0$.			

The dimensions of the ICRP-07 collection can be tabulated by selecting the penultimate item on the menu displayed via the F4 key. The listing created gives the maximum number of radiations of the various types in the RAD file and the number of discrete energy points in the continuous beta and neutron spectra. For example, the maximum number of records in the RAD file for radiations emitted by a single radionuclide is 4121 in the case of Lu-170. The resultant list is shown below.

```
Dimensions of the ICRP-07 Collection

 Radionuclides        - 1252
 Radiation records    - 4121 (Lu-170)
 Beta transitions     -   79 (Gd-145)
 Alpha transitions    -   52 (Pu-239)
 Photons: E < 10 keV  -   83 (Sm-141m)
 Photons: E > 10 keV  -  664 (Lu-170)
              Total   -  699 (Lu-170)
 Discrete electrons   - 3409 (Lu-170)

 Energy Range: Discrete Radiations
   Betas*             -  6.2E-04 to  4.9806 MeV (Re-187, N-16)
   Photons            -  3.1E-07 to  9.9100 MeV (Na-24, Cf-246)
   Electrons          -  8.8E-06 to  8.8693 MeV (In-114m, N-16)
   Alphas             -  1.85224 to 11.6512 MeV (Nd-144, Po-212m)
   Alpha recoils      -  0.05148 to  0.2242 MeV (Pb-202, Po-212m)
   Fission fragments$ - 84.84610 to 97.7707 MeV (U-238, Fm-252)
   Fission neutrons$  -  1.68813 to  2.3823 MeV (U-238, Cm-240)
   --------------------
   *Average energy of beta transitions
   $Average energy in spontaneous fission

 Spectral Dimensions
   Beta spectrum      -  138 (N-16)
   Auger-CK spectrum  - 3015 (Hg-195m)
   Neutron spectrum   -   52 (Cf-246)

 Energy Range: Spectra
   Beta               - 0.00    to 10.4207 MeV (N-16)
   Neutron (bins)     - 0.41 eV to 15.0000 MeV (U-238, Cm-240)
   Auger-CK electrons - 0.15 eV to 88.1763 keV (Tb-157, Bi-204)

 Decay Chains
   Chain length       -   30 (Es-254m)

 Elements
   Number             -   97
   Radioisotopes      -   29 (Indium)

 Data File             Record length  # records
   ICRP-07.NDX        -      226          1253
   ICRP-07.RAD        -       29        455625
   ICRP-07.BET        -       17        111325
   ICRP-07.ACK        -       32        131571
   ICRP-07.NSF        -       29          1484
```

The DECDATA source code is included in the folder SOURCE of the ARCHIVE folder on the CD. The functions and subroutines of the code can be readily translated to other programming languages.

References

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