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Nuclear Decay Data Files of the Dosimetry Research Group

K. F. Eckerman
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Health Sciences Research Division

**NUCLEAR DECAY DATA FILES
OF THE DOSIMETRY RESEARCH GROUP**

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R. J. Westfall
J. C. Ryman
M. Cristy

December 1993

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ABSTRACT

This report documents the nuclear decay data files used by the Dosimetry Research Group at Oak Ridge National Laboratory and the utility DEXRAX which provides access to the files. The files are accessed, by nuclide, to extract information on the intensities and energies of the radiations associated with spontaneous nuclear transformation of the radionuclides. In addition, beta spectral data are available for all beta-emitting nuclides. Two collections of nuclear decay data are discussed. The larger collection contains data for 838 radionuclides, which includes the 825 radionuclides assembled during the preparation of Publications 30 and 38 of the International Commission on Radiological Protection (ICRP) and 13 additional nuclides evaluated in preparing a monograph for the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine. The second collection is composed of data from the MIRD monograph and contains information for 242 radionuclides. Abridged tabulations of these data have been published by the ICRP in Publication 38 and by the Society of Nuclear Medicine in a monograph entitled "MIRD: Radionuclide Data and Decay Schemes." The beta spectral data reported here have not been published by either organization. Electronic copies of the files and the utility, along with this report, are available from the Radiation Shielding Information Center at Oak Ridge National Laboratory.

I. INTRODUCTION

The Dosimetry Research Group (DRG) of the Health Sciences Research Division at Oak Ridge National Laboratory (ORNL) has for several years maintained data bases of nuclear decay data for use in dosimetric calculations¹⁻⁴. Although other sources of radioactive decay information are available^{5,6}, our data base, in machine-readable form, has been explicitly designed to address the needs in medical, environmental, and occupational radiation protection. These needs are generally served by information on the mean or unique energy of each radiation and its absolute intensity, including the subsequent atomic radiations. Calculations of the spatial distribution of absorbed dose (depth-dose) requires information on the beta spectra, and these are compiled in a separate data file, also described herein.

The computer program EDISTR, developed by Dillman⁷, is used to calculate the intensities and energies of the radiations of the radionuclides contained in the data files. Information on nuclear structure is taken from the Evaluated Nuclear Structure Data File (ENSDF) at the Brookhaven National Laboratory⁸. EDISTR, using information from ENSDF, computes and tabulates data for alpha, beta, gamma, internal conversion electron, x-ray, Auger-electron, and bremsstrahlung radiations emitted in spontaneous nuclear transformations of radionuclides. Beta spectral shapes are calculated to determine the mean energy of each beta transition. Data on radiations from spontaneously fissioning radionuclides (fission fragments, neutrons, prompt gammas, delayed gammas, and betas) are computed from the methods of Dillman and Jones¹⁴. The nuclear decay data used in the dosimetric calculations for Publication 30⁹ of the International Commission on Radiological Protection (ICRP) were derived from EDISTR and were subsequently published, in an abridged format, in ICRP Publication 38³. The unabridged data, including the beta spectral data, were maintained within the ICRP/ORNL dosimetric data files of the DRG. It is the unabridged data that is the subject of this report.

This report documents the decay data files currently used in dosimetric calculations at ORNL. The decay data files were constructed on the mainframe computers at ORNL, were subsequently moved to a microVAX computer, and now reside on various computing platforms, including personal computers and workstations. Access to the decay data records is provided by the FORTRAN utility code DEXRAX (DEcay eXtRActor[X]). The data are assembled in two collections. The collection referred to as "ICRP38" consists of data for 825 radionuclides that were within the ICRP/ORNL dosimetric files, plus an additional 13 radionuclides (see Table 1) evaluated during preparation of a

Table 1. Nuclides in ICRP38 Collection from MIRD Monograph

Nuclide	Half-life	Nuclide	Half-life
O-14	70.599 s	Er-167m	2.28 s
O-19	26.91 s	Hg-206	8.15 m
Cu-57	233 ms	Pb-204m	67.2 m
Se-72	8.40 d	Bi-204	11.22 h
Rb-77	3.70 m	Po-209	102 y
In-111m	7.7 m	Tl-210	1.30 m
Sb-118	3.6 m		

monograph⁴ for the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine. The collection referred to as "MIRD" contains 242 radionuclides of interest to the medical community as published in the MIRD monograph⁴. The MIRD collection contains data for 161 radionuclides whose ENSDF dates are later than those in the ICRP38 collection (Table 2). In most instances the differences are of no dosimetric significance, but considerable differences may exist for some nuclides. For example, the total emitted energies for Te-123 in the two collections differ by more than a factor of two as a result of change in the estimated total energy (the Q value) available for the beta transition.

Both data collections resulted from processing the ENSDF information through the EDISTR code plus adding information on spontaneously fissioning radionuclides from Dillman and Jones¹⁴. Our interest here is limited to the following data elements of the EDISTR output:

- the complete listing of the emitted radiations, their types, energies, and absolute intensities for the radionuclide, and
- the composite beta spectrum for a beta-emitting radionuclide ("composite" means that all the beta radiations are combined into one spectrum — see Fig. 1).

We shall refer to the former as "radiations" data and the latter as "beta spectra" data. Extraction of radiations data and/or beta spectra data for the radionuclide of interest via DEXRAX is the starting point of all dosimetric calculations performed for internal emitters by the DRG staff.

The ICRP38 and the MIRD collections and DEXRAX are available in electronic form, along with this report, from the Radiation Shielding Information Center (RSIC), Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6362, by requesting data library package DLC-172, entitled *NUCDECAY, ICRP and MIRD Nuclear Decay Data*.

Table 2. Nuclides for which MIRD collection has later ENSDF date than ICRP38 collection.

Nuclide	Energy/nuclear transformation (MeV/nt)			Ratio MIRD/ICRP			Nuclide	Energy/nuclear transformation (MeV/nt)			Ratio MIRD/ICRP		
	ICRP38 collection alpha elec. photon	MIRD collection alpha elec. photon		alpha elec. photon				ICRP38 collection alpha elec. photon	MIRD collection alpha elec. photon		alpha elec. photon		
Am-241	5.4791 .0520 .0325	5.4791 .0585 .0340	1	1.13**	1.05		Dy-157	.0134 .3565	.0138 .3405	1.03	.96		
As-72	1.0257 1.7938	1.0332 1.7763		1.01	.99		Dy-159	.0128 .0450	.0131 .0451	1.02	1		
As-73	.0603 .0160	.0603 .0160		1	1		Er-171	.4218 .3812	.4200 .3727	1	.98		
At-218	6.6969 .0399 .0067	6.6969 .0398 .0066	1	1	.99		Fe-52	.1935 .7404	.1935 .7404	1	1		
Au-198	.3274 .4051	.3269 .4043		1	1		Fe-55	.0042 .0016	.0042 .0016	1	1		
Ba-128	.0094 .0761	.0088 .0659		.94	.87**		Fe-59	.1176 1.1888	.1177 1.1883	1	1		
Ba-133	.0542 .4019	.0535 .4018		.99	1		Ga-66	.9699 2.4733	.9833 2.4545	1.01	.99		
Be-7	.0493	.0496			1.01		Ga-67	.0355 .1580	.0343 .1548	.97	.98		
Bi-210	.3889	.3888		1			Ga-68	.7392 .9507	.7393 .9474	1	1		
Bi-212	2.1741 .4720 .1855	2.1746 .5035 .1062	1	1.07	.57**		Ga-72	.4969 2.7110	.5020 2.7241	1.01	1		
Bi-214	.6593 1.5082	.6593 1.5082	.0011/0	1	1		Gd-153	.0439 .1055	.0415 .1010	.95	.96		
Br-75	.5241 1.2157	.5062 1.2027		.97	.99		Ge-68	.0049 .0041	.0049 .0041	1	1		
Br-76	.6906 2.6329	.6456 2.7904		.93	1.06		H-3	.0056	.0056	1	1		
Br-77	.0092 .3208	.0095 .3314		1.03	1.03		Hg-197	.0664 .0700	.0664 .0703	1	1		
Br-80	.7236 .0796	.7266 .0758		1	.95		Hg-197m	.2146 .0943	.2161 .0942	1.01	1		
Br-80m	.0603 .0240	.0615 .0242		1.02	1.01		Hg-203	.0988 .2381	.0989 .2380	1	1		
C-11	.3846 1.0195	.3846 1.0195		1	1		I-123	.0281 .1717	.0283 .1726	1.01	1.01		
Ca-45	.0772	.0772		1			I-124	.1937 1.0982	.1955 1.0832	1.01	.99		
Ca-47	.3448 1.0627	.3505 1.0471		1.02	.99		I-125	.0193 .0420	.0194 .0419	1.01	1		
Ca-49	.8695 3.1646	.8699 3.1675		1	1		I-126	.1573 .4548	.1459 .4329	.93	.95		
Cd-109	.0826 .0263	.0825 .0259		1	.98		I-129	.0638 .0246	.0632 .0244	.99	.99		
Ce-134	.0069 .0262	.0084 .0278		1.22**	1.06		I-132	.4953 2.2804	.4953 2.2804	1	1		
Ce-139	.0355 .1595	.0355 .1587		1	.99		I-132m	.1588 .3222	.1563 .3207	.98	1		
Ce-141	.1705 .0762	.1707 .0765		1	1		In-109	.0468 .6722	.0468 .6722	1	1		
Cf-252	5.9223 .0056 .0012	5.9223 .0056 .0012	1	1	1		In-111	.0344 .4053	.0347 .4049	1.01	1		
Co-55	.4294 1.9942	.4315 1.9961		1	1		In-113m	.1339 .2576	.1339 .2576	1	1		
Co-57	.0186 .1252	.0186 .1252		1	1		In-114	.7714 .0027	.7760 .0023	1.01	.85**		
Co-58	.0341 .9756	.0341 .9757		1	1		In-114m	.1430 .0944	.1430 .0944	1	1		
Co-60	.0965 2.5043	.0964 2.5045		1	1		In-115m	.1723 .1611	.1724 .1611	1	1		
Cr-48	.0084 .4358	.0086 .4321		1.02	.99		Ir-190	.1288 1.4427	.0758 1.5030	.59**	1.04		
Cr-51	.0038 .0325	.0038 .0333		1	1.02		Ir-190m	.0243 .0019	.0243 .0019	1	1		
Cs-128	.8455 .9004	.8701 .8895		1.03	.99		Ir-190n	.1255 1.5546	.1263 1.5479	1.01	1		
Cs-129	.0179 .2815	.0178 .2812		.99	1		Ir-192	.2173 .8179	.2172 .8153	1	1		
Cs-134	.1636 1.5551	.1642 1.5552		1	1		Kr-77	.6420 1.0160	.8243 1.1044	1.28**	1.09		
Cs-134m	.1117 .0267	.1124 .0270		1.01	1.01		Kr-79	.0243 .2574	.0244 .2571	1	1		
Cs-137	.1870	.1874		1			Kr-81	.0051 .0117	.0051 .0168	1	1.44**		
Cu-62	1.2848 1.0067	1.2848 1.0069		1	1		Kr-81m	.0594 .1308	.0590 .1300	.99	.99		
Cu-64	.1226 .1906	.1224 .1907		1	1		Kr-83m	.0387 .0026	.0387 .0026	1	1		
Cu-67	.1553 .1153	.1558 .1153		1	1		Kr-85	.2505 .0022	.2505 .0022	1	1		
							Kr-85m	.2553 .1581	.2554 .1566	1	.99		

** Difference between MIRD and ICRP38 > 10%.

Note: Ratios 1.00 shown as 1.

Table 2 (cont'd).

Nuclide	Energy/nuclear transformation (MeV/nt)			Ratio MIRD/ICRP			Nuclide	Energy/nuclear transformation (MeV/nt)			Ratio MIRD/ICRP		
	ICRP38 collection	MIRD collection		alpha	elec.	photon		ICRP38 collection	MIRD collection		alpha	elec.	photon
	alpha	elec.	photon					alpha	elec.	photon			
La-134	.7386	.6978		.7591	.7164	1.03	1.03	Ru-103	.0748	.4687	.0665	.4947	.89** 1.06
La-140	.5370	2.3149		.5351	2.3159	1	1	Ru-97	.0133	.2399	.0130	.2404	.98 1
Mn-51	.9344	.9977		.9347	.9977	1	1	Sc-47	.1625	.1083	.1628	.1082	1 1
Mn-52	.0748	3.4576		.0748	3.4576	1	1	Sc-49	.8223	.0010	.8177	.0010	.99 1
Mn-52m	1.1318	2.4088		1.1326	2.4102	1	1	Se-73	.3855	1.0873	.3894	1.0965	1.01 1.01
Mn-54	.0042	.8360		.0042	.8360	1	1	Se-73m	.1779	.2439	.1710	.2519	.96 1.03
Mo-99	.3922	.1500		.3926	.1492	1	.99	Se-75	.0145	.3942	.0146	.3916	1.01 .99
Na-22	.1941	2.1925		.1941	2.1925	1	1	Sm-145	.0319	.0652	.0310	.0640	.97 .98
Na-24	.5535	4.1212		.5535	4.1231	1	1	Sm-153	.2726	.0619	.2702	.0619	.99 1
Nb-95	.0444	.7658		.0445	.7643	1	1	Sn-113	.0063	.0228	.0063	.0227	1 1
Nb-95m	.1663	.0683		.1745	.0686	1.05	1	Sr-83	.1494	.8013	.1494	.8013	1 1
Ni-57	.1431	1.9219		.1550	1.9421	1.08	1.01	Sr-85	.0089	.5118	.0089	.5133	1 1
Ni-63	.0171			.0171		1		Sr-85m	.0122	.2195	.0131	.2160	1.07 .98
Os-190m	.1163	1.5884		.1168	1.5886	1	1	Sr-87m	.0669	.3203	.0670	.3210	1 1
Os-191	.1353	.0795		.1330	.0748	.98	.94	Ta-177	.0238	.0671	.0238	.0671	1 1
Os-191m	.0650	.0091		.0652	.0089	1	.98	Ta-178a	.0335	.1086	.0335	.1086	1 1
P-30	1.4363	1.0219		1.4362	1.0220	1	1	Ta-182	.2169	1.2943	.2169	1.2943	1 1
P-32	.6946			.6946		1		Tc-94m	.7558	1.8589	.7546	1.9382	1 1.04
Pb-201	.0575	.7580		.0599	.7576	1.04	1	Tc-95	.0068	.7964	.0068	.7979	1 1
Pb-203	.0523	.3118		.0527	.3141	1.01	1.01	Tc-95m	.0155	.6750	.0154	.7191	.99 1.07
Pb-210	.0379	.0048		.0379	.0048	1	1	Tc-97m	.0868	.0095	.0867	.0095	1 1
Pb-212	.1755	.1483		.1754	.1451	1	.98	Tc-99	.1012		.1012		1 1
Pb-214	.2932	.2497		.2932	.2497	1	1	Tc-99m	.0162	.1263	.0161	.1265	.99 1
Pd-103	.0058	.0144		.0058	.0144	1	1	Te-123	.0063	.0197	.0028	.0001	.44** .01**
Pd-109	.4374	.0117		.4374	.0117	1	1	Te-123m	.0993	.1480	.1024	.1482	1.03 1
Pm-145	.0140	.0310		.0126	.0309	.90**	1	Tl-201	.0434	.0934	.0434	.0934	1 1
Po-210	5.2970		5.3045			1		Tl-208	.5976	3.3745	.6109	3.3601	1.02 1
Po-211	7.4421	.0001 .0078	7.4423	.0001 .0077		1	1 .99	Tm-171	.0255	.0006	.0255	.0006	1 1
Po-212	8.7848		8.7843			1		V-48	.1488	2.9141	.1478	2.9127	.99 1
Po-214	7.6871		7.6871			1		W-181	.0108	.0404	.0136	.0398	1.26** .99
Po-216	6.7786		6.7786			1		W-188	.0996	.0019	.0996	.0019	1 1
Ra-224	5.6739	.0022 .0099	5.6739	.0022 .0099		1	1 1	Xe-123	.1837	.6336	.1876	.6410	1.02 1.01
Ra-226	4.7743	.0035 .0067	4.7743	.0035 .0067		1	1 1	Xe-127	.0325	.2802	.0324	.2800	1 1
Rb-79	.8201	1.3578	.7770	1.4381		.95	1.06	Xe-129m	.1847	.0512	.1847	.0512	1 1
Rb-81	.1965	.6233	.1842	.6448		.94	1.03	Xe-133	.1357	.0461	.1357	.0461	1 1
Rb-82m	.0954	2.9099	.0954	2.9099		1	1	Y-87	.0070	.4572	.0071	.4579	1.01 1
Rb-83	.0146	.5044	.0146	.5044		1	1	Yb-169	.1247	.3097	.1232	.3114	.99 1.01
Rb-84	.1548	.9187	.1615	.8865		1.04	.96	Zn-62	.0326	.4389	.0326	.4389	1 1
Re-188	.7800	.0576	.7800	.0577		1	1	Zn-65	.0068	.5842	.0068	.5832	1 1
Rh-103m	.0379	.0017	.0371	.0017		.98	1	Zn-69	.3209		.3209		1 1
								Zn-69m	.0222	.4166	.0222	.4164	1 1
								Zr-95	.1163	.7388	.1179	.7321	1.01 .99

** after ratio means difference between ICRP & MIRD > 10%

** Difference between MIRD and ICRP38 > 10%.

Note: Ratios 1.00 shown as 1.

Figure 1. Composite Beta Spectrum for ^{87}Kr . Each point represents a tabulated value.

II. NUCLEAR DECAY DATA FILES

The radiations data files ICRP38.RAD and MIRD.RAD contain information on the absolute intensities and mean energies of all radiations emitted by the 838 and 242 radionuclides in the ICRP38 and MIRD collections, respectively. (For the fission component of spontaneously fissioning radionuclides, these files contain instead the number of spontaneous fissions per 100 decays and the number of neutrons per fission. When data on selected nuclides are extracted from the RAD files, as described later, the output files contain the information on the intensities and the mean energies of the various radiations associated with fission. See Fig. 7 and Table 13.) The radiations data extracted from these files are used in computing SEE values, the specific effective energy of Publication 30⁹. Our computer program for computing SEEs, SEECAL, is documented by Cristy and Eckerman¹⁰, and is also available from RSIC.

Two other files, ICRP38.BET and MIRD.BET, contain the beta spectra data for all beta emitters in the two collections. EDISTR computed the spectra for each beta transition to determine the mean beta energy of the transition and tabulated the composite spectra for all beta transitions. The spectral data were not tabulated in ICRP Publication 38³ nor in the MIRD monograph⁴, but the former data were used in the calculations of the derived air concentration (DAC) for submersion exposure given in ICRP Publication 30⁹. Note: if your only interest in DEXRAX is extracting data to compute SEEs with SEECAL¹⁰, you will never need to extract data for beta spectra, because SEECAL uses the average energy of each beta transition contained in either ICRP38.RAD or MIRD.RAD. A future version of SEECAL will, however, use the spectral data.

To facilitate access to the information in the rather large data files, two additional files, the index files ICRP38.IDX and MIRD.IDX, have been constructed. The index files contain information needed to retrieve the records for the nuclide of interest from their corresponding RAD and BET files. Thus a triplet of files, with extensions IDX, RAD, and BET, define each collection. Our interest here is with the manner in which records are extracted from these files — the reader should consult the EDISTR manual² for details regarding the generation of the information. Summary information on the nuclear transformations of the nuclides in the two collections is given in Appendix A. We proceed with a brief description of the three types of files, i.e., the index files ICRP38.IDX and MIRD.IDX, the radiation files ICRP38.RAD and MIRD.RAD, and the beta spectra files ICRP38.BET and MIRD.BET. When it is not necessary to differentiate between the collections we will refer to the files by their extensions, i.e., IDX, RAD, and BET.

Index Files ICRP38.IDX and MIR.D.IDX

The IDX files serve as the entrance into the larger radiations (RAD) and beta spectra (BET) data files. The IDX file contains one record for each nuclide in the collection. Each record has fields giving the location of and the number of records for the nuclide in the RAD and BET files. In addition to these pointers, other fields give the half-life, the modes of decay (e.g., alpha or beta), the identity of any radioactive decay products (daughters), the fraction of the nuclear transformations forming the daughters (the branching fractions), and the total energy emitted by alpha, electron, and photon radiations (excluding electrons and photons accompanying spontaneous fission). A description of the IDX records is given in Table 3, and excerpts from ICRP38.IDX are shown in Table 4.

The index files are direct-access files with the records sorted by the nuclide field so that a binary search can be performed to locate the record for a particular nuclide quickly. While the purpose of the IDX file was to provide the entrance into the larger RAD and BET files, they are of considerable utility in their own right. For example, it is possible to construct the entire decay chain for a radionuclide from the information in these files.

Table 3. Structure of Records in ICRP38.IDX and MIRD.IDX Files.

Variable	Format	Description
Record #1 FORMAT(2I4); length = 125		
First	I4	Record number of first data record.
Last	I4	Record number of last data record.
Data Records (First, ..., Last) FORMAT(A7,A8,A2,A8,I7,I5,I6,I4,3(I4,E11.0),E7.0,2F8.0,A10); length = 125		
Nuclide	A7	Name of nuclide; e.g., Am-241, Tc-99m.
Half-life	A8	Half-life of nuclide.
Units	A2	Half-life units: us - microseconds, ms - milliseconds, s - seconds, m - minutes, d - day, and y - year.
Decay Modes	A8	Decay modes; A denotes alpha, B- beta minus, B+ beta plus, EC electron capture, IT internal transition, and SF spontaneous fission.
Index, Radiat.	I7	Location of nuclide in ICRP38.RAD or MIRD.RAD file.
Nrad	I5	Number of radiation records for nuclide in *.RAD file.
Index, Beta	I6	Location of nuclide in ICRP38.BET or MIRD.BET file.
Neng	I4	For nuclide, number of spectral energies in *.BET.
Index, D1	I4	Location of first daughter in IDX file (ICRP38 or MIRD).
Frac1	E11.0	Fraction of nuclear transformation forming first daughter (branching fraction).
Index, D2	I4	Location of second daughter in IDX file.
Frac2	E11.0	Branching fraction for second daughter.
Index, D3	I4	Location of third daughter in IDX file.
Frac3	E11.0	Branching fraction for third daughter.
E _T : Alpha	F7.0	Total energy of alpha emissions, MeV/nt.
E _T : Electron	F8.0	Total energy of electron emissions, MeV/nt.
E _T : Photon	F8.0	Total energy of photon emissions, MeV/nt.
Date	A10	Date of ENSDF evaluation for nuclide.

Table 4. First 36 and Last 13 Records of File ICRP38.IDX.

The x's within the dashed header lines mark the end of each field. See Table 3 for explanation of each field.

Nuclide	Half-life & units	Decay Modes	Index, Radiat.	# Rec	Index, Beta Rec	# Rec	Index D1	Frac1	Index D2	Frac2	Index D3	Frac3	Energy Alpha	Energy Electron	Energy Photon	ENDSDF Date
Ac-223	2.2m	A	187724	187	0	0	230	1.0000E 00					6.5532	0.0150	0.0062	21-OCT-77
Ac-224	2.9h	A EC	188838	434	0	0	548	9.0000E-01	231	1.0000E-01			0.6107	0.0402	0.2000	28-MAR-79
Ac-225	10.0d	A	189349	382	0	0	232	1.0000E 00					5.7873	0.0223	0.0180	05-MAY-77
Ac-226	29h	A B-EC	189766	128	57018	112	739	8.2800E-01	550	1.7200E-01	233	6.0000E-05	0.0003	0.2893	0.1300	23-MAR-79
Ac-227	21.773y	B-A	190099	232	57132	73	740	9.8620E-01	234	1.3800E-02			0.0680	0.0157	0.0002	20-OCT-77
Ac-228	6.13h	B-	192575	1246	57323	119	741	1.0000E 00					0.0	0.4751	0.9708	03-JUN-77
Ag-102	12.9m	ECB+	35136	291	19651	125							0.0	0.8189	3.3532	05-MAR-76
Ag-103	65.7m	ECB+	35942	769	19986	117	483	1.0000E 00					0.0	0.2593	0.7651	23-MAR-78
Ag-104	69.2m	ECB+	37373	530	20337	118							0.0	0.0914	2.6834	29-DEC-78
Ag-104m	33.5m	ECB+IT	37032	340	20213	122	10	3.3000E-01					0.0	0.5087	1.1739	09-FEB-76
Ag-105	41.0d	ECB+	38959	322	20691	97							0.0	0.0192	0.5254	29-MAR-78
Ag-106	23.96m	ECB+	40263	115	21009	118							0.0	0.5078	0.7108	23-MAR-78
Ag-106m	8.41d	EC	39830	432	0	0							0.0	0.0132	2.8219	23-MAR-78
Ag-108	2.37m	ECB+B-	42554	176	21732	117							0.0	0.6104	0.0178	19-DEC-75
Ag-108m	127y	ECIT	42438	115	0	0	15	8.9000E-02					0.0	0.0160	1.6267	09-AUG-77
Ag-109m	39.6s	IT	42731	47	0	0							0.0	0.0768	0.0111	01-APR-78
Ag-110	24.6s	B-EC	44158	182	22177	123							0.0	1.1815	0.0306	19-JAN-78
Ag-110m	249.9d	ITB-	43633	524	22073	102	18	1.3300E-02					0.0	0.0722	2.7505	19-JAN-78
Ag-111	7.45d	B-	45184	116	22526	111							0.0	0.3542	0.0263	17-JUN-78
Ag-112	3.12h	B-	45558	667	22756	126							0.0	1.3836	0.6571	20-APR-78
Ag-115	20.0m	B-	46560	519	23309	124	120	9.3400E-01	121	6.6000E-02			0.0	1.0424	0.7069	20-DEC-77
Al-26	7.16E5y	ECB+	122	30	1085	112							0.0	0.4449	2.6756	19-SEP-75
Al-28	2.240m	B-	153	23	1199	123							0.0	1.2422	1.7788	06-MAR-77
Am-237	73.0m	A EC	203195	348	0	0	536	9.9970E-01	432	2.5000E-04			0.0015	0.0772	0.3696	23-MAR-78
Am-238	98m	ECA	204293	530	0	0	537	1.0000E 00	433	1.0000E-06			0.0000	0.0524	0.8911	28-JUN-77
Am-239	11.9h	A EC	205429	284	0	0	538	9.9990E-01	434	1.0000E-04			0.0005	0.1678	0.2393	21-DEC-77
Am-240	50.8h	A EC	207916	302	0	0	539	1.0000E 00	436	1.9000E-06			0.0000	0.0748	1.0287	22-DEC-77
Am-241	432.2y	A	209262	976	0	0	437	1.0000E 00					5.4791	0.0520	0.0325	23-MAR-78
Am-242	16.02h	ECB-	210851	81	59652	105	147	8.2700E-01	541	1.7300E-01			0.0	0.1794	0.0183	22-DEC-77
Am-242m	152y	A IT	210664	186	0	0	30	9.9500E-01	438	4.7600E-03			0.0247	0.0442	0.0051	22-DEC-77
Am-243	7380y	A	211111	142	0	0	439	1.0000E 00					5.2702	0.0217	0.0560	01-FEB-78
Am-244	10.1h	B-	211668	90	59981	99	149	1.0000E 00					0.0	0.3423	0.8071	22-DEC-77
Am-244m	26m	B-	211634	33	59864	115	149	1.0000E 00					0.0	0.5088	0.0015	22-DEC-77
Am-245	2.05h	B-	211869	85	60082	109	150	1.0000E 00					0.0	0.2875	0.0323	15-APR-76
Am-246	39m	B-	214196	123	60430	112	151	1.0000E 00					0.0	0.6549	0.6994	24-DEC-75
Am-246m	25.0m	B-	213149	1046	60308	120	151	1.0000E 00					0.0	0.4977	1.0180	24-DEC-75
...																
Zn-62	9.26h	ECB+	4499	177	7130	104	186	1.0000E 00					0.0	0.0326	0.4389	26-JAN-79
Zn-63	38.1m	ECB+	4679	375	7316	120							0.0	0.9177	1.0998	07-MAR-78
Zn-65	243.9d	ECB+	5757	47	7788	98							0.0	0.0068	0.5842	29-MAR-78
Zn-69	57m	B-	7926	45	9050	110							0.0	0.3209	0.0000	06-APR-76
Zn-69m	13.76h	ITB-	7852	73	8941	107	830	9.9970E-01					0.0	0.0222	0.4166	30-SEP-76
Zn-71m	3.92h	B-	9250	418	9634	121							0.0	0.5479	1.5519	11-MAR-78
Zn-72	46.5h	B-	10752	86	10010	96	240	1.0000E 00					0.0	0.1017	0.1519	20-DEC-77
Zr-86	16.5h	EC	23488	59	0	0	808	1.0000E 00					0.0	0.0300	0.2877	29-MAR-78
Zr-88	83.4d	EC	25051	45	0	0	811	1.0000E 00					0.0	0.0162	0.4025	07-MAR-78
Zr-89	78.43h	ECB+	26283	75	16007	110							0.0	0.1013	1.1650	08-AUG-75
Zr-93	1.53E6y	B-	28175	1	17190	77	407	1.0000E 00					0.0	0.0196	0.0	24-MAY-77
Zr-95	63.98d	B-	29674	57	18063	109	409	9.9300E-01	410	6.9800E-03			0.0	0.1163	0.7388	03-MAY-77
Zr-97	16.90h	B-	30958	239	18397	118	413	9.4700E-01	412	5.3000E-02			0.0	0.7003	0.1793	29-MAR-78

Radiation Files ICRP38.RAD and MIRD.RAD

The RAD files are direct-access files whose records contain data on the intensity and energy of each radiation emitted in nuclear transformations of the radionuclides. These are large files — ICRP38.RAD contains 221,174 records for 838 radionuclides (6 Mbytes), and MIRD.RAD file has 43,851 records for 242 radionuclides (1.2 Mbytes).

For each nuclide, there is a header record containing the name of the nuclide, its half-life, and the number of radiation records for the nuclide. The radiation records follow the header — one record for each emitted radiation — and contain the following data: (1) an integer code (ICODE), which identifies the type of radiation; (2) the absolute intensity of the radiation, in percent (i.e., radiations per 100 decays); and (3) the unique or average energy of the radiation, in MeV. (For the fission component of spontaneously fissioning radionuclides (ICODE=9), these files contain instead the number of spontaneous fissions per 100 decays and the number of neutrons per fission. When data on selected nuclides are extracted from the RAD files, as described later, the output files contain the information on the intensities and the mean energies of the various radiations associated with fission.) An excerpt from ICRP38.RAD is given in Table 5, and the ICODE code is explained in Table 6. (In Table 6 note that, for spontaneous fission, ICODE is defined differently in ICRP38.RAD or MIRD.RAD from that in files of data extracted from these files.) The record number of the header and the number of radiation records for the nuclide of interest in the RAD files are contained in the corresponding index file (IDX).

Table 5. Records for First 8 Radionuclides in File ICRP38.RAD.

Contents of ICRP38.RAD

```

H-3   12.35 y           1
5 1.00000E+02 5.68276E-03
Be-7   53.3 d           4
1 1.03400E+01 4.77605E-01
6 8.04306E-06 4.77550E-01
6 1.18019E-07 4.77605E-01
2 1.63500E-02 5.47500E-05
Be-10  1.600E 06 y      1
5 1.00000E+02 2.52256E-01
C-11   20.38 m          4
4 9.97600E+01 3.85535E-01
3 1.99520E+02 5.11000E-01
2 1.61920E-04 1.83300E-04
2 8.09600E-05 1.83300E-04
N-13    9.965 m          9
4 9.98200E+01 4.91829E-01
3 1.99640E+02 5.11000E-01
2 2.37600E-04 2.77400E-04
2 1.18800E-04 2.77400E-04
7 5.13373E-02 2.43000E-04
7 3.28914E-02 2.51999E-04
7 1.02230E-02 2.58000E-04
7 5.18559E-03 2.65000E-04
7 8.00061E-02 2.66000E-04
C-14   5730 y           1
5 1.00000E+02 4.94534E-02
O-15   122.2 s          9
4 9.98870E+01 7.35329E-01
3 1.99774E+02 5.11000E-01
2 2.64721E-04 3.92400E-04
2 1.32360E-04 3.92400E-04
7 2.11093E-02 3.56000E-04
7 2.28289E-02 3.62000E-04
7 6.70043E-03 3.68999E-04
7 4.44718E-03 3.73000E-04
7 5.75170E-02 3.75000E-04
F-18   109.8 m          2
4 1.00000E+02 2.49776E-01
3 2.00000E+02 5.11000E-01

```

Notes

Header record for H-3.
First (and only) data record for H-3.
Header record for Be-7.
ICODE, intensity, and energy.

Intensity of radiation is in percent
(i.e., radiations per 100 decays).
Unique or average energy is in MeV.

Table 6. Description of ICODE.

ICODE	Mnemonic for ICODE ^b	Description	ICODE pertains to Input/Output File? ^a
1	g	Gamma rays	Both
2	x	X-rays	Both
3	aq	Annihilation quanta	Both
4	b+	Beta + particles	Both
5	b-	Beta - particles	Both
6	ic	Internal conversion electrons	Both
7	ae	Auger electrons	Both
8	a	Alpha particles	Both
9		Spontaneous fission	Input file
9	ff	Fission fragments	Output file
10	n	Neutrons	Output file
11	pg	Prompt gamma rays	Output file
12	dg	Delayed gamma rays	Output file
13	sb	Beta particles associated with spontaneous fission	Output file

^aInput file refers to standard file ICRP38.RAD or MIRD.RAD.
Output file refers to DEXRAX radiations output file (see Tables 8-9).

^bMnemonic appears in output file only.

Beta Spectra Files ICRP38.BET and MIRD.BET

The direct-access files ICRP38.BET and MIRD.BET contain the beta spectra data for the beta emitters in these collections. ICRP38.BET contains 61,249 records (0.7 Mbytes of data), while MIRD.BET has 3333 records (0.2 Mbytes). These spectral data were computed by EDISTR⁷ on a fixed energy grid, to facilitate tabulation of the composite spectra.

For each nuclide, the header record gives the name of the nuclide. The header is followed by a record containing the end-point energy of the spectrum, in MeV. The subsequent data records contain the frequency $N(E)$ (number of betas per MeV per decay) at the standard energy grid points that are less than the end-point energy. The very last record is the frequency at the nuclide unique end-point energy. The number of beta particles per decay Y is

$$Y = \int_0^{\infty} N(E) dE \quad (1)$$

and the average energy of the spectrum is

$$\bar{E} = \frac{\int_0^{\infty} E N(E) dE}{Y} \quad (2)$$

The DEXRAX utility, discussed below, is used to extract the spectral data. It generates the appropriate energy grid and tabulates the spectrum as the number pairs $[E, N(E)]$.

For a beta emitter, the record number of the header and the number of points in the beta spectrum are given in the IDX record for the nuclide. If the beta spectrum is represented by N number pairs, then BET contains $N + 2$ records for the nuclide. Excerpts from ICRP38.BET are given in Table 7.

Table 7. Excerpts from First 5 Records of File ICRP38.BET.

ICRP38.BET	Notes
H-3	Header record for H-3.
0.01860	End-point energy, in Mev. (First data record for H-3).
8.218E 01	Frequency of spectrum at 1st energy grid point.
8.333E 01	Frequency of spectrum at 2nd energy grid point.
8.350E 01	Frequency of spectrum at 3rd energy grid point.
...	
...	
5.452E 00	Frequency at next-to-last energy grid point before end-point energy.
3.067E-01	Frequency at last energy grid point before end-point energy.
0.0	Frequency at end-point energy. (Last data record for H-3).
Be-10	
0.55570	
4.922E-01	
4.918E-01	
4.917E-01	
...	
...	
5.044E-01	
7.510E-03	
0.0	
C-11	
0.96000	
0.0	
4.625E-06	
7.835E-06	
...	
...	
1.660E-01	
5.342E-02	
0.0	
N-13	
1.19850	
0.0	
3.534E-07	
6.654E-07	
...	
...	
2.740E-01	
7.738E-02	
0.0	
C-14	
0.15648	
9.910E 00	
9.900E 00	
9.899E 00	
...	
...	
4.380E-01	
7.105E-02	
0.0	

Table 8. Structure of Records in DEXRAX Radiations Data Output File.
(See text on p. 17 for Tables 8 and 9)

Header Record for Each Nuclide		
Variable	Format	Description
Nuclide	A7	Nuclide name; e.g., Am-241.
Half-life	A8	Half-life of nuclide.
Units	A2	Units of half-life; see Table 3.
Decay Modes	A8	Decay modes; see Table 3.
No. Data Records	I4	Number of data records = number of radiations.
D1	A7	Name of daughter nuclide 1.
Frac1	A10	Branching fraction for D1.
D2	A7	Name of daughter nuclide 2.
Frac2	A10	Branching fraction for D2.
D3	A7	Name of daughter nuclide 3.
Frac3	A10	Branching fraction for D3.

FORMAT(A7, 1X, A8, A2, A8, I4, 3(1X,A7,1X,A10)).

Data (Radiations) Records, One for each Radiation.		
Variable	Format	Description
ICODE	I1 or I2	Radiation type (see Table 6).
Intensity	E11.5	Number of radiations per decay.
Energy	E11.5	Unique or average energy, in MeV.
Mnemonic	A2	Mnemonic for ICODE (see Table 6).

FORMAT(I1, 1X, E11.5, 1X, E11.5, 1X, A2) for ICODE ≤ 9 .

FORMAT(I2, 0X, E11.5, 1X, E11.5, 1X, A2) for ICODE ≥ 10 .

Table 9. Example of a DEXRAX Radiations Data Output File: Excerpts from File for U-236 and its Daughters.

The first 2 lines give the name of the output file, the version number and date of the DEXRAX code, and the date and time DEXRAX was run to produce this file. The next 3 lines give the pedigree of the DEXRAX executable file and the files ICRP38.IDX and ICRP38.RAD that were read during the run, i.e., directory information on size, date, and time of creation.

Then follow the data for each nuclide. See Table 8 for explanation of each field in the header and data records.

```

This is DEXRAX radiations data file u236d.rad
<< DEXRAX Ver. 1.0 (Sep 1, 1993) --- Run Sep 04, 1993, at 12:43 >>
DEXRAX exe file was:      Dexrax.exe      163816 09-01-93  12:00a
Index file was:          ICRP38.idx       106556 09-01-93  12:00a
Radiations data read from file: ICRP38.rad  5971698 09-01-93  12:00a
U-236  2.3415E7y A      58 Th-232  1.0000E 00
8 2.59326E-03 4.35888E+00 a
8 2.59326E-01 4.46972E+00 a
8 7.38081E-01 4.51825E+00 a
...
7 2.64388E-01 3.66821E-03 ae
7 8.13181E-02 8.11459E-04 ae
Th-232  1.405E10y A      58 Ra-228  1.0000E 00
8 1.99601E-03 3.82780E+00 a
8 2.29541E-01 3.95163E+00 a
8 7.68464E-01 4.00961E+00 a
...
7 2.39637E-01 3.42636E-03 ae
7 7.24302E-02 7.37885E-04 ae
Ra-228  5.75y B-        6 Ac-228  1.0000E 00
5 1.00000E+00 9.86455E-03 b-
1 6.21118E-07 6.67000E-03 g
6 5.55684E-01 2.76100E-03 lc
6 4.44315E-01 6.67000E-03 lc
7 5.55684E-01 3.90899E-03 ae
7 4.44315E-01 8.90000E-04 ae
Ac-228  6.13h B-       1246 Th-228  1.0000E 00
5 1.75748E-03 3.32876E-02 b-
5 2.63622E-04 4.56668E-02 b-
5 2.63622E-03 5.16137E-02 b-
...
7 1.11652E+00 3.70476E-03 ae
7 3.37875E-01 8.11352E-04 ae
Th-228  1.9131y A      81 Ra-224  1.0000E 00
8 5.00050E-04 5.13839E+00 a
8 1.80018E-03 5.17695E+00 a
8 3.60036E-03 5.21114E+00 a
...
7 2.69060E-01 3.42801E-03 ae
7 8.13378E-02 7.37746E-04 ae
Ra-224  3.66d A       75 Rn-220  1.0000E 00
8 3.09946E-05 5.03347E+00 a
8 7.19874E-05 5.04692E+00 a
8 7.29872E-05 5.16115E+00 a
...
7 1.18733E-02 3.30837E-03 ae
7 3.24997E-03 6.51053E-04 ae

```

```

Rn-220  55.6s A      51 Po-216  1.0000E 00
8 7.00000E-04 5.74865E+00 a
8 9.99300E-01 6.28835E+00 a
1 6.99999E-04 5.49700E-01 g
...
7 2.06560E-05 3.14186E-03 ae
7 5.25494E-06 5.75990E-04 ae
Po-216  0.15s A      51 Pb-212  1.0000E 00
8 2.10000E-05 5.98755E+00 a
8 9.99979E-01 6.77862E+00 a
1 2.10000E-05 8.06000E-01 g
...
7 2.51954E-07 2.91524E-03 ae
7 6.27569E-08 5.05100E-04 ae
Pb-212  10.64h B-     80 Bi-212  1.0000E 00
5 5.21375E-02 4.19441E-02 b-
5 8.48982E-01 9.44627E-02 b-
5 9.88814E-02 1.72668E-01 b-
...
7 5.37795E-01 3.04071E-03 ae
7 1.33146E-01 5.39340E-04 ae
Bi-212  60.55m B-A    236 Po-212  6.4070E-01 Tl-208  3.5930E-01
5 1.19004E-02 1.28119E-01 b-
5 4.80015E-04 1.29618E-01 b-
5 4.40014E-03 1.70319E-01 b-
...
7 2.99105E-01 2.67166E-03 ae
7 8.71924E-02 5.04845E-04 ae
Po-212  0.305usA      4
8 9.99776E-01 8.78453E+00 a
8 3.69917E-05 9.49700E+00 a
8 1.59964E-05 1.04260E+01 a
8 1.71961E-04 1.05490E+01 a
Tl-208  3.07m B-     230
5 5.48395E-04 1.52139E-01 b-
5 1.69504E-04 1.85507E-01 b-
5 4.38716E-04 1.94015E-01 b-
...
7 1.08696E-01 2.92035E-03 ae
7 2.67824E-02 5.03921E-04 ae

```

III. OUTPUT FILES FROM UTILITY DEXRAX

When DEXRAX is run, the principal output files are the radiations data file and/or the beta spectra file for the user-specified radionuclides. The output radiations data file, which always has the extension RAD, contains data for user-specified nuclides extracted from either the ICRP38.RAD or MIRD.RAD files, and some information from the associated index file is also included. As mentioned previously, the data for the fission component of spontaneously fissioning radionuclides is expanded in the output file (see Fig. 7 and Table 13). The beta spectra file, which always has the extension BET, includes data for user-specified nuclides extracted from either ICRP38.BET or MIRD.BET, along with the standard energy grid points and some information from the index file.

The structure of records in the radiations data file is given in Table 8, and excerpts from a file for U-236 and its daughters, as obtained from ICRP38.RAD, are given in Table 9. Note that each intensity in the radiation data output file is given as a fraction rather than a percent (i.e., radiations per decay rather than radiations per 100 decays). The structure of records in the beta spectra file is given in Table 10, and excerpts from a file for U-236 and its daughters are given in Table 11.

Two other types of output files, the LST file containing a list of nuclides for input to a later DEXRAX run and the LOG file, will be described later.

Table 10. Structure of Records in DEXRAX Beta Spectra Output File.

Header Record for Each Nuclide		
Same as shown in Table 8 for radiations data output files, except that the number of data records = number of energies at which the beta spectrum is tabulated.		
Data (Beta Spectra) Records, One for Each Energy		
Variable	Format	Description
Energy	F8.5	Standard energy of grid point, or end-point energy for this nuclide.
Frequency	E10.3	Number of beta particles per Mev per nuclear transformation at this energy.

Table 11. Example of a DEXRAX Beta Spectra Output File: Excerpts from File for U-236 and its Daughters.

The first 2 lines give the name of the output file, the version number and date of the DEXRAX code, and the date and time DEXRAX was run to produce this file. The next 3 lines give the pedigree of the DEXRAX executable file and the files ICRP38.IDX and ICRP38.BET that were read during the run, i.e., directory information on size, date, and time of creation.

Then follows the data for each nuclide. See Table 10 for explanation of each field in the header and data records.

This is DEXRAX beta spectra file u236d.bet
 << DEXRAX Ver. 1.0 (Sep 1, 1993) --- Run Sep 04, 1993, at 12:43 >>
 DEXRAX exe file was: Dexrax.exe 163816 09-01-93 12:00a
 Index file was: ICRP38.idx 106556 09-01-93 12:00a
 Beta spectra read from file: ICRP38.bet 684882 09-01-93 12:00a
 Ra-228 5.75y B- 72 Ac-228 1.6000E 00

.00000 7.551E+01
 .00010 7.514E+01
 .00011 7.510E+01
 .00012 7.506E+01

.03200 2.579E+00
 .03600 4.661E-01
 .03893 0.000E+00

Ac-228 6.13h B- 119 Th-228 1.0000E 00

.00000 1.915E+00
 .00010 1.915E+00
 .00011 1.915E+00

.00016 1.915E+00
 .00018 1.915E+00
 .00020 1.915E+00

.00032 1.914E+00
 .00036 1.914E+00
 .00040 1.914E+00
 .00045 1.914E+00
 .00050 1.914E+00

.00100 1.913E+00
 .00110 1.912E+00
 .00120 1.912E+00

.00160 1.911E+00
 .00180 1.911E+00
 .00200 1.910E+00

.00320 1.907E+00
 .00360 1.906E+00
 .00400 1.905E+00
 .00450 1.904E+00
 .00500 1.902E+00

.01000 1.889E+00
 .01100 1.887E+00
 .01200 1.884E+00

.01600 1.874E+00
 .01800 1.868E+00
 .02000 1.868E+00

.03200 1.853E+00
 .03600 1.847E+00
 .04000 1.842E+00
 .04500 1.834E+00
 .05000 1.827E+00

.10000 1.740E+00
 .11000 1.721E+00
 .12000 1.701E+00

.16000 1.619E+00
 .18000 1.575E+00
 .20000 1.530E+00

.32000 1.232E+00
 .36000 1.133E+00
 .40000 1.042E+00
 .45000 9.425E-01
 .50000 8.582E-01

1.00000 1.913E-01
 1.10000 1.256E-01
 1.20000 9.561E-02

1.60000 2.328E-02
 1.80000 6.780E-03
 2.00000 5.771E-04
 2.07924 0.000E+00

Pb-212 10.64h B- 103 Bi-212 1.0000E 00
 .00000 7.356E+00
 .00010 7.353E+00
 .00011 7.353E+00

.55000 1.721E-03
 .57290 0.000E+00
 Bi-212 60.55m B-A 120 Po-212 6.4070E-01 Tl-208 3.5930E-01
 .00000 5.222E-01
 .00010 5.222E-01
 .00011 5.222E-01

2.20000 1.023E-03
 2.24600 0.000E+00
 Tl-208 3.07m B- 117
 .00000 8.041E-01
 .00010 8.041E-01
 .00011 8.041E-01

1.60000 3.189E-02
 1.79460 0.000E+00

IV. THE DEXRAX PROGRAM

Introduction

DEXRAX is distributed in one of three ways: (i) as a stand-alone package for those interested only in the nuclear decay data; (ii) with program SEECAL¹⁰; or (iii) as part of a larger dosimetric system, the *DCAL system*. The DCAL system (see Fig. 2) is a comprehensive radiation dose and risk calculational system being developed for the Environmental Protection Agency and will be documented elsewhere¹¹.

Installation instructions are given with the appropriate distribution packet. In either case, the installation procedure sets up a standard directory structure on the hard disk of the user's PC and installs all necessary files into their appropriate directories. About 12 Mbytes of space on the disk is required during the installation, and about 3 Mbytes will be released following the installation.

From here on, only the stand-alone system and running DEXRAX by itself are considered. The files given below are identical to the DEXRAX-related files supplied with the DCAL system, and the directories given below are a subset of the directories required for the DCAL system. Running DEXRAX in the DCAL system is trivial, because no user responses are required. Running DEXRAX and SEECAL as a unit is described in Cristy and Eckerman¹⁰.

Directory Structure Required for DEXRAX

You may choose a directory (or directory plus subdirectory) where the system is installed. The notation "\$DCAL", used below, stands for the name of the place where you install the system, e.g., "\DCAL", "\PHOENIX", "\PHOENIX\DCAL", or "\ANYTHNG1\ANYTHNG2". The default is "\DCAL". Files supplied with DEXRAX and their directories are as follows:

<u>File</u>	<u>Directory</u>
DEXRAX.BAT	\$DCAL
DEXRAX.EXE	\$DCAL\BIN
DEXRAX.INI	\$DCAL\INI
ICRP38.IDX	\$DCAL\DAT\NUC
ICRP38.RAD	\$DCAL\DAT\NUC
ICRP38.BET	\$DCAL\DAT\NUC
MIRD.IDX	\$DCAL\DAT\NUC
MIRD.RAD	\$DCAL\DAT\NUC
MIRD.BET	\$DCAL\DAT\NUC

DCAL: RADIATION DOSE AND RISK CALCULATIONAL SYSTEM

Figure 2. Schematic showing the programs, input data, and flow in the DCAL dosimetric system. The major data elements of the system are shown at the top of the figure (in the rectangles with rounded corners). The two cylinders at the bottom denote the repositories of dosimetric and risk data. Major computation modules in the system have names that end in "CAL" (large rectangles). No naming convention was applied to utilities modules (small rectangles). One might enter into the DCAL system using the utility MODDEF to define an age-specific biokinetic model, run ACTACAL to compute the activity of the radionuclide and any decay products in the body as a function of time following the intake either via ingestion, inhalation, or injection. The module SEECAL computes the dose rate in target tissues and organs per unit activity residing in source regions (as considered by ACTACAL). EPACAL operates on the activity-time information with the data from SEECAL to compute the dose rate as a function of time following the intake. These data can then be processed by RISKCAL with information on the age-specific risk per dose generated by ALRCAL to compute the lifetime risk and years of life lost per unit activity inhaled or ingested. U.S. vital statistical data, including the age and sex-specific cancer mortality data are accessed by MORTVIEW and ALRCAL to compute cancer risk information.

When DEXRAX is installed, a directory \$DCAL\WORK2 is created. All output files of DEXRAX are placed in the WORK2 directory. Note that DEXRAX is always run from the root directory \$DCAL, using the DEXRAX.BAT file.

The file DEXRAX.INI gives the name and location of the index file to be used by DEXRAX. Specifying the index file (IDX) uniquely determines which RAD and BET files are to be used. When DEXRAX is installed, these files are all placed in the directory \$DCAL\DAT\NUC as shown above. If desired, you may elect to locate these files elsewhere by editing the DEXRAX.INI file and moving the files. Note that DEXRAX expects that the three files will be in the same directory. The file DEXRAX.INI contains the following:

'INDEX.DAT' '\$DCAL\DAT\NUC\ICRP38.IDX'

The first field of the line gives the standard name of the index file as coded in DEXRAX, and the second field gives the path structure on your system to the ICRP38.IDX file. If you wish to use the MIRD collection, you should replace "ICRP38.IDX" with "MIRD.IDX." *Note: you must not change the name in the first field.*

Description of the DEXRAX Utility

The DEXRAX utility was written to extract the radiations data and beta spectra data for user-specified radionuclides from the RAD and BET files. This function is carried out as:

1. A list is created of the user-specified radionuclides. You have the option for automatic inclusion of any daughter nuclides to the list. Duplicate nuclides in the list are eliminated.
2. You have the option of extracting the radiations data and/or beta spectra for the nuclides in the above list or writing the list to a file for later processing.

As an example of the extraction of a complete decay chain by DEXRAX, consider uranium-236. After starting DEXRAX, you would be prompted for the nuclide name and would enter "U-236." You would be prompted whether to extract the data for daughter nuclides. If an affirmative response is given, DEXRAX assembles a list of all radioactive daughter nuclides associated with the decay of U-236 and subsequent radioactive daughter nuclides. For this example the resulting list would be:

U-236	Th-232	Ra-228	Ac-228	Th-228	Ra-224
Rn-220	Po-216	Pb-212	Bi-212	Tl-208	Po-212

Input

In addition to the information you specify, DEXRAX uses three data files, in read-only mode. These files were discussed in some detail above.

1. *IDX File:* The records of this file contain the pointers to the locations of the radiations data and beta spectra data in the corresponding RAD and BET files, respectively. In addition, it contains other data and information of interest.
2. *RAD File:* The records of this large direct-access file contain the information on the type of radiation, its absolute intensity, and its mean energy emitted in the nuclear transformation.
3. *BET File:* This direct-access file contains records of the absolute intensity of beta emission as a function of particle energy.

Output

DEXRAX creates several output files, the number depending on the nature of your requests. In all instances, the you are prompted for the stem of the file name, and DEXRAX adds a standard extension. The following files may be created:

1. *Radiations Data File, extension RAD:* At your option, the radiations data is extracted for the nuclides identified by you (and their daughter nuclides, if so elected). For each nuclide an appropriate header record is written, followed by the information on each emitted radiation.
2. *Beta Spectra File, extension BET:* At your option, beta spectra will be extracted for each beta emitter in the user-specified nuclide list (including any beta-emitting radioactive daughter nuclides if so elected.) The output file consists of a header record followed by records of the energy and differential yield of beta particles at the indicated energy.
3. *Nuclide List File, extension LST:* You may elect to create a file containing the names of nuclides of interest and extract the data, using the file, at a later time. The nuclide list file will include any radioactive daughter nuclides, if you so elect. Delaying the extraction may be useful if you want to examine the nuclide listing and eliminate from it any nuclides of limited dosimetric interest, e.g., very long-lived daughter nuclides. This file will not be created if you elect to extract the data during the interactive session.

4. *Log File, DEXRAX.LOG:* Some of the information written to the screen during a DEXRAX session is written to the log file. The pedigree of the DEXRAX executable file and the standard input files read by DEXRAX during the session are also written here.

DEXRAX begins by asking you whether the names of the nuclides will be supplied during the session from the keyboard or from a file created during a previous DEXRAX run that contains the list of nuclides. You are asked what type of data should be extracted from the files, i.e., radiations data, beta spectra data, or both. You are further asked whether radioactive daughter nuclides should be included with each user-specified nuclide. An affirmative response will treat the user-specified radionuclide as the parent of a decay chain.

You are prompted to input the nuclide's name in the conventional notation; e.g., H-3, Al-26, Tc-99m, etc. The nuclide name is checked for appropriate format and it and any daughter products, if inclusion of daughter products was selected, are added to the nuclide list. If the requested nuclide is not contained in the files, you are so notified. You terminate the entry of nuclides by entering a blank line.

Once entry of nuclides has been terminated, the list is checked for any duplicate nuclides which might have occurred from consideration of decay chains headed by each of the user-specified nuclides. The final list of nuclides is shown and you are asked if you wish to extract the data for this list. If your response is affirmative, you will be prompted for names of the files that contain the extracted information. The session terminates after the extraction has been completed and the files written. A negative response results in an inquiry whether the list of nuclides should be written to a file for later use. An affirmative response is followed by a request for a name for the file, while a negative response results in termination of the program.

Description of DEXRAX Routines

DEXRAX is written in Microsoft FORTRAN and uses two special libraries. The two menus are based on the FORTRAN library FASTPLOT developed by R. C. Ward¹², and DEXRAX uses a C language routine¹³ to obtain the date and time stamp of the files accessed by DEXRAX.

MAIN Routine

MAIN prompts you for input, calls routines to check the nuclide names (CHECK), assembles the decay chain (CHAIN), removes duplicate nuclides for the assembled list (WEED), and extracts the radiations data (EXTRAD) and/or the beta spectra (EXTBET). The list of nuclides, including daughter nuclides if requested, is contained in the array NAME, which is dimensioned to 400 at present. The record number of the nuclides in the index file (IDX) is contained in the array INDEX, also dimensioned to 400.

CHAIN Routines

The routine CHAIN and its associated routines, FORWARD and RECOVER, assemble the list of radioactive daughter nuclides headed by the specified parent nuclide. The COMMON block /CHAINS/ is used to communicate with CHAIN and its routines. The block is defined as:

COMMON /CHAINS/ NAMEN(30), IPOINTS(30), NDAU

where NAMEN is a CHARACTER*7 variable containing the names of the members of the decay chain (NAMEN(1) is the parent nuclide) of length NDAU (an integer). The integer variable IPOINTS contains the record number of the nuclides in the index file. CHAIN directs the assembly of the chain by calling the routine FORWARD to read a linear chain, noting the occurrence of any branches and their convergence, when processing previously detected branches. CHAIN calls RECOVER to recover the location of any branches detected by FORWARD as it is processing a linear chain to termination. This collection of routines uses the index file to construct the decay chain.

WEED Routine

The routine WEED eliminates duplicate nuclides that entered into the assembled list either by overlapping decay chains or through user error. The former would occur, for example, if you requested the inclusion of daughters and then indicated Pu-236 and Th-232 as two nuclides of interest.

EXTRAD Routine

This routine extracts the radiations data for the selected radionuclides from the direct-access file ICRP38.RAD or MIRD.RAD. Which RAD file is accessed depends on which index file (IDX) is being used. The input to the routine consists of the record number of the nuclides in the index file, contained in the INDEX array. For each nuclide a header record is included with the data records, as shown in Table 8.

EXTBET Routine

The EXTBET routine extracts the number of beta particles emitted per unit energy per decay from the direct-access file ICRP38.BET or MIRD.BET. Which BET file is accessed depends on which index file (IDX) is being used. The standard energy grid is computed by EXTBET when it is first called. EXTBET writes the beta spectrum to the BET output file as pairs of energy and intensity of beta emission. The input to EXTBET is the list of record numbers of nuclides of interest in the IDX file, contained in the INDEX array. For each nuclide a header record is included in the same format as for the radiations data. The structure of the beta spectra file is given in Table 10.

IBINRY Function

The IBINRY function preforms a binary search of the appropriate index file to determine the number of the record for the radionuclide of interest. If the requested nuclide is not contained in the file, the routine returns a value of zero.

CHECK Function

The CHECK function accepts the current nuclide name and returns the name in the format used in the index files. That is, the first character of the chemical symbol must be upper case, the second character, if present, lower case, and the final character — the metastable notation, if applicable — is in lower case. Thus, if CHECK is called with cm-244, it returns Cm-244; if TC-99M, it returns Tc-99m.

V. HOW TO RUN DEXRAX

Before running DEXRAX for the first time, install the program and related files, following instructions included with the installation diskettes.

To run DEXRAX, do the following:

1. Check file \$DCAL\INI\DEXRAX.INI. If desired, edit this file to change from ICRP38 standard input files to MIRD standard input files, or vice-versa, as described above in the section "Directory Structure Required for DEXRAX" under "IV. THE DEXRAX PROGRAM." (Recall that \$DCAL is our notation for whatever you chose as the DCAL root directory during installation; e.g., "\DCAL", "\PHOENIX\DCAL", or "\ANYTHNG1\ANYTHNG2".
2. Change directory to \$DCAL.
3. Type "dexrax" to run the program.
4. Select menu items and answer queries as they appear on the screen. This is explained by example below.
5. When finished, the output files will be in the directory \$DCAL\WORK2.

Examples

In Figs. 3-6 are shown four examples of DEXRAX runs using the ICRP38.IDX index file. In the "a" part of each figure is shown what appears on the screen during the run — menus, queries, and output. In these examples the user has installed the system on drive C: and the root directory \$DCAL for the system is \DCAL. Screen clearing is indicated in the figures by the solid horizontal lines, and the user's input is underlined. In the "b" part is shown the LOG file for Figs. 3, 4, and 6 or the LST file for Fig. 5.

Each run begins with the user typing "dexrax" from the DOS prompt in directory \DCAL. The first screen produced by DEXRAX (see Fig. 3a) gives a header with the name, version number and date, and authors of DEXRAX, followed by information regarding the LOG file. If no file named DEXRAX.LOG exists in directory \DCAL\WORK2, then the simple message "Log file will be: Dexrax.log" is printed, as in Example 1 (Fig. 3a). Otherwise, the user is given the choice whether to overwrite the existing file, append the new log file to the existing file, or rename the new log file, as in Examples 2-4.

The second screen (see Fig. 3a) is a menu regarding mode of input for the nuclides: "Enter nuclides via the keyboard" or "Use existing LST file of nuclides". The former is the most common mode of input and is used in Examples 1, 2, and 3. The latter is used in Example 4.

The third screen is another menu, with choices on what type(s) of data to extract: radiations data only, beta spectra data only, or both types. If you are preparing data for input to SEECAL, select "radiations data only."

On the fourth (and final) screen you are queried about various things, e.g., whether to add radioactive daughters to the list of nuclides, the nuclide names or the name of the LST file containing the nuclides, the file name you want for the output files, etc. Various information on the nuclides is also written to the screen. See the various examples and figures for details.

Example 1: Extracting Radiations Data for a Chain

In the first example (Figs. 3a and 3b), the user extracted radiations data only (i.e., no beta spectra) for U-236 and its daughters. In the first menu he chose "Enter nuclides via the keyboard" and in the second menu he chose "Radiations data only." On the following screen he responded "y" to the question, "Add radioactive daughters to nucl. list?", which is the default, and entered "U-236" when prompted for nuclide name # 1. When prompted for nuclide name # 2, he hit <Enter> to indicate there were no further nuclides desired.

Then the program wrote a list of the 12 nuclides requested, i.e., U-236 and its daughters, wrote a message that data would be extracted from the ICRP38 collection (determined by file DEXRAX.INI), and then asked, "Do you want to extract the data now?" The user chose "y", the default, and the program then prompted for the stem name of the radiations data output file. The user responded with "u236d", which was his personal mnemonic to indicate U-236 plus daughters (the stem can be anything from 1-8 characters). DEXRAX automatically adds the extension RAD to radiations data output files, so the output file is U236D.RAD.

DEXRAX then wrote to the screen summary information on each nuclide in the list: name, half-life, decay modes, number of radiations in file ICRP38.RAD for the nuclide, and the total energy of all emitted alpha particles, all electrons, and all photon radiations.

The message "Program DEXRAX ended normally" appeared and then the prompt for directory \DCAL.

The output files created during this run were DEXRAX.LOG and U236D.RAD, which appear in the directory \DCAL\WORK2. The contents of DEXRAX.LOG are shown in Fig. 3b, and excerpts from U236D.RAD were given previously in Table 9.

Figure 3a. DEXRAX Run, Example 1.

User elected to enter nuclides via the keyboard, chose radiations data only (i.e., no beta spectra), chose to include radioactive daughters, chose U-236, elected to extract the data during the run, and named the radiations data output file U236D.RAD. User's responses are underlined, including menu selections. A long, solid horizontal line indicates that the screen was cleared by DEXRAX.

Session began when user typed "dexrax" in directory \DCAL.

C:\DCAL>dexrax

DEXRAX: Decay Data Extractor
Ver. 1.0 (Sep 1, 1993)
Oak Ridge National Laboratory Report ORNL/TM-12350
Authors: R.J. Westfall, J.C. Ryman, M. Cristy, K.F. Eckerman
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6383

Log file will be: Dexrax.log

Press <Enter> to clear screen & continue DEXRAX
<Enter>

DEXRAX - Decay Data Extractor
Ver. 1.0 (Sep 1, 1993)

Enter nuclides via the keyboard
Use existing LST file of nuclides

Use Arrow Keys To Make Selection
Press <Enter> To Execute, <Esc> To Exit

DEXRAX - Decay Data Extractor

Select Type of Data to be Extracted

Radiations data only
Beta spectra only
Radiations and beta spectra

Use Arrow Keys To Make Selection
Press <Enter> To Execute, <Esc> To Exit

(Figure 3a, cont'd)

Add radioactive daughters to nucl. list ([y]/n)? y

Enter nuclides (7 characters maximum!), e.g., Md-258, H-3, Pm-148m

Blank entry terminates the read.

Nuclide # 1: U-236

Nuclide # 2: <Enter>

No duplicates existed in list of length 12. List includes:

U-236	Th-232	Ra-228	Ac-228	Th-228	Ra-224	Rn-220	Po-216
Pb-212	Bi-212	Po-212	Tl-208				

Data will be extracted from the ICRP38 nuclear decay data files.

Do you want to extract the data now ([y]/n)? y

Name of radiations file, .rad added -> u236d

Nuclide	T-1/2	DecMode	# rad.	Emitted Energy (MeV/nt)		
				Alpha	Elec.	Photon
U-236	2.3415E7 y	A	58	4.5052	.0113	.0015
Th-232	1.405E10 y	A	58	3.9959	.0124	.0013
Ra-228	5.75 y	B-	6	.0000	.0169	.0000
Ac-228	6.13 h	B-	1246	.0000	.4751	.9708
Th-228	1.9131 y	A	81	5.3998	.0205	.0032
Ra-224	3.66 d	A	75	5.6739	.0022	.0099
Rn-220	55.6 s	A	51	6.2879	.0000	.0003
Po-216	0.15 s	A	51	6.7786	.0000	.0000
Pb-212	10.64 h	B-	80	.0000	.1755	.1483
Bi-212	60.55 m	B-A	236	2.1741	.4720	.1855
Po-212	0.305 us	A	4	8.7848	.0000	.0000
Tl-208	3.07 m	B-	230	.0000	.5976	3.3745

Program DEXRAX ended normally.

Stop - Program terminated.

C:\DCAL>

Figure 3b. Log File from DEXRAX Run, Example 1.

Note that some of the information written to the screen during the run is repeated here. Fatal error messages written to the screen would also be repeated here. In addition is information on the pedigree of some of the DEXRAX standard files, which is also written to the radiations data output file. This file, like all DEXRAX output files, is written in directory \SDCAL\WORK2.

This is DEXRAX log file Dexrax.log

<< DEXRAX Ver. 1.0 (Sep 1, 1993) --- Run Sep 04, 1993, at 14:35 >>

No duplicates existed in list of length 12. List includes:

U-236 Th-232 Ra-228 Ac-228 Th-228 Ra-224 Rn-220 Po-216
Pb-212 Bi-212 Po-212 Tl-208

Data will be extracted from the ICRP38 nuclear decay data files.

Radiations data written to file u236d.rad

DEXRAX exe file was: Dexrax.exe 163816 09-01-93 12:00a

Index file was: ICRP38.idx 106556 09-01-93 12:00a

Radiations data read from file: ICRP38.rad 5971698 09-01-93 12:00a

Nuclide	T-1/2	DecMode	# rad.	Emitted Energy (MeV/nt)		
				Alpha	Elec.	Photon
U-236	2.3415E7 y	A	58	4.5052	.0113	.0015
Th-232	1.405E10 y	A	58	3.9959	.0124	.0013
Ra-228	5.75 y	B-	6	.0000	.0169	.0000
Ac-228	6.13 h	B-	1246	.0000	.4751	.9708
Th-228	1.9131 y	A	81	5.3998	.0205	.0032
Ra-224	3.66 d	A	75	5.6739	.0022	.0099
Rn-220	55.6 s	A	51	6.2879	.0000	.0003
Po-216	0.15 s	A	51	6.7786	.0000	.0000
Pb-212	10.64 h	B-	80	.0000	.1755	.1483
Bi-212	60.55 m	B-A	236	2.1741	.4720	.1855
Po-212	0.305 us	A	4	8.7848	.0000	.0000
Tl-208	3.07 m	B-	230	.0000	.5976	3.3745

Program DEXRAX ended normally.

Example 2: Extracting Radiations Data and Beta Spectra for 2 Overlapping Chains

In the second example (Figs. 4a and 4b), the user extracted both radiations data and beta spectra for Pu-236 and Th-232 and their radioactive daughters. These two chains overlap, i.e., they have a common daughter, Th-228.

On the first screen the program noted that a log file named DEXRAX.LOG already existed, and the user chose to overwrite the file. On the next 2 screens with menus, the user chose "Enter nuclides via the keyboard" and "Radiations and beta spectra". On the following screen he responded "y" to adding daughters and input the names of the 2 parent nuclides. The program then responded that it had weeded out 8 duplicates, i.e., that the 8 nuclides common to both chains would not be duplicated in the output files, and then wrote the names of the nuclides.

The user then again chose to extract the data during the run, and named the radiations data output file EXAMPLE2.RAD. The program then wrote summary information on the nuclides.

Next the program asked for a name for the beta spectra data output file, and the user named it EXAMPLE2.BET. Note that it did not have to have the same stem name as the RAD file. The program then wrote summary information on the beta-emitting nuclides from the list, including the number of records in file ICRP38.BET for each nuclide. Then the program terminated, as in the previous example.

Output files appearing in \DCAL\WORK2 for this example were DEXRAX.LOG, EXAMPLE2.RAD, and EXAMPLE2.BET. The log file is shown in Fig. 4b. The RAD and BET files are not shown, but look similar to those shown previously in Tables 9 and 11.

Figure 4a. DEXRAX Run, Example 2.

In this example, the user requested nuclides Pu-236 and Th-232 and their daughters. These two chains converge (at Th-228), and duplicate chain members were weeded out. Both radiations data and beta spectra were selected, and user named these files Example2.RAD and Example2.BET. Note that on the first screen DEXRAX wrote a message that a log file DEXRAX.LOG already existed, and the user was given choices whether to overwrite the old file, append new log information to the old file, or give the new log file a new name by changing the extension.

C:\DCAL>dextrax

DEXRAX: Decay Data Extractor
Ver. 1.0 (Sep 1, 1993)
Oak Ridge National Laboratory Report ORNL/TM-12350
Authors: R.J. Westfall, J.C. Ryman, M. Cristy, K.F. Eckerman
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6383

Log file Dextrax.log already exists --
[o]verwrite, (a)ppend, or (r)ename by changing extension ([o]/a/r)? o
Log file Dextrax.log will be overwritten

Press <Enter> to clear screen & continue DEXRAX
<Enter>

DEXRAX - Decay Data Extractor
Ver. 1.0 (Sep 1, 1993)

Enter nuclides via the keyboard
Use existing LST file of nuclides

Use Arrow Keys To Make Selection
Press <Enter> To Execute, <Esc> To Exit

DEXRAX - Decay Data Extractor

Select Type of Data to be Extracted

Radiations data only
Beta spectra only
Radiations and beta spectra

Use Arrow Keys To Make Selection
Press <Enter> To Execute, <Esc> To Exit

(Figure 4a, cont'd)

Add radioactive daughters to nucl. list ([y]/n)? y

Enter nuclides (7 characters maximum!), e.g., Md-258, H-3, Pm-148m

Blank entry terminates the read.

Nuclide # 1: Pu-236

Nuclide # 2: Th-232

Nuclide # 3: <Enter>

Weeded out 8 duplicates in list of length 21. New list, length 13, includes:

Pu-236	U-232	Th-228	Ra-224	Rn-220	Po-216	Pb-212	Bi-212
Po-212	Tl-208	Th-232	Ra-228	Ac-228			

Data will be extracted from the ICRP38 nuclear decay data files.

Do you want to extract the data now ([y]/n)? y

Name of radiations file, .rad added -> Example2

Nuclide	T-1/2	DecMode	# rad.	Emitted Energy (MeV/nt)		
				Alpha	Elec.	Photon
Pu-236	2.851 y	SFA	96	5.7530	.0134	.0020
[Emitted energy given here excludes elec. & photons from spontaneous fission]						
U-232	72 y	A	83	5.3021	.0174	.0021
Th-228	1.9131 y	A	81	5.3998	.0205	.0032
Ra-224	3.66 d	A	75	5.6739	.0022	.0099
Rn-220	55.6 s	A	51	6.2879	.0000	.0003
Po-216	0.15 s	A	51	6.7786	.0000	.0000
Pb-212	10.64 h	B-	80	.0000	.1755	.1483
Bi-212	60.55 m	B-A	236	2.1741	.4720	.1855
Po-212	0.305 us	A	4	8.7848	.0000	.0000
Tl-208	3.07 m	B-	230	.0000	.5976	3.3745
Th-232	1.405E10 y	A	58	3.9959	.0124	.0013
Ra-228	5.75 y	B-	6	.0000	.0169	.0000
Ac-228	6.13 h	B-	1246	.0000	.4751	.9708

Name of spectra file, .bet added -> Example2

Nuclide	T-1/2	DecMode	# records
Pb-212	10.64 h	B-	103
Bi-212	60.55 m	B-A	120
Tl-208	3.07 m	B-	117
Ra-228	5.75 y	B-	72
Ac-228	6.13 h	B-	119

Program DEXRAX ended normally.

Stop - Program terminated.

C:\DCAL>

Figure 4b. Log File from DEXRAX Run, Example 2.

 This is DEXRAX log file Dexrax.log

<< DEXRAX Ver. 1.0 (Sep 1, 1993) --- Run Sep 04, 1993, at 14:59 >>

Weeded out 8 duplicates in list of length 21. New list, length 13, includes:

Pu-236	U-232	Th-228	Ra-224	Rn-220	Po-216	Pb-212	Bi-212
Po-212	Tl-208	Th-232	Ra-228	Ac-228			

Data will be extracted from the ICRP38 nuclear decay data files.

Radiations data written to file Example2.rad

DEXRAX exe file was: Dexrax.exe 163816 09-01-93 12:00a

Index file was: ICRP38.idx 106556 09-01-93 12:00a

Radiations data read from file: ICRP38.rad 5971698 09-01-93 12:00a

Nuclide	T-1/2	DecMode	# rad.	Emitted Energy (MeV/nt)		
				Alpha	Elec.	Photon
Pu-236	2.851 y	SFA	96	5.7530	.0134	.0020
[Emitted energy given here excludes elec. & photons from spontaneous fission]						
U-232	72 y	A	83	5.3021	.0174	.0021
Th-228	1.9131 y	A	81	5.3998	.0205	.0032
Ra-224	3.66 d	A	75	5.6739	.0022	.0099
Rn-220	55.6 s	A	51	6.2879	.0000	.0003
Po-216	0.15 s	A	51	6.7786	.0000	.0000
Pb-212	10.64 h	B-	80	.0000	.1755	.1483
Bi-212	60.55 m	B-A	236	2.1741	.4/20	.1855
Po-212	0.305 us	A	4	8.7848	.0000	.0000
Tl-208	3.07 m	B-	230	.0000	.5976	3.3745
Th-232	1.405E10 y	A	58	3.9959	.0124	.0013
Ra-228	5.75 y	B-	6	.0000	.0169	.0000
Ac-228	6.13 h	B-	1246	.0000	.4751	.9708

Beta spectra written to file Example2.bet

DEXRAX exe file was: Dexrax.exe 163816 09-01-93 12:00a

Index file was: ICRP38.idx 106556 09-01-93 12:00a

Beta spectra read from file: ICRP38.bet 684882 09-01-93 12:00a

Nuclide	T-1/2	DecMode	# records
Pb-212	10.64 h	B-	103
Bi-212	60.55 m	B-A	120
Tl-208	3.07 m	B-	117
Ra-228	5.75 y	B-	72
Ac-228	6.13 h	B-	119

Program DEXRAX ended normally.

Example 3: Choosing a List of Nuclides, Without Daughters, and Writing the List to an LST File

In the third example (Figs. 5a and 5b), the user requested 14 different nuclides, but without daughters this time. And instead of extracting the data during the run, he chose to write the nuclides to an LST file for later processing.

Note, on the screen after the menus, what happened when the user requested a non-existent nuclide (Nuclide # 6, first attempt: Cs-237) or used improper format (Nuclide # 12, first attempt: Cf252, without the required hyphen). The program responded with "Entry error or unlisted nuclide Cs-237", for example, and prompted the user for another nuclide name. Note, from other nuclides input, that the input is case-insensitive. Within DEXRAX, case is important, but nuclide names entered via the keyboard are converted by the program to the standard format. After nuclide input is finished, DEXRAX writes the names of the nuclides in standard format (see Fig. 5a).

Note also that DEXRAX could not find Np-236 in ICRP38.IDX (Nuclide # 8, first attempt). There are two isomers of Np-236, which are designated as Np-236a and Np-236b in ICRP38.IDX, which must be requested by these names. Similarly, there are in the index files some metastable isomers, which are designated with "m" and "n", e.g., Ir-190m and Ir-190n. A list of the nuclides with our nonstandard naming convention (a, b, and n nuclides) is given in Table 12 and is discussed in Appendix A.

When the user requested Np-236, the program wrote a message with the half-lives of Np-236a and Np-236b and asked the user to re-input the desired isomer. Note that the user later requested Eu-150a and Eu-150b (# 11 and # 12). Here DEXRAX assumed that he knew what he wanted; ergo, if you are not sure, omit the "a" or "b" and let DEXRAX help you.

When the user requested Sb-124m, DEXRAX wrote that there are two metastable isomers, Sb-124m and Sb-124n, gave their half-lives, and gave the user an opportunity to select either one. However, note later (# 14) that when the user asked specifically for the "n" isomer, Ir-190n, that DEXRAX assumed that he knew that he wanted the "n" isotope and wrote no message. Ergo, if you are not sure which metastable isomer you want, request the "m" isomer and let DEXRAX help you.

After nuclide entry was finished, DEXRAX responded that it had weeded out one nuclide. The user asked for Cf-252 twice (# 12 and # 15), and DEXRAX catches errors of this kind.

Note that when the user answered "n" to the extracting the data now, the program then asked whether to write the nuclide list to a file. The user responded "y" and then named the file MISC.LST in answer to a prompt. (If the user had responded "n", the program would have terminated immediately.)

The program terminated, as in the previous examples. The two output files, DEXRAX.LOG and MISC.LST, were created in \DCAL\WORK2. The contents of MISC.LST are given in Fig. 5b. Note that it is simply a list of nuclides in the standard format, one per line, ending with the key words "END LIST". The log file is given in Fig. 6b, combined with the log file for Example 4.

Figure 5a. DEXRAX Run, Example 3.

In this example, the user requested 14 different nuclides, without daughters, and chose to write the nuclide list to a file instead of extracting the data during the run. The user named this file MISC.LST. The next example, shown in Figure 6, will use the list file. Note also what happened when the user requested a nuclide that was not in the correct format, was not in the data base, or was one of the nuclides with "a,b" or "m,n" isomers.

C:\DCAL>dextrax

DEXRAX: Decay Data Extractor
Ver. 1.0 (Sep 1, 1993)
Oak Ridge National Laboratory Report ORNL/TM-12350
Authors: R.J. Westfall, J.C. Ryman, M. Cristy, K.F. Eckerman
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6383

Log file Dextrax.log already exists --
[o]verwrite, (a)ppend, or (r)ename by changing extension ([o]/a/r)? o
Log file Dextrax.log will be overwritten

Press <Enter> to clear screen & continue DEXRAX
<Enter>

DEXRAX - Decay Data Extractor
Ver. 1.0 (Sep 1, 1993)

Enter nuclides via the keyboard
Use existing LST file of nuclides

Use Arrow Keys To Make Selection
Press <Enter> To Execute, <Esc> To Exit

(Figure 5a, cont'd)

DEXRAX - Decay Data Extractor

Select Type of Data to be Extracted

<u>Radiations data only</u> Beta spectra only Radiations and beta spectra

Use Arrow Keys To Make Selection
 Press <Enter> To Execute, <Esc> To Exit

Add radioactive daughters to nucl. list ([y]/n)? n

Enter nuclides (7 characters maximum!), e.g., Md-258, H-3, Pm-148m
 Blank entry terminates the read.

Nuclide # 1: Na-24Nuclide # 2: k-40Nuclide # 3: Sr-90Nuclide # 4: TC-99MNuclide # 5: I-131Nuclide # 6: Cs-237

Entry error or unlisted nuclide Cs-237

Nuclide # 6: Cs-137Nuclide # 7: Np-237Nuclide # 8: Np-236

Entry error or unlisted nuclide Np-236

Nuclide Np-236 has 2 isomers:

Np-236a with halflife 115E3y

and Np-236b with halflife 22.5h

Re-input entire name with appropriate "a" or "b" designation

Nuclide # 8: Np-236aNuclide # 9: Am-241Nuclide #10: Eu-150aNuclide #11: Eu-150bNuclide #12: Cf252

Entry error or unlisted nuclide Cf252

Nuclide #12: Cf-252Nuclide #13: Sb-124m

Nuclide Sb-124m has 2 metastable isomers:

Sb-124m with halflife 93s

and Sb-124n with halflife 20.2m

Input <Enter> to accept Sb-124m, or input "n" for Sb-124n: nNuclide #14: Ir-190nNuclide #15: Cf-252Nuclide #16: <Enter>

(Figure 5a, cont'd)

Weeded out 1 duplicates in list of length 15. New list, length 14, includes:

Na-24	K-40	Sr-90	Tc-99m	I-131	Cs-137	Np-237	Np-236a
Am-241	Eu-150a	Eu-150b	Cf-252	Sb-124n	Ir-190n		

Do you want to extract the data now ([y]/n)? n

Write the nuclide list to file ([y]/n)? y

Name of nuclide list file, .lst added: -> misc

Program DEXRAX ended normally.

Stop - Program terminated.

C:\DCAL>

Figure 5b. Contents of File MISC.LST Created in DEXRAX Run of Example 3.

Na-24
K-40
Sr-90
Tc-99m
I-131
Cs-137
Np-237
Np-236a
Am-241
Eu-150a
Eu-150b
Cf-252
Sb-124n
Ir-190n
END LIST

Table 12. Isomers with Nonstandard Naming Convention¹

Nuclide	Half-life	Decay Modes	Radioactive Daughters and Branching Fractions			
Eu-150a	12.62h	B-ECB+				
Eu-150b	34.2y	EC				
In-110a	69.1m	ECB+				
In-110b	4.9h	ECB+				
Ir-186a	15.8h	ECB+				
Ir-186b	1.75h	ECB+				
Ir-190m	1.2h	IT				
Ir-190n	3.1h	ITEC				
Nb-89a	66m	ECB+	Zr-89	1.000E+00		
Nb-89b	122m	ECB+	Zr-89	1.000E+00		
Np-236a	115E3y	ECB-	Pu-236	8.900E-02	U-236	9.110E-01
Np-236b	22.5h	B-EC	Pu-236	4.800E-01	U-236	5.200E-01
Re-182a	12.7h	ECB+				
Re-182b	64.0h	EC				
Sb-120a	15.89m	ECB+				
Sb-120b	5.76d	EC				
Sb-124m	93s	ITB-	Sb-124	8.000E-01		
Sb-124n	20.2m	IT	Sb-124m	1.000E+00		
Sb-128a	10.4m	B-				
Sb-128b	9.01h	B-				
Ta-178a	9.31m	EC				
Ta-178b	2.2h	EC				
Tb-156m	24.4h	IT	Tb-156	1.000E+00		
Tb-156n	5.0h	IT	Tb-156	1.000E+00		

¹ The MIRD collection contains only the Ir-190 isomers. The MIRD collection contains the 9.31m Ta-178 nuclide, which is listed as Ta-178 rather than Ta-178a because the Ta-178b isomer is not included.

Example 4: Using an LST File

In the fourth example (Figs. 6a and 6b), the LST file created in Example 3 is used. Note, in the first screen, that the user chose to append the log file to the existing log file, which is the one just created in Example 3. The combined log file is given in Fig. 6b.

In the first menu the user selected "Use existing LST file of nuclides." In the second menu he chose "Radiations and beta spectra", which is different from what he chose in Example 3. He may do this, because the LST file contains no information on type of data to be extracted.

On the screen after the menus, he is prompted for the name of the LST file. After he inputs "misc", the program gives the names of the nuclides in the LST file and follows with the standard prompts and information as in previous examples. Output files are written in the standard work area, as before.

Example 5: Radiations Data from a Radionuclide with Spontaneous Fission

As mentioned previously, for spontaneous fission there is a difference between the standard files ICRP38.RAD or MIRD.RAD and the radiations data output file written by DEXRAX. Fig. 7 shows the radiations data for Cf-252: as given in ICRP38.RAD on the left and as given in an output file on the right.

On the left, note that the first radiation listed is spontaneous fission, ICODE = 9. The numbers following ICODE indicate that 3.092% of the transformations of Cf-252 are spontaneous fission and that there are 3.73 neutrons per fission. The rest of the radiations in the file are from alpha decay and show the radiation type (ICODE), intensity (percent), and average energy (MeV), as usual.

On the right, note that the first 5 radiations are from spontaneous fission, with ICODE values of 9 to 13 for fission fragments, neutrons, prompt gammas, delayed gammas, and beta particles, respectively. The numbers following ICODE give the intensity (fraction rather than percent, i.e., radiations per decay) and mean energy, and there is a mnemonic for ICODE at the end of the line. DEXRAX uses the methods of Dillman and Jones¹⁴, as given in Table 13, to calculate these numbers.

Figure 6a. DEXRAX Run, Example 4.

In this example, the user used the previously created LST file, MISC.LST. Note that he changed his mind about including beta spectra, but was not given the choice to add daughter nuclides. Note also that he chose to append the log file to the existing log file for Example 3; the combined log file is shown in Figure 6b. He chose to name the radiations data and beta spectra output files MISC.DEX and MISC.BET.

C:\DCAL>dexrax

DEXRAX: Decay Data Extractor
Ver. 1.0 (Sep 1, 1993)
Oak Ridge National Laboratory Report ORNL/TM-12350
Authors: R.J. Westfall, J.C. Ryman, M. Cristy, K.F. Eckerman
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6383

Log file Dexrax.log already exists --
[o]verwrite, (a)ppend, or (r)ename by changing extension ([o]/a/r)? a
Log file will be appended to existing Dexrax.log

Press <Enter> to clear screen & continue DEXRAX
<Enter>

DEXRAX - Decay Data Extractor
Ver. 1.0 (Sep 1, 1993)

Enter nuclides via the keyboard
Use existing LST file of nuclides

Use Arrow Keys To Make Selection
Press <Enter> To Execute, <Esc> To Exit

DEXRAX - Decay Data Extractor

Select Type of Data to be Extracted

Radiations data only
Beta spectra only
Radiations and beta spectra

Use Arrow Keys To Make Selection
Press <Enter> To Execute, <Esc> To Exit

(Figure 6a, cont'd)

Name of nuclide list file for input, .lst added -> misc

No duplicates existed in list of length 14. List includes:

Na-24	K-40	Sr-90	Tc-99m	I-131	Cs-137	Np-237	Np-236a
Am-241	Eu-150a	Eu-150b	Cf-252	Sb-124n	Ir-190n		

Data will be extracted from the ICRP38 nuclear decay data files.

Do you want to extract the data now ([y]/n)? y

Name of radiations data file, .rad added -> misc

Nuclide	T-1/2	DecMode	# rad.	Emitted Energy (MeV/nt)		
				Alpha	Elec	Photon
Na-24	15.00 h	B-	47	.0000	.5535	4.1212
K-40	1.28E9 y	B-EC	25	.0000	.5226	.1563
Sr-90	29.12 y	B-	1	.0000	.1957	.0000
Tc-99m	6.02 h	IT	57	.0000	.0162	.1263
I-131	8.04 d	B-	172	.0000	.1917	.3815
Cs-137	30.0 y	B-	2	.0000	.1870	.0000
Np-237	2.14E6 y	A	367	4.7687	.0701	.0346
Np-236a	115E3 y	ECB-	99	.0000	.2083	.1363
Am-241	432.2 y	A	976	5.4791	.0520	.0325
Eu-150a	12.62 h	B-ECB+	168	.0000	.3124	.0468
Eu-150b	34.2 y	EC	927	.0000	.0435	1.4964
Cf-252	2.638 y	SFA	67	5.9223	.0056	.0012
[Emitted energy given here excludes elec. & photons from spontaneous fission]						
Sb-124n	20.2 m	IT	29	.0000	.0247	.0002
Ir-190n	3.1 h	ITEC	125	.0000	.1255	1.5546

Name of spectra file, .bet added -> misc

Nuclide	T-1/2	DecMode	# records
Na-24	15.00 h	B-	127
K-40	1.28E9 y	B-EC	114
Sr-90	29.12 y	B-	102
I-131	8.04 d	B-	108
Cs-137	30.0 y	B-	112
Np-236a	115E3 y	ECB-	98
Eu-150a	12.62 h	B-ECB+	113

Program DEXRAX ended normally.

Stop - Program terminated.

C:\DCAL>

Figure 6b. Log File DEXRAX.LOG from Examples 3 and 4.

Note that the log file for Example 4 was appended to that for Example 3, because user requested it to be (see Figure 6a, first screen).

This is DEXRAX log file Dexrax.log

<< DEXRAX Ver. 1.0 (Sep 1, 1993) --- Run Sep 04, 1993, at 15:52 >>

Program DEXRAX ended normally.

This is DEXRAX log file Dexrax.log

<< DEXRAX Ver. 1.0 (Sep 1, 1993) --- Run Sep 04, 1993, at 15:53 >>

No duplicates existed in list of length 14. List includes:

Na-24	K-40	Sr-90	Tc-99m	I-131	Cs-137	Np-237	Np-236a
Am-241	Eu-150a	Eu-150b	Cf-252	Sb-124n	Ir-190n		

Data will be extracted from the ICRP38 nuclear decay data files.

Radiations data written to file misc.rad

DEXRAX exe file was:	Dexrax.exe	163816	09-01-93	12:00a
----------------------	------------	--------	----------	--------

Index file was:	ICRP38.idx	106556	09-01-93	12:00a
-----------------	------------	--------	----------	--------

Radiations data read from file:	ICRP38.rad	5971698	09-01-93	12:00a
---------------------------------	------------	---------	----------	--------

Nuclide	T-1/2	DecMode	# rad.	Emitted Energy (MeV/nt)		
				Alpha	Elec.	Photon
Na-24	15.00 h	B-	47	.0000	.5535	4.1212
K-40	1.28E9 y	B-EC	25	.0000	.5226	.1563
Sr-90	29.12 y	B-	1	.0000	.1957	.0000
Tc-99m	6.02 h	IT	57	.0000	.0162	.1263
I-131	8.04 d	B-	172	.0000	.1917	.3815
Cs-137	30.0 y	B-	2	.0000	.1870	.0000
Np-237	2.14E6 y	A	367	4.7687	.0701	.0346
Np-236a	115E3 y	ECB-	99	.0000	.2083	.1363
Am-241	432.2 y	A	976	5.4791	.0520	.0325
Eu-150a	12.62 h	B-ECB+	168	.0000	.3124	.0468
Eu-150b	34.2 y	EC	927	.0000	.0435	1.4964
Cf-252	2.638 y	SFA	67	5.9223	.0056	.0012
[Emitted energy given here excludes elec. & photons from spontaneous fission]						
Sb-124n	20.2 m	IT	29	.0000	.0247	.0002
Ir-190n	3.1 h	ITEC	125	.0000	.1255	1.5546

(Figure 6b, cont'd)

Beta spectra written to file misc.bet

DEXRAX exe file was: Dexrax.exe 163816 09-01-93 12:00a

Index file was: ICRP38.idx 106556 09-01-93 12:00a

Beta spectra read from file: ICRP38.bet 684882 09-01-93 12:00a

Nuclide	T-1/2	DecMode	# records
Na-24	15.00 h	B-	127
K-40	1.28E9 y	B-EC	114
Sr-90	29.12 y	B-	102
I-131	8.04 d	B-	108
Cs-137	30.0 y	B-	112
Np-236a	115E3 y	ECB-	98
Eu-150a	12.62 h	B-ECB+	113

Program DEXRAX ended normally.

Table 13. Expressions for Computation of Intensities and Average Energies of Radiations Accompanying Spontaneous Fission^{a,b}

Radiation type	Average energy (MeV)	Intensity in fraction per decay
Neutrons	$0.75 + 0.65 (\bar{\nu} + 1)^{1/2}$	$\bar{\nu} f_{\text{SF}}$
Fission fragments	$0.0698Z^2 / A^{1/3} - 10.988$	$2f_{\text{SF}}$
Prompt gamma rays	0.8847	$8.636f_{\text{SF}}$
Delayed gamma rays	0.9578	$0.2102m^2f_{\text{SF}}$
Beta particles	0.2058m	mf_{SF}

^aMethods of Dillman and Jones¹⁴, as given by Dillman⁷^bIn this table, $\bar{\nu}$ = neutrons per fission, f_{SF} = spontaneous fissions per decay, Z = atomic number of parent, A = mass number of parent, and $m = 5.98 + 92A/236 - Z$.

Figure 7. Example 5: Input and Output RAD Files for a Nuclide with Spontaneous Fission.

Radiations Data for Cf-252, as Given in ICRP38.RAD

```
Cf-252    2.638y    67
9 3.09200E 00 3.73000E 00
8 5.80624E-05 5.61645E 00
8 1.93541E-03 5.82607E 00
8 2.32250E-01 5.97664E 00
8 1.51930E 01 6.07564E 00
8 8.14810E 01 6.11835E 00
1 1.48269E-02 4.33990E-02
6 2.19204E-01 1.89390E-02
6 5.87066E 00 1.96200E-02
6 4.86026E 00 2.44690E-02
6 3.07137E 00 3.86020E-02
6 1.21195E 00 4.33990E-02
1 1.25980E-02 1.00200E-01
6 5.67693E-03 7.57399E-02
6 1.01993E-01 7.64208E-02
6 6.41127E-02 8.12699E-02
6 4.85042E-02 9.54028E-02
6 1.90970E-02 1.00200E-01
1 1.93816E-03 1.60000E-01
6 3.43580E-04 3.17800E-02
6 1.92170E-04 1.35540E-01
6 1.97074E-03 1.36221E-01
6 9.95704E-04 1.41070E-01
6 8.91590E-04 1.55203E-01
6 3.47181E-04 1.60000E-01

...
2 2.14785E 00 1.49590E-02
2 2.40130E-01 1.47030E-02
2 2.44729E 00 1.95520E-02
2 5.78417E-01 1.80601E-02
2 1.50561E-02 1.96630E-02

...
7 1.19882E-02 1.55252E-02
7 9.11604E-03 1.95302E-02
7 1.62866E-03 2.26386E-02
7 8.79871E-01 1.48442E-02
7 6.20168E-01 1.88492E-02
7 1.03720E-01 2.19576E-02
7 1.59331E 00 9.99524E-03
7 1.14014E 00 1.40002E-02
7 1.90396E-01 1.71086E-02
7 1.49235E 01 4.38850E-03
7 4.80867E 00 1.00747E-03
```

Notes:

ICODE = 9 refers to spontaneous fission in this file. Frequency of fissioning is 3.092% and there are 3.73 neutrons per fission.

Intensities are in percent in this file, but are in absolute fractions in output file.

Radiations Data for Cf-252, as Given in RAD Output File

```
This is DEXRAX radiations data file Cf252.rad
<< DEXRAX Ver. 1.0 (Sep 1, 1993) --- Run Sep 04, 1993, at 16:30 >>
DEXRAX exe file was:      Dexrax.exe      163816 09-01-93 12:00a
Index file was:          ICRP38.idx      106556 09-01-93 12:00a
Radiations data read from file:  ICRP38.rad  5971698 09-01-93 12:00a
Cf-252    2.638y SFA      71 Cm-248   9.6910E-01 sf      3.0920E-02
```

Notes:

In output file, spontaneous fission is expanded into ICODE = 9 to 13 (fission fragments, neutrons, prompt gammas, delayed gammas, and betas, resp.). Values following ICODE on each line are intensities and energies.

Mnemonics for each radiation type are given in output file.

```
9 6.18400E-02 9.51426E+01 ff
101.15332E-01 2.16366E+00 n
112.67025E-01 8.84700E-01 pg
122.51232E-01 9.57800E-01 dg
131.92239E-01 1.27952E+00 sb
8 5.80624E-07 5.61645E+00 a
8 1.93541E-05 5.82607E+00 a
8 2.32250E-03 5.97664E+00 a
8 1.51930E-01 6.07564E+00 a
8 8.14810E-01 6.11835E+00 a
1 1.48269E-04 4.33990E-02 g
6 2.19204E-03 1.89390E-02 ic
6 5.87066E-02 1.96200E-02 ic
6 4.86026E-02 2.44690E-02 ic
6 3.07137E-02 3.86020E-02 ic
6 1.21195E-02 4.33990E-02 ic
1 1.25980E-04 1.00200E-01 g
6 5.67693E-05 7.57399E-02 ic
6 1.01993E-03 7.64208E-02 ic
6 6.41127E-04 8.12699E-02 ic
6 4.85042E-04 9.54028E-02 ic
6 1.90970E-04 1.00200E-01 ic
1 1.93816E-05 1.60000E-01 g
6 3.43580E-06 3.17800E-02 ic
6 1.92170E-06 1.35540E-01 ic
6 1.97074E-05 1.36221E-01 ic
6 9.95704E-06 1.41070E-01 ic
6 8.91590E-06 1.55203E-01 ic
6 3.47181E-06 1.60000E-01 ic

...
2 2.14785E-02 1.49590E-02 x
2 2.40130E-03 1.47030E-02 x
2 2.44729E-02 1.95520E-02 x
2 5.78417E-03 1.80601E-02 x
2 1.50561E-04 1.96630E-02 x

...
7 1.19882E-04 1.55252E-02 ae
7 9.11604E-05 1.95302E-02 ae
7 1.62866E-05 2.26386E-02 ae
7 8.79871E-03 1.48442E-02 ae
7 6.20168E-03 1.88492E-02 ae
7 1.03720E-03 2.19576E-02 ae
7 1.59331E-02 9.99524E-03 ae
7 1.14014E-02 1.40002E-02 ae
7 1.90396E-03 1.71086E-02 ae
7 1.49235E-01 4.38850E-03 ae
7 4.80867E-02 1.00747E-03 ae
```

VI. CONCLUSIONS

The data files and extraction utility discussed in this document have brought a large radionuclide data base from the ORNL IBM mainframe environment to the PC environment, while at the same time creating a convenient system for management of nuclear decay data. Access time to the data for a particular radionuclide has been noticeably reduced, and additional conveniences have been included, such as extraction of data for an entire decay chain. Furthermore, the index files provide a convenient source of information on the half-lives, decay modes, and radioactive decay products for the radionuclides.

VII. REFERENCES

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APPENDIX A

SUMMARY OF NUCLEAR DECAY DATA

Tables A.1 and A.2 list the nuclides present in the ICRP38 and MIRD collections, respectively. It should be noted that, unlike the ICRP38 collection, the MIRD collection is not complete with respect to inclusion of all decay chain members.

The tables contain the following information. The physical half-life of the radionuclides is given in the second column of the table. The time units are abbreviated as: y for year, d for day, h for hour, m for minutes, s for second, ms for millisecond, and μ s for microsecond. The modes of nuclear transformation applicable to the radionuclide are given in the column headed "Decay Mode." The modes are abbreviated as: B- for beta minus decay, B+ for beta plus decay, EC for electron capture, A for alpha decay, IT for isometric transition, and SF for spontaneous fission. The nuclear transformations of a radionuclide (the parent) may form a nucleus which is also radioactive (radioactive decay product). The entries in the columns headed by "Radioactive Decay Products and Fractional Yield" identifies radioactive nuclei formed by nuclear transformations of the parent radionuclide and gives the fraction (referred to as the branching fraction) of the parent's transformations forming the decay product. No attempt is made to identify the radioactive nuclei formed by spontaneous fission. The notation "SF" simply indicates that the accompanying branching fraction refers to spontaneous fission. The three columns on the extreme right give the *total kinetic energy per nuclear transformation* of emitted alpha particles, electrons, and photons¹ (excluding electrons and photons from spontaneous fission). The entry for alpha particles represents only the kinetic energy of the alpha particles and does not include the recoil energy of the newly formed nucleus. The entry for electrons includes the kinetic energy of all beta particles, internal conversion

¹The total kinetic energy of radiation type R , $E_{T,R}$, is computed as

$$E_{T,R} = \sum_{i=1}^n y_{i,R} E_{i,R} ,$$

where $y_{i,R}$ is the mean number of radiations of type R emitted per nuclear transformation with unique or mean energy $E_{i,R}$. This quantity should not be confused with the mean energy of radiation type R , which is

$$\bar{E}_R = \frac{E_{T,R}}{\sum_{i=1}^n y_{i,R}} .$$

electrons, and Auger electrons emitted in the nuclear transformations. Similarly, the photon entry presents gamma rays, and characteristic x rays, and annihilation photons. If nuclear transformations of the radionuclide do not result in emission of a particular radiation then a dash, "-", is shown in the appropriate column. If, however, radiations of a particular type are emitted, but the total energy per nuclear transformation is less than 1 keV, then the symbol "<" appears in the column.

For each radionuclide, the radioactive decay products, if formed, are identified in the tables. Consider the radionuclide ^{144}Ce . The ^{144}Ce entry in Table A.1 indicates that ^{144}Ce has a $T_{1/2}$ of 284.3 days and forms ^{144}Pr in 98.22% of its transformations and ^{144m}Pr in 1.78% of its transformations. The entry for ^{144m}Pr , $T_{1/2} = 7.2$ m, indicates that it decays (in 99.90% of the transformations) by internal transition to ^{144}Pr ; the remaining transformations form the stable nucleus ^{144}Nd . Nuclear transformations of ^{144}Pr , half-life of 17.28 minutes, do not form a radioactive decay product. Thus, by repeated entry into Table A.1, one can follow the serial transformations (decay chain) associated with a radionuclide. For nuclides with multiple modes of transformation, the serial chain formed by each mode must be followed. In some instances the chains may converge. It should be noted that the branching fractions may not always add to exactly one, since only branches leading to *radioactive* decay products are tabulated, and because of uncertainties in the fractions. The stated values are considered to be appropriate for use in dosimetric calculations.

In some instances a radionuclide is not uniquely identified by its atomic number (or chemical symbol) and mass number. Nuclei of the same atomic and mass numbers, but with distinguishable nuclear properties, are referred to as isomers. Identification of an isomer requires reference to its physical half-life. The nuclide designations in our decay data collections (ICRP38 and MIRD) involve some nonstandard notation to reference isomers.

To differentiate isomers, when neither isomer has been designated as a metastable state, an "a" or "b" has been added to the chemical symbol-mass number notation; e.g., the ^{89a}Nb entry in Table A.1 is the isomer of ^{89}Nb with a half-life of 66 m. Which isomer was assigned "a" and which "b" was done arbitrarily. To identify multiple metastable states, "m" and "n" are used; e.g., ^{124m}Sb in Table A.1 refers to the metastable state with a half-life of 93 s while ^{124a}Sb refers to the state with a half-life of 20.2 min. Additional examples of a, b, m, and n isomers can be seen in Table 12 and Table A.1 for indium (In), europium (Eu), terbium (Tb), rhenium (Re), iridium (Ir), tantalum (Ta), and neptunium (Np). Note that in Table A.1 ^{178a}Ta and ^{178b}Ta appear, while in Table A.2 ^{178a}Ta appears as ^{178}Ta , because only one isomer is in the collection. With respect to this non-standard notation, the MIRD collection contains only the isomers ^{190m}Ir and ^{190n}Ir .

Table A-1. Summary Information on the Nuclear Transformation of the Radionuclides in ICRP38 Collection.

Nuclide	T _{1/2}	Decay Mode	Radioactive Decay Products and Fractional Yield				Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon
Hydrogen									
H-3	12.35y	B-						-	0.006 -
Beryllium									
Be-7	53.3d	EC						-	< 0.049
Be-10	1.6E6y	B-						-	0.252 -
Carbon									
C-11	20.38m	ECB+						-	0.385 1.020
C-14	5730y	B-						-	0.049 -
Nitrogen									
N-13	9.965m	ECB+						-	0.491 1.020
Oxygen									
O-14	70.599s	ECB+						-	0.777 3.319
O-15	122.24s	ECB+						-	0.734 1.021
O-19	26.91s	B-						-	1.733 0.957
Fluorine									
F-18	109.77m	ECB+						-	0.250 1.022
Neon									
Ne-19	17.22s	ECB+						-	0.963 1.022
Sodium									
Na-22	2.602y	ECB+						-	0.194 2.193
Na-24	15.00h	B-						-	0.554 4.121
Magnesium									
Mg-28	20.91h	B-	Al-28	1.000E+00				-	0.163 1.371
Aluminium									
Al-26	7.16E5y	ECB+						-	0.445 2.676
Al-28	2.240m	B-						-	1.242 1.779
Silicon									
Si-31	157.3m	B-						-	0.595 <
Si-32	450y	B-	P-32	1.000E+00				-	0.065 -
Phosphorus									
P-30	2.499m	ECB+						-	1.436 1.022
P-32	14.29d	B-						-	0.695 -
P-33	25.4d	B-						-	0.077 -
Sulfur									
S-35	87.44d	B-						-	0.049 -
Chlorine									
Cl-36	3.01E5y	ECB+B-						-	0.274 <
Cl-38	37.21m	B-						-	1.529 1.488
Cl-39	55.6m	B-	Ar-39	1.000E+00				-	0.823 1.438
Argon									
Ar-37	35.02d	EC						-	0.002 <
Ar-39	269y	B-						-	0.219 -
Ar-41	1.827h	B-						-	0.464 1.284
Potassium									
K-38	7.636m	ECB+						-	1.209 3.187
K-40	1.28E9y	B-EC						-	0.523 0.156
K-42	12.36h	B-						-	1.430 0.276
K-43	22.6h	B-						-	0.309 0.970
K-44	22.13m	B-						-	1.491 2.267
K-45	20m	B-	Ca-45	1.000E+00				-	0.984 1.866
Calcium									
Ca-41	1.4E5y	EC						-	0.002 <
Ca-45	163d	B-						-	0.077 <
Ca-47	4.53d	B-	Sc-47	1.000E+00				-	0.345 1.063
Ca-49	8.716m	B-	Sc-49	1.000E+00				-	0.870 3.165
Scandium									
Sc-43	3.891h	ECB+						-	0.313 1.096
Sc-44m	58.6h	ECIT	Sc-44	9.863E-01				-	0.033 0.280
Sc-44	3.927h	ECB+						-	0.597 2.137
Sc-46	83.83d	B-						-	0.112 2.009
Sc-47	3.351d	B-						-	0.163 0.108
Sc-48	43.7h	B-						-	0.229 3.349
Sc-49	57.4m	B-						-	0.822 0.001

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield									
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon
Titanium									
Ti-44	47.3y	EC	Sc-44	1.000E+00				-	0.013 0.135
Ti-45	3.08h	ECB+						-	0.373 0.870
Vanadium									
V-47	32.6m	ECB+						-	0.803 0.995
V-48	16.238d	ECB+						-	0.149 2.914
V-49	330d	EC						-	0.004 <
Chromium									
Cr-48	22.96h	ECB+	V-48	1.000E+00				-	0.008 0.436
Cr-49	42.09m	ECB+	V-49	1.000E+00				-	0.602 1.055
Cr-51	27.704d	EC						-	0.004 0.033
Manganese									
Mn-51	46.2m	ECB+	Cr-51	1.000E+00				-	0.934 0.998
Mn-52m	21.1m	ECB+IT	Mn-52	1.750E-02				-	1.132 2.409
Mn-52	5.591d	ECB+						-	0.075 3.458
Mn-53	3.7E6y	EC						-	0.004 0.001
Mn-54	312.5d	EC						-	0.004 0.836
Mn-56	2.5785h	B-						-	0.830 1.692
Iron									
Fe-52	8.275h	ECB+	Mn-52m	1.000E+00				-	0.194 0.740
Fe-55	2.7y	EC						-	0.004 0.002
Fe-59	44.529d	B-						-	0.118 1.189
Fe-60	1E5y	B-	Co-60m	1.000E+00				-	0.049 -
Cobalt									
Co-55	17.54h	ECB+	Fe-55	1.000E+00				-	0.429 1.994
Co-56	78.76d	ECB+						-	0.124 3.580
Co-57	270.9d	EC						-	0.019 0.125
Co-58m	9.15h	IT	Co-58	1.000E+00				-	0.023 0.002
Co-58	70.80d	ECB+						-	0.034 0.976
Co-60m	10.47m	ITB-	Co-60	9.975E-01				-	0.058 0.007
Co-60	5.271y	B-						-	0.097 2.504
Co-61	1.65h	B-						-	0.463 0.091
Co-62m	13.91m	B-						-	1.051 2.698
Nickel									
Ni-56	6.10d	EC	Co-56	1.000E+00				-	0.007 1.721
Ni-57	36.08h	ECB+	Co-57	1.000E+00				-	0.143 1.922
Ni-59	7.5E4y	EC						-	0.005 0.002
Ni-63	96y	B-						-	0.017 -
Ni-65	2.520h	B-						-	0.632 0.549
Ni-66	54.6h	B-	Cu-66	1.000E+00				-	0.067 -
Copper									
Cu-57	233ms	ECB+	Ni-57	1.000E+00				-	3.622 1.063
Cu-60	23.2m	ECB+						-	0.895 3.898
Cu-61	3.408h	ECB+						-	0.311 0.829
Cu-62	9.74m	ECB+						-	1.285 1.007
Cu-64	12.701h	B-ECB+						-	0.123 0.191
Cu-66	5.10m	B-						-	1.068 0.085
Cu-67	61.86h	B-						-	0.155 0.115
Zinc									
Zn-62	9.26h	ECB+	Cu-62	1.000E+00				-	0.033 0.439
Zn-63	38.1m	ECB+						-	0.918 1.100
Zn-65	243.9d	ECB+						-	0.007 0.584
Zn-69m	13.76h	ITB-	Zn-69	9.997E-01				-	0.022 0.417
Zn-69	57m	B-						-	0.321 <
Zn-71m	3.92h	B-						-	0.548 1.552
Zn-72	46.5h	B-	Ga-72	1.000E+00				-	0.102 0.152
Gallium									
Ga-65	15.2m	ECB+	Zn-65	1.000E+00				-	0.831 1.176
Ga-66	9.40h	ECB+						-	0.970 2.473
Ga-67	78.26h	EC						-	0.036 0.158
Ga-68	68.0m	ECB+						-	0.739 0.951
Ga-70	21.15m	B-EC						-	0.644 0.008

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon
Gallium, cont'd										
Ga-72	14.1h	B-						-	0.497	2.711
Ga-73	4.91h	B-						-	0.494	0.316
Germanium										
Ge-66	2.27h	ECB+	Ga-66	1.000E+00				-	0.102	0.687
Ge-67	18.7m	ECB+	Ga-67	1.000E+00				-	1.297	1.406
Ge-68	288d	EC	Ga-68	1.000E+00				-	0.005	0.004
Ge-69	39.05h	ECB+						-	0.179	0.873
Ge-71	11.8d	EC						-	0.005	0.004
Ge-75	82.78m	B-						-	0.420	0.034
Ge-77	11.30h	B-	As-77	1.000E+00				-	0.648	1.086
Ge-78	87m	B-	As-78	1.000E+00				-	0.238	0.278
Arsenic										
As-69	15.2m	ECB+	Ge-69	1.000E+00				-	1.274	1.013
As-70	52.6m	ECB+						-	0.865	4.095
As-71	64.8h	ECB+	Ge-71	1.000E+00				-	0.119	0.574
As-72	26.0h	ECB+						-	1.026	1.794
As-73	80.30d	EC						-	0.060	0.016
As-74	17.76d	B-ECB+						-	0.268	0.759
As-76	26.32h	B-						-	1.064	0.430
As-77	38.8h	B-						-	0.229	0.009
As-78	90.7m	B-						-	1.356	1.252
Selenium										
Se-70	41.0m	ECB+	As-70	1.000E+00				-	0.489	0.999
Se-72	8.40d	EC	As-72	1.000E+00				-	0.023	0.034
Se-73m	39m	ECB+IT	Se-73	7.300E-01	As-73	2.700E-01		-	0.178	0.244
Se-73	7.15h	ECB+	As-73	1.000E+00				-	0.386	1.087
Se-75	119.8d	EC						-	0.015	0.394
Se-77m	17.45s	IT						-	0.072	0.088
Se-79	65000y	B-						-	0.056	-
Se-81m	57.25m	ITB-	Se-81	1.000E+00				-	0.085	0.018
Se-81	18.5m	B-						-	0.611	0.009
Se-83	22.5m	B-	Br-83	1.000E+00				-	0.508	2.429
Bromine										
Br-74m	41.5m	ECB+						-	1.412	4.082
Br-74	25.3m	ECB+						-	1.115	4.549
Br-75	98m	ECB+	Se-75	1.000E+00				-	0.524	1.216
Br-76	16.2h	ECB+						-	0.691	2.633
Br-77	56h	ECB+						-	0.009	0.321
Br-80m	4.42h	IT	Br-80	1.000E+00				-	0.060	0.024
Br-80	17.4m	B-ECB+						-	0.724	0.080
Br-82	35.30h	B-						-	0.139	2.642
Br-83	2.39h	B-	Kr-83m	9.998E-01				-	0.321	0.008
Br-84	31.80m	B-						-	1.229	1.788
Krypton										
Kr-74	11.50m	ECB+	Br-74	1.000E+00				-	0.792	1.169
Kr-76	14.8h	EC	Br-76	1.000E+00				-	0.015	0.435
Kr-77	74.7m	ECB+	Br-77	1.000E+00				-	0.642	1.016
Kr-79	35.04h	ECB+						-	0.024	0.257
Kr-81m	13s	IT	Kr-81	1.000E+00				-	0.059	0.131
Kr-81	2.1E5y	EC						-	0.005	0.012
Kr-83m	1.83h	IT						-	0.039	0.003
Kr-85m	4.48h	ITB-	Kr-85	2.110E-01				-	0.255	0.158
Kr-85	10.72y	B-						-	0.251	0.002
Kr-87	76.3m	B-	Rb-87	1.000E+00				-	1.324	0.793
Kr-88	2.84h	B-	Rb-88	1.000E+00				-	0.364	1.955
Rubidium										
Rb-77	3.70m	ECB+	Kr-77	1.000E+00				-	1.646	1.831
Rb-79	22.9m	ECB+	Kr-79	1.000E+00				-	0.820	1.358
Rb-80	34s	ECB+						-	2.011	1.246
Rb-81m	32m	IT	Rb-81	1.000E+00				-	0.074	0.010
Rb-81	4.58h	ECB+	Kr-81	1.000E+00				-	0.197	0.623

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon	
Rubidium, cont'd										
Rb-82m	6.2h	ECB+						-	0.095	2.910
Rb-82	1.3m	ECB+						-	1.407	1.093
Rb-83	86.2d	EC	Kr-83m	7.620E-01				-	0.015	0.504
Rb-84	32.77d	ECB+B-						-	0.155	0.919
Rb-86	18.66d	B-						-	0.668	0.095
Rb-87	4.7E10y	B-						-	0.111	-
Rb-88	17.8m	B-						-	2.066	0.629
Rb-89	15.2m	B-	Sr-89	1.000E+00				-	1.013	2.071
Strontium										
Sr-80	100m	EC	Rb-80	1.000E+00				-	0.005	0.008
Sr-81	25.5m	ECB+	Rb-81	1.000E+00				-	1.000	1.386
Sr-82	25.0d	EC	Rb-82	1.000E+00				-	0.005	0.008
Sr-83	32.4h	ECB+	Rb-83	1.000E+00				-	0.149	0.801
Sr-85m	69.5m	ITEC	Sr-85	8.790E-01				-	0.012	0.220
Sr-85	64.84d	EC						-	0.009	0.512
Sr-87m	2.805h	ECIT	Rb-87	3.000E-03				-	0.067	0.320
Sr-89	50.5d	B-						-	0.583	<
Sr-90	29.12y	B-	Y-90	1.000E+00				-	0.196	-
Sr-91	9.5h	B-	Y-91m	5.780E-01	Y-91	4.220E-01		-	0.856	0.697
Sr-92	2.71h	B-	Y-92	1.000E+00				-	0.196	1.339
Yttrium										
Y-86m	48m	ECB+IT	Y-86	9.931E-01				-	0.025	0.221
Y-86	14.74h	ECB+						-	0.226	3.589
Y-87	80.3h	ECB+	Sr-87m	9.990E-01				-	0.007	0.457
Y-88	106.64d	ECB+						-	0.007	2.692
Y-90m	3.19h	IT	Y-90	9.920E-01				-	0.047	0.629
Y-90	64.0h	B-						-	0.935	<
Y-91m	49.71m	IT	Y-91	1.000E+00				-	0.027	0.530
Y-91	58.51d	B-						-	0.602	0.004
Y-92	3.54h	B-						-	1.446	0.252
Y-93	10.1h	B-	Zr-93	1.000E+00				-	1.174	0.089
Y-94	19.1m	B-						-	1.675	1.110
Y-95	10.7m	B-	Zr-95	1.000E+00				-	1.528	0.894
Zirconium										
Zr-86	16.5h	EC	Y-86	1.000E+00				-	0.030	0.288
Zr-88	83.4d	EC	Y-88	1.000E+00				-	0.016	0.403
Zr-89	78.43h	ECB+						-	0.101	1.165
Zr-93	1.53E6y	B-	Nb-93m	1.000E+00				-	0.020	-
Zr-95	63.98d	B-	Nb-95	9.930E-01	Nb-95m	6.980E-03		-	0.116	0.739
Zr-97	16.90h	B-	Nb-97m	9.470E-01	Nb-97	5.300E-02		-	0.700	0.179
Niobium										
Nb-88	14.3m	ECB+	Zr-88	1.000E+00				-	1.237	4.126
Nb-89b	122m	ECB+	Zr-89	1.000E+00				-	1.115	1.391
Nb-89a	66m	ECB+	Zr-89	1.000E+00				-	0.834	1.925
Nb-90	14.60h	ECB+						-	0.403	4.224
Nb-93m	13.6y	IT						-	0.028	0.002
Nb-94	2.03E4y	B-						-	0.168	1.574
Nb-95m	86.6h	IT	Nb-95	1.000E+00				-	0.166	0.068
Nb-95	35.15d	B-						-	0.044	0.766
Nb-96	23.35h	B-						-	0.253	2.472
Nb-97m	60s	IT	Nb-97	1.000E+00				-	0.015	0.728
Nb-97	72.1m	B-						-	0.468	0.655
Nb-98	51.5m	B-						-	0.887	2.426
Molybdenum										
Mo-90	5.67h	ECB+	Nb-90	1.000E+00				-	0.204	0.827
Mo-93m	6.85h	IT	Mo-93	1.000E+00				-	0.097	2.250
Mo-93	3.5E3y	EC	Nb-93m	1.000E+00				-	0.006	0.011
Mo-99	66.0h	B-	Tc-99m	8.760E-01	Tc-99	1.240E-01		-	0.392	0.150
Mo-101	14.62m	B-	Tc-101	1.000E+00				-	0.589	1.368
Technetium										
Tc-93m	43.5m	ITEC	Tc-93	8.180E-01	Mo-93	1.820E-01		-	0.079	0.724

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield									
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon
Technetium, cont'd									
Tc-93	2.75h	EC	Mo-93	1.000E+00			-	0.006	1.459
Tc-94m	52m	ECB+					-	0.756	1.859
Tc-94	293m	ECB+					-	0.049	2.671
Tc-95m	61d	ECB+IT	Tc-95	4.000E-02			-	0.016	0.675
Tc-95	20.0h	EC					-	0.007	0.796
Tc-96m	51.5m	ITEC	Tc-96	9.800E-01			-	0.027	0.052
Tc-96	4.28d	EC					-	0.009	2.506
Tc-97m	87d	IT	Tc-97	1.000E+00			-	0.087	0.010
Tc-97	2.6E6y	EC					-	0.006	0.011
Tc-98	4.2E6y	B-					-	0.159	1.413
Tc-99m	6.02h	IT	Tc-99	1.000E+00			-	0.016	0.126
Tc-99	2.13E5y	B-					-	0.101	-
Tc-101	14.2m	B-					-	0.478	0.334
Tc-104	18.2m	B-					-	1.601	1.981
Ruthenium									
Ru-94	51.8m	EC	Tc-94m	1.000E+00			-	0.008	0.535
Ru-97	2.9d	EC	Tc-97	9.992E-01	Tc-97m	7.550E-04	-	0.013	0.240
Ru-103	39.28d	B-	Rh-103m	9.970E-01			-	0.075	0.469
Ru-105	4.44h	B-	Rh-105	1.000E+00			-	0.400	0.784
Ru-106	368.2d	B-	Rh-106	1.000E+00			-	0.010	-
Rhodium									
Rh-99m	4.7h	ECB+					-	0.032	0.685
Rh-99	16d	ECB+					-	0.042	0.608
Rh-100	20.8h	ECB+					-	0.070	2.767
Rh-101m	4.34d	ECIT	Rh-101	7.200E-02			-	0.020	0.307
Rh-101	3.2y	EC					-	0.032	0.269
Rh-102m	207d	ECB+IT	Rh-102	5.000E-02			-	0.168	0.486
Rh-102	2.9y	ECB+					-	0.012	2.140
Rh-103m	56.12m	IT					-	0.038	0.002
Rh-105	35.36h	B-					-	0.154	0.078
Rh-106m	132m	B-					-	0.313	2.915
Rh-106	29.9s	B-					-	1.413	0.205
Rh-107	21.7m	B-	Pd-107	1.000E+00			-	0.445	0.312
Palladium									
Pd-100	3.63d	EC	Rh-100	1.000E+00			-	0.044	0.129
Pd-101	8.27h	ECB+	Rh-101m	9.970E-01	Rh-101	3.000E-03	-	0.039	0.337
Pd-103	16.96d	EC	Rh-103m	9.997E-01			-	0.006	0.014
Pd-107	6.5E6y	B-					-	0.009	-
Pd-109	13.427h	B-					-	0.437	0.012
Silver									
Ag-102	12.9m	ECB+					-	0.819	3.353
Ag-103	65.7m	ECB+	Pd-103	1.000E+00			-	0.259	0.765
Ag-104m	33.5m	ECB+IT	Ag-104	3.300E-01			-	0.509	1.174
Ag-104	69.2m	ECB+					-	0.091	2.683
Ag-105	41.0d	ECB+					-	0.019	0.525
Ag-106m	8.41d	EC					-	0.013	2.822
Ag-106	23.96m	ECB+					-	0.508	0.711
Ag-108m	127y	ECIT	Ag-108	8.900E-02			-	0.016	1.627
Ag-108	2.37m	ECB+B-					-	0.610	0.018
Ag-109m	39.6s	IT					-	0.077	0.011
Ag-110m	249.9d	ITB-	Ag-110	1.330E-02			-	0.072	2.751
Ag-110	24.6s	B-EC					-	1.182	0.031
Ag-111	7.45d	B-					-	0.354	0.026
Ag-112	3.12h	B-					-	1.384	0.657
Ag-115	20.0m	B-	Cd-115	9.340E-01	Cd-115m	6.600E-02	-	1.042	0.707
Cadmium									
Cd-104	57.7m	ECB+	Ag-104	1.000E+00			-	0.032	0.259
Cd-107	6.49h	ECB+					-	0.087	0.034
Cd-108	464d	EC					-	0.083	0.026
Cd-113m	13.6y	B-					-	0.185	-
Cd-113	9.3E15y	B-					-	0.093	-

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield									
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon
Cadmium, cont'd									
Cd-115m	44.6d	B-	In-115	1.000E+00				-	0.607 0.022
Cd-115	53.46h	B-	In-115m	1.000E+00				-	0.303 0.233
Cd-117m	3.36h	B-	In-117	9.900E-01	In-117m	9.980E-03		-	0.229 2.044
Cd-117	2.49h	B-	In-117m	9.200E-01	In-117	8.000E-02		-	0.439 1.087
Indium									
In-109	4.2h	ECB+	Cd-109	1.000E+00				-	0.047 0.672
In-110b	4.9h	ECB+						-	0.012 3.049
In-110a	69.1m	ECB+						-	0.626 1.557
In-111m	7.7m	IT	In-111	1.000E+00				-	0.067 0.469
In-111	2.83d	EC						-	0.034 0.405
In-112	14.4m	B-ECB+						-	0.243 0.268
In-113m	1.658h	IT						-	0.134 0.258
In-114m	49.51d	ECIT	In-114	9.570E-01				-	0.143 0.094
In-114	71.9s	B-ECB+						-	0.771 0.003
In-115m	4.486h	ITB-	In-115	9.500E-01				-	0.172 0.161
In-115	5.1E15y	B-						-	0.152 -
In-116m	54.15m	B-						-	0.312 2.473
In-117m	116.5m	B-IT	In-117	4.710E-01				-	0.434 0.091
In-117	43.8m	B-	Sn-117m	3.170E-03				-	0.267 0.692
In-119m	18.0m	B-IT	In-119	2.500E-02				-	1.065 0.011
In-119	2.4m	B-	Sn-119m	1.090E-01				-	0.634 0.769
Tin									
Sn-110	4.0h	EC	In-110a	1.000E+00				-	0.014 0.301
Sn-111	35.3m	ECB+	In-111	1.000E+00				-	0.221 0.510
Sn-113	115.1d	EC	In-113m	1.000E+00				-	0.006 0.023
Sn-117m	13.61d	IT						-	0.161 0.158
Sn-119m	293.0d	IT						-	0.078 0.011
Sn-121m	55y	B-IT	Sn-121	7.760E-01				-	0.035 0.005
Sn-121	27.06h	B-						-	0.114 -
Sn-123m	40.08m	B-						-	0.475 0.140
Sn-123	129.2d	B-						-	0.520 0.007
Sn-125	9.64d	B-	Sb-125	1.000E+00				-	0.811 0.313
Sn-126	1.0E5y	B-	Sb-126m	1.000E+00				-	0.172 0.057
Sn-127	2.10h	B-	Sb-127	1.000E+00				-	0.534 1.910
Sn-128	59.1m	B-	Sb-128a	1.000E+00				-	0.255 0.666
Antimony									
Sb-115	31.8m	ECB+						-	0.238 0.909
Sb-116m	60.3m	ECB+						-	0.153 3.143
Sb-116	15.8m	ECB+						-	0.424 2.158
Sb-117	2.80h	ECB+						-	0.029 0.185
Sb-118m	5.00h	ECB+						-	0.040 2.585
Sb-118	3.6m	ECB+						-	0.896 0.811
Sb-119	38.1h	EC						-	0.026 0.023
Sb-120b	5.76d	EC						-	0.045 2.469
Sb-120a	15.89m	ECB+						-	0.308 0.452
Sb-122	2.70d	ECB-						-	0.565 0.441
Sb-124n	20.2m	IT	Sb-124m	1.000E+00				-	0.025 <
Sb-124m	93s	ITB-	Sb-124	8.000E-01				-	0.092 0.352
Sb-124	60.20d	B-						-	0.387 1.817
Sb-125	2.77y	B-	Te-125m	2.280E-01				-	0.100 0.431
Sb-126m	19.0m	ITB-	Sb-126	1.400E-01				-	0.591 1.548
Sb-126	12.4d	B-						-	0.283 2.834
Sb-127	3.85d	B-	Te-127	8.240E-01	Te-127m	1.760E-01		-	0.316 0.688
Sb-128b	9.01h	B-						-	0.438 3.093
Sb-128a	10.4m	B-						-	0.935 1.986
Sb-129	4.32h	B-	Te-129	7.750E-01	Te-129m	2.250E-01		-	0.408 1.437
Sb-130	40m	B-						-	0.722 3.264
Sb-131	23m	B-	Te-131	9.007E-01	Te-131m	9.930E-02		-	0.553 1.864
Tellurium									
Te-116	2.49h	EC	Sb-116	1.000E+00				-	0.053 0.073
Te-121m	154d	ECIT	Te-121	8.860E-01				-	0.080 0.217

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode							Energy (MeV/nt)	
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon
Tellurium, cont'd										
Te-121	17d	EC							-	0.010 0.577
Te-123m	119.7d	IT	Te-123	1.000E+00					-	0.099 0.148
Te-123	1E13y	EC							-	0.006 0.020
Te-125m	58d	IT							-	0.109 0.036
Te-127m	109d	ITB-	Te-127	9.780E-01					-	0.082 0.011
Te-127	9.35h	B-							-	0.223 0.005
Te-129m	33.6d	ITB-	Te-129	6.500E-01	I-129	3.500E-01			-	0.260 0.038
Te-129	69.6m	B-	I-129	1.000E+00					-	0.544 0.059
Te-131m	30h	ITB-	I-131	7.780E-01	Te-131	2.220E-01			-	0.202 1.425
Te-131	25.0m	B-	I-131	1.000E+00					-	0.719 0.420
Te-132	78.2h	B-	I-132	1.000E+00					-	0.102 0.234
Te-133m	55.4m	ITB-	I-133	8.700E-01	Te-133	1.300E-01			-	0.705 2.313
Te-133	12.45m	B-	I-133	1.000E+00					-	0.819 0.929
Te-134	41.8m	B-	I-134	1.000E+00					-	0.300 0.886
Iodine										
I-120m	53m	ECB+							-	1.244 5.297
I-120	81.0m	ECB+							-	1.423 2.729
I-121	2.12h	ECB+	Te-121	1.000E+00					-	0.083 0.419
I-122	3.62m	ECB+							-	1.055 0.946
I-123	13.2h	EC	Te-123	9.999E-01	Te-123m	5.000E-05			-	0.028 0.172
I-124	4.18d	ECB+							-	0.194 1.098
I-125	60.14d	EC							-	0.019 0.042
I-126	13.02d	ECB+B-							-	0.157 0.455
I-128	24.99m	ECB+B-							-	0.748 0.085
I-129	1.57E7y	B-							-	0.064 0.025
I-130	12.36h	B-							-	0.297 2.139
I-131	8.04d	B-	Xe-131m	1.110E-02					-	0.192 0.382
I-132m	83.6m	ITB-	I-132	8.600E-01					-	0.159 0.322
I-132	2.30h	B-							-	0.495 2.280
I-133	20.8h	B-	Xe-133	9.710E-01	Xe-133m	2.900E-02			-	0.411 0.607
I-134	52.6m	B-							-	0.622 2.625
I-135	6.61h	B-	Xe-135	8.460E-01	Xe-135m	1.540E-01			-	0.367 1.576
Xenon										
Xe-120	40m	ECB+	I-120	1.000E+00					-	0.055 0.432
Xe-121	40.1m	ECB+	I-121	1.000E+00					-	0.569 1.815
Xe-122	20.1h	EC	I-122	1.000E+00					-	0.010 0.068
Xe-123	2.08h	ECB+	I-123	1.000E+00					-	0.184 0.634
Xe-125	17.0h	ECB+	I-125	1.000E+00					-	0.034 0.271
Xe-127	36.41d	EC							-	0.033 0.280
Xe-129m	8.0d	IT							-	0.185 0.051
Xe-131m	11.9d	IT							-	0.144 0.020
Xe-133m	2.188d	IT	Xe-133	1.000E+00					-	0.192 0.041
Xe-133	5.245d	B-							-	0.136 0.046
Xe-135m	15.29m	ITB-	Xe-135	1.000E+00	Cs-135	4.000E-05			-	0.098 0.429
Xe-135	6.09h	B-	Cs-135	1.000E+00					-	0.317 0.249
Xe-138	14.17m	B-	Cs-138	1.000E+00					-	0.673 1.125
Cesium										
Cs-125	45m	ECB+	Xe-125	1.000E+00					-	0.347 0.678
Cs-126	1.64m	ECB+							-	1.464 1.086
Cs-127	6.25h	ECB+	Xe-127	1.000E+00					-	0.029 0.420
Cs-128	3.9m	ECB+							-	0.846 0.900
Cs-129	32.06h	ECB+							-	0.018 0.282
Cs-130	29.8m	ECB+							-	0.401 0.517
Cs-131	9.69d	EC							-	0.007 0.023
Cs-132	6.475d	ECB+B-							-	0.014 0.705
Cs-134m	2.90h	IT	Cs-134	1.000E+00					-	0.112 0.027
Cs-134	2.062y	ECB-							-	0.164 1.555
Cs-135m	53m	IT	Cs-135	1.000E+00					-	0.036 1.586
Cs-135	2.3E6y	B-							-	0.067 -
Cs-136	13.1d	B-							-	0.139 2.166
Cs-137	30.0y	B-	Ba-137m	9.460E-01					-	0.187 -
Cs-138	32.2m	B-							-	1.207 2.361

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield									
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon
Barium									
Ba-126	96.5m	ECB+	Cs-126	1.000E+00			-	0.020	0.163
Ba-128	2.43d	EC	Cs-128	1.000E+00			-	0.009	0.076
Ba-131m	14.6m	IT	Ba-131	1.000E+00			-	0.109	0.077
Ba-131	11.8d	ECB+	Cs-131	1.000E+00			-	0.046	0.459
Ba-133m	38.9h	IT	Ba-133	1.000E+00			-	0.221	0.067
Ba-133	10.74y	EC					-	0.054	0.402
Ba-135m	28.7h	IT					-	0.208	0.060
Ba-137m	2.552m	IT					-	0.065	0.597
Ba-139	82.7m	B-					-	0.898	0.043
Ba-140	12.74d	B-	La-140	1.000E+00			-	0.313	0.183
Ba-141	18.27m	B-	La-141	1.000E+00			-	0.901	0.845
Ba-142	10.6m	B-	La-142	1.000E+00			-	0.440	1.047
Lanthanum									
La-131	59m	ECB+	Ba-131	1.000E+00			-	0.208	0.671
La-132	4.8h	ECB+					-	0.522	2.011
La-134	6.67m	ECB+					-	0.739	0.698
La-135	19.5h	ECB+					-	0.007	0.036
La-137	6E4y	EC					-	0.007	0.024
La-138	1.35E11y	B-EC					-	0.037	1.236
La-140	40.272h	B-					-	0.537	2.315
La-141	3.93h	B-	Ce-141	1.000E+00			-	0.948	0.043
La-142	92.5m	B-					-	0.846	2.753
La-143	14.23m	B-	Ce-143	1.000E+00			-	1.324	0.094
Cerium									
Ce-134	72.0h	EC	La-134	1.000E+00			-	0.007	0.026
Ce-135	17.6h	ECB+	La-135	1.000E+00			-	0.244	1.776
Ce-137m	34.4h	ECIT	Ce-137	9.941E-01	La-137	5.900E-03	-	0.203	0.053
Ce-137	9.0h	EC	La-137	1.000E+00			-	0.017	0.036
Ce-139	137.66d	EC					-	0.036	0.160
Ce-141	32.501d	B-					-	0.171	0.076
Ce-143	33.0h	B-	Pr-143	1.000E+00			-	0.433	0.282
Ce-144	284.3d	B-	Pr-144	9.822E-01	Pr-144m	1.780E-02	-	0.092	0.021
Praseodymium									
Pr-136	13.1m	ECB+					-	0.743	2.101
Pr-137	76.6m	ECB+	Ce-137	1.000E+00			-	0.198	0.501
Pr-138m	2.1h	ECB+					-	0.224	2.478
Pr-138	1.45m	ECB+					-	1.159	0.813
Pr-139	4.51h	ECB+	Ce-139	1.000E+00			-	0.046	0.122
Pr-142m	14.6m	IT	Pr-142	1.000E+00			-	0.004	<
Pr-142	19.13h	B-EC					-	0.808	0.058
Pr-143	13.56d	B-					-	0.314	<
Pr-144m	7.2m	ITB-	Pr-144	9.990E-01			-	0.047	0.013
Pr-144	17.28m	B-					-	1.208	0.032
Pr-145	5.98h	B-					-	0.677	0.013
Pr-147	13.6m	B-	Nd-147	1.000E+00			-	0.807	0.863
Neodymium									
Nd-136	50.65m	ECB+	Pr-136	1.000E+00			-	0.093	0.293
Nd-138	5.04h	EC	Pr-138	1.000E+00			-	0.008	0.043
Nd-139m	5.5h	ECB+IT	Pr-139	8.800E-01	Nd-139	1.200E-01	-	0.111	1.572
Nd-139	29.7m	ECB+	Pr-139	1.000E+00			-	0.201	0.406
Nd-141m	62.4s	ECIT	Nd-141	9.996E-01			-	0.068	0.759
Nd-141	2.49h	ECB+					-	0.016	0.075
Nd-147	10.98d	B-	Pm-147	1.000E+00			-	0.270	0.140
Nd-149	1.73h	B-	Pm-149	1.000E+00			-	0.506	0.384
Nd-151	12.44m	B-	Pm-151	1.000E+00			-	0.649	0.816
Promethium									
Pm-141	20.90m	ECB+	Nd-141	9.990E-01	Nd-141m	9.680E-04	-	0.632	0.744
Pm-142	40.5s	ECB+					-	1.365	0.868
Pm-143	265d	EC					-	0.008	0.315
Pm-144	363d	EC					-	0.017	1.563
Pm-145	17.7y	EC					-	0.014	0.031
Pm-146	2020d	B-EC	Sm-146	3.590E-01			-	0.097	0.753

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode	Radioactive Decay Products and Fractional Yield				Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon
Promethium, cont'd										
Pm-147	2.6234y	B-	Sm-147	1.000E+00				-	0.062	<
Pm-148m	41.3d	B-IT	Pm-148	4.600E-02				-	0.170	2.000
Pm-148	5.37d	B-						-	0.724	0.575
Pm-149	53.08h	B-						-	0.366	0.011
Pm-150	2.68h	B-						-	0.807	1.431
Pm-151	28.40h	B-	Sm-151	1.000E+00				-	0.306	0.321
Samarium										
Sm-141m	22.6m	ITECB+	Pm-141	9.969E-01	Sm-141	3.100E-03		-	0.435	1.984
Sm-141	10.2m	ECB+	Pm-141	1.000E+00				-	0.706	1.405
Sm-142	72.49m	ECB+	Pm-142	1.000E+00				-	0.034	0.094
Sm-145	340d	EC	Pm-145	1.000E+00				-	0.032	0.065
Sm-146	1.03E8y	A						2.474	-	-
Sm-147	1.06E11y	A						2.248	-	-
Sm-151	90y	B-						-	0.020	<
Sm-153	46.7h	B-						-	0.273	0.062
Sm-155	22.1m	B-	Eu-155	1.000E+00				-	0.566	0.103
Sm-156	9.4h	B-	Eu-156	1.000E+00				-	0.206	0.121
Europium										
Eu-145	5.94d	ECB+	Sm-145	1.000E+00				-	0.029	1.458
Eu-146	4.61d	ECB+	Sm-146	1.000E+00				-	0.048	2.504
Eu-147	24d	A ECB+	Sm-147	1.000E+00	Pm-143	2.200E-05		<	0.042	0.497
Eu-148	54.5d	A ECB+	Pm-144	9.400E-09				<	0.023	2.177
Eu-149	93.1d	EC						-	0.011	0.063
Eu-150b	34.2y	EC						-	0.044	1.496
Eu-150a	12.62h	B-ECB+						-	0.312	0.047
Eu-152m	9.32h	ECB+B-	Gd-152	7.200E-01				-	0.507	0.293
Eu-152	13.33y	B-ECB+	Gd-152	2.792E-01				-	0.139	1.155
Eu-154	8.8y	ECB-						-	0.292	1.242
Eu-155	4.96y	B-						-	0.063	0.061
Eu-156	15.19d	B-						-	0.423	1.329
Eu-157	15.15h	B-						-	0.395	0.262
Eu-158	45.9m	B-						-	0.963	1.057
Gadolinium										
Gd-145	22.9m	ECB+	Eu-145	1.000E+00				-	0.549	2.257
Gd-146	48.3d	EC	Eu-146	1.000E+00				-	0.130	0.250
Gd-147	38.1h	ECB+	Eu-147	1.000E+00				-	0.060	1.337
Gd-148	93y	A						3.183	-	-
Gd-149	9.4d	EC	Eu-149	1.000E+00				-	0.059	0.420
Gd-151	120d	A EC	Sm-147	8.000E-09				<	0.034	0.064
Gd-152	1.08E14y	A						2.148	-	-
Gd-153	242d	EC						-	0.044	0.106
Gd-159	18.56h	B-						-	0.304	0.050
Terbium										
Tb-147	1.65h	ECB+	Gd-147	1.000E+00				-	0.564	1.590
Tb-149	4.15h	ECB+A	Gd-149	8.000E-01	Eu-145	2.000E-01		0.793	0.186	1.614
Tb-150	3.27h	ECB+						-	0.546	1.679
Tb-151	17.6h	ECB+A	Gd-151	1.000E+00	Eu-147	9.500E-05		<	0.080	0.892
Tb-153	2.34d	ECB+	Gd-153	1.000E+00				-	0.049	0.229
Tb-154	21.4h	ECB+						-	0.081	2.352
Tb-155	5.32d	EC						-	0.034	0.140
Tb-156m	24.4h	IT	Tb-156	1.000E+00				-	0.024	0.025
Tb-156n	5.0h	IT	Tb-156	1.000E+00				-	0.084	0.004
Tb-156	5.34d	EC						-	0.103	1.826
Tb-157	150y	EC						-	0.005	0.003
Tb-158	150y	B-EC						-	0.116	0.798
Tb-160	72.3d	B-						-	0.257	1.124
Tb-161	6.91d	B-						-	0.197	0.035
Dysprosium										
Dy-155	10.0h	ECB+	Tb-155	1.000E+00				-	0.028	0.582
Dy-157	8.1h	EC	Tb-157	1.000E+00				-	0.013	0.357
Dy-159	144.4d	EC						-	0.013	0.045

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield								
Nuclide	T _{1/2}	Decay Mode	Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction
								Energy (MeV/nt)
								Alpha Elec. Photon
Dysprosium, cont'd								
Dy-165	2.334h	B-						- 0.449 0.026
Dy-166	81.6h	B-	Ho-166	1.000E+00				- 0.159 0.040
Holmium								
Ho-155	48m	ECB+	Dy-155	1.000E+00				- 0.241 0.387
Ho-157	12.6m	ECB+	Dy-157	1.000E+00				- 0.081 0.493
Ho-159	33m	ECB+	Dy-159	1.000E+00				- 0.052 0.366
Ho-161	2.5h	EC						- 0.033 0.062
Ho-162m	68m	ITEC	Ho-162	6.100E-01				- 0.078 0.576
Ho-162	15m	ECB+						- 0.062 0.168
Ho-164m	37.5m	IT	Ho-164	1.000E+00				- 0.092 0.047
Ho-164	29m	ECB-						- 0.148 0.030
Ho-166m	1.20E3y	B-						- 0.132 1.747
Ho-166	26.80h	B-						- 0.695 0.029
Ho-167	3.1h	B-						- 0.219 0.365
Erbium								
Er-161	3.24h	ECB+	Ho-161	1.000E+00				- 0.051 0.914
Er-165	10.36h	EC						- 0.008 0.038
Er-167m	2.28s	IT						- 0.111 0.097
Er-169	9.3d	B-						- 0.104 <
Er-171	7.52h	B-	Tm-171	1.000E+00				- 0.422 0.381
Er-172	49.3h	B-	Tm-172	1.000E+00				- 0.129 0.522
Thulium								
Tm-162	21.7m	ECB+						- 0.370 1.781
Tm-166	7.70h	ECB+						- 0.103 1.870
Tm-167	9.24d	EC						- 0.128 0.146
Tm-170	128.6d	ECB-						- 0.331 0.005
Tm-171	1.92y	B-						- 0.026 <
Tm-172	63.6h	B-						- 0.530 0.477
Tm-173	8.24h	B-						- 0.319 0.388
Tm-175	15.2m	B-	Yb-175	1.000E+00				- 0.555 1.053
Ytterbium								
Yb-162	18.9m	EC	Tm-162	1.000E+00				- 0.031 0.137
Yb-166	56.7h	EC	Tm-166	1.000E+00				- 0.042 0.086
Yb-167	17.5m	ECB+	Tm-167	1.000E+00				- 0.092 0.267
Yb-169	32.01d	EC						- 0.125 0.310
Yb-175	4.19d	B-						- 0.130 0.040
Yb-177	1.9h	B-	Lu-177	1.000E+00				- 0.430 0.187
Yb-178	74m	B-	Lu-178	1.000E+00				- 0.191 0.035
Lutetium								
Lu-169	34.06h	ECB+	Yb-169	1.000E+00				- 0.054 1.041
Lu-170	2.00d	ECB+						- 0.094 2.484
Lu-171	8.22d	EC						- 0.084 0.697
Lu-172	6.70d	ECB+						- 0.119 1.888
Lu-173	1.37y	EC						- 0.036 0.130
Lu-174m	142d	ECIT	Lu-174	9.930E-01				- 0.116 0.063
Lu-174	3.31y	ECB+						- 0.042 0.126
Lu-176m	3.68h	B-						- 0.477 0.014
Lu-176	3.60E10y	B-						- 0.296 0.491
Lu-177m	160.9d	B-IT	Lu-177	2.100E-01				- 0.272 1.003
Lu-177	6.71d	B-						- 0.148 0.035
Lu-178m	22.7m	B-						- 0.591 1.109
Lu-178	28.4m	B-						- 0.773 0.140
Lu-179	4.59h	B-						- 0.464 0.031
Hafnium								
Hf-170	16.01h	EC	Lu-170	1.000E+00				- 0.091 0.549
Hf-172	1.87y	EC	Lu-172	1.000E+00				- 0.118 0.118
Hf-173	24.0h	ECB+	Lu-173	1.000E+00				- 0.053 0.408
Hf-175	70d	EC						- 0.046 0.369
Hf-177m	51.4m	IT						- 0.500 2.252
Hf-178m	31y	IT						- 0.297 2.358
Hf-179m	25.1d	IT						- 0.188 0.901

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield									
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon
Hafnium, cont'd									
Hf-180m	5.5h	IT					-	0.139	1.008
Hf-181	42.4d	B-					-	0.203	0.555
Hf-182m	61.5m	ITB-	Ta-182	5.400E-01	Hf-182	4.600E-01	-	0.235	0.933
Hf-182	9E6y	B-	Ta-182	1.000E+00			-	0.083	0.239
Hf-183	64m	B-	Ta-183	1.000E+00			-	0.451	0.752
Hf-184	4.12h	B-	Ta-184	1.000E+00			-	0.477	0.251
Tantalum									
Ta-172	36.8m	ECB+	Hf-172	1.000E+00			-	0.505	1.550
Ta-173	3.65h	ECB+	Hf-173	1.000E+00			-	0.358	0.585
Ta-174	1.2h	ECB+	SF	1.000E+00			-	0.367	0.627
Ta-175	10.5h	ECB+	Hf-175	1.000E+00			-	0.064	0.933
Ta-176	8.08h	ECB+					-	0.104	2.145
Ta-177	56.6h	EC					-	0.024	0.067
Ta-178b	2.2h	EC					-	0.155	1.023
Ta-178a	9.31m	EC					-	0.034	0.109
Ta-179	664.9d	EC					-	0.008	0.032
Ta-180m	8.1h	ECB-					-	0.055	0.049
Ta-180	1.0E13y	EC					-	0.123	0.560
Ta-182m	15.84m	IT	Ta-182	1.000E+00			-	0.251	0.252
Ta-182	115.0d	B-					-	0.217	1.294
Ta-183	5.1d	B-					-	0.345	0.293
Ta-184	8.7h	B-					-	0.547	1.612
Ta-185	49m	B-	W-185	1.000E+00			-	0.725	0.193
Ta-186	10.5m	B-					-	0.992	1.560
Wolfram									
W-176	2.3h	EC	Ta-176	1.000E+00			-	0.073	0.177
W-177	135m	ECB+	Ta-177	1.000E+00			-	0.104	0.903
W-178	21.7d	EC	Ta-178a	1.000E+00			-	0.007	0.014
W-179	37.5m	EC	Ta-179	1.000E+00			-	0.027	0.060
W-181	121.2d	EC					-	0.011	0.040
W-185	75.1d	B-					-	0.127	<
W-187	23.9h	B-	Re-187	1.000E+00			-	0.312	0.481
W-188	69.4d	B-	Re-188	1.000E+00			-	0.100	0.002
Rhenium									
Re-177	14.0m	ECB+	W-177	1.000E+00			-	0.361	0.620
Re-178	13.2m	ECB+	W-178	1.000E+00			-	0.578	1.218
Re-180	2.43m	ECB+					-	0.156	1.183
Re-181	20h	ECB+	W-181	1.000E+00			-	0.137	0.771
Re-182b	64.0h	EC					-	0.213	1.886
Re-182a	12.7h	ECB+					-	0.088	1.179
Re-184m	165d	ITEC	Re-184	7.470E-01			-	0.141	0.390
Re-184	38.0d	EC					-	0.056	0.891
Re-186m	2.0E5y	IT	Re-186	1.000E+00			-	0.124	0.019
Re-186	90.64h	B-EC					-	0.345	0.021
Re-187	5E10y	B-					-	<	-
Re-188m	18.6m	IT	Re-188	1.000E+00			-	0.098	0.080
Re-188	16.98h	B-					-	0.780	0.058
Re-189	24.3h	B-	Os-189m	2.410E-01			-	0.340	0.069
Osmium									
Os-180	22m	ECB+	Re-180	1.000E+00			-	0.028	0.065
Os-181	105m	ECB+	Re-181	1.000E+00			-	0.108	1.222
Os-182	22h	EC	Re-182a	1.000E+00			-	0.056	0.435
Os-185	94d	EC					-	0.019	0.719
Os-189m	6.0h	IT					-	0.029	0.002
Os-190m	9.9m	IT					-	0.116	1.588
Os-191m	13.03h	IT	Os-191	1.000E+00			-	0.065	0.009
Os-191	15.4d	B-					-	0.135	0.080
Os-193	30.0h	B-					-	0.373	0.073
Os-194	6.0y	B-	Ir-194	1.000E+00			-	0.034	0.002
Iridium									
Ir-182	15m	ECB+	Os-182	1.000E+00			-	0.935	1.340
Ir-184	3.02h	ECB+					-	0.279	1.908

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield									
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon
Iridium, cont'd									
Ir-185	14.0h	ECB+	Os-185	1.000E+00			-	0.115	0.601
Ir-186a	15.8h	ECB+					-	0.113	1.641
Ir-186b	1.75h	ECB+					-	0.203	0.964
Ir-187	10.5h	EC					-	0.060	0.363
Ir-188	41.5h	ECB+					-	0.058	1.584
Ir-189	13.3d	EC	Os-189a	8.300E-02			-	0.049	0.081
Ir-190n	3.1h	ITEC	Ir-190m	5.000E-02			-	0.126	1.555
Ir-190m	1.2h	IT	Ir-190	1.000E+00			-	0.024	0.002
Ir-190	12.1d	EC					-	0.129	1.443
Ir-191m	4.94s	IT					-	0.096	0.075
Ir-192m	241.y	IT	Ir-192	1.000E+00			-	-	0.161
Ir-192	74.02d	B-EC					-	0.217	0.818
Ir-194m	171d	B-					-	0.156	2.335
Ir-194	19.15h	B-					-	0.812	0.090
Ir-195m	3.8h	ITB-	Ir-195	4.000E-02			-	0.480	0.432
Ir-195	2.5h	B-					-	0.380	0.059
Platinum									
Pt-186	2.0h	A EC	Ir-186b	1.000E+00	Os-182	1.400E-06	<	0.012	0.740
Pt-188	10.2d	EC	Ir-188	1.000E+00			-	0.080	0.202
Pt-189	10.87h	ECB+	Ir-189	1.000E+00			-	0.055	0.325
Pt-191	2.8d	EC					-	0.064	0.304
Pt-193m	4.33d	IT	Pt-193	1.000E+00			-	0.137	0.013
Pt-193	50y	EC					-	0.007	0.002
Pt-195m	4.02d	IT					-	0.183	0.076
Pt-197m	94.4m	B-IT	Pt-197	9.670E-01			-	0.324	0.083
Pt-197	18.3h	B-					-	0.254	0.025
Pt-199	30.8m	B-	Au-199	1.000E+00			-	0.535	0.202
Pt-200	12.5h	B-	Au-200	1.000E+00			-	0.243	0.061
Gold									
Au-193	17.65h	EC	Pt-193	1.000E+00			-	0.064	0.160
Au-194	39.5h	ECB+					-	0.043	1.067
Au-195m	30.5s	IT	Au-195	1.000E+00			-	0.117	0.201
Au-195	183d	EC					-	0.051	0.085
Au-198m	2.30d	IT	Au-198	1.000E+00			-	0.289	0.577
Au-198	2.696d	B-					-	0.327	0.405
Au-199	3.139d	B-					-	0.143	0.089
Au-200m	18.7h	B-IT	Au-200	1.800E-01			-	0.276	2.087
Au-200	48.4m	B-					-	0.740	0.272
Au-201	26.4m	B-					-	0.422	0.053
Mercury									
Hg-193m	11.1h	ECB+IT	Au-193	9.200E-01	Hg-193	8.000E-02	-	0.139	1.046
Hg-193	3.5h	ECB+	Au-193	1.000E+00			-	0.125	0.203
Hg-194	260y	EC	Au-194	1.000E+00			-	0.007	0.003
Hg-195m	41.6h	ITEC	Hg-195	5.420E-01	Au-195	4.580E-01	-	0.150	0.214
Hg-195	9.9h	EC	Au-195	1.000E+00			-	0.065	0.204
Hg-197m	23.8h	ECIT	Hg-197	9.300E-01			-	0.215	0.094
Hg-197	64.1h	EC					-	0.066	0.070
Hg-199m	42.6m	IT					-	0.352	0.186
Hg-203	46.60d	B-					-	0.099	0.238
Hg-206	8.15m	B-	Tl-206	1.000E+00			-	0.428	0.106
Thallium									
Tl-194m	32.8m	ECB+	Hg-194	1.000E+00			-	0.342	2.319
Tl-194	33m	EC	Hg-194	1.000E+00			-	0.030	0.779
Tl-195	1.16h	ECB+	Hg-195	1.000E+00			-	0.086	1.271
Tl-197	2.84h	ECB+	Hg-197	1.000E+00			-	0.061	0.409
Tl-198m	1.87h	ECB+IT	Tl-198	4.700E-01			-	0.201	1.195
Tl-198	5.3h	ECB+					-	0.041	2.006
Tl-199	7.42h	ECB+					-	0.056	0.249
Tl-200	26.1h	ECB+					-	0.040	1.311
Tl-201	3.044d	EC					-	0.043	0.093
Tl-202	12.23d	ECB+					-	0.023	0.468

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon
Thallium, cont'd										
Tl-204	3.779y	ECB-						-	0.238	0.001
Tl-206	4.20m	B-						-	0.537	<
Tl-207	4.77m	B-						-	0.493	0.002
Tl-208	3.07m	B-						-	0.598	3.375
Tl-209	2.20m	B-	Pb-209	1.000E+00				-	0.688	2.032
Tl-210	1.30m	B-	Pb-210	1.000E+00				-	1.273	2.736
Lead										
Pb-195m	15.8m	ECB+	Tl-195	1.000E+00				-	0.302	1.599
Pb-198	2.4h	EC	Tl-198	1.000E+00				-	0.079	0.439
Pb-199	90m	ECB+	Tl-199	1.000E+00				-	0.054	1.476
Pb-200	21.5h	EC	Tl-200	1.000E+00				-	0.099	0.209
Pb-201	9.4h	ECB+	Tl-201	1.000E+00				-	0.058	0.758
Pb-202m	3.62h	ITEC	Pb-202	9.050E-01	Tl-202	9.500E-02		-	0.076	2.043
Pb-202	3E5	EC	Tl-202	1.000E+00				-	0.006	0.002
Pb-203	52.05h	EC						-	0.052	0.312
Pb-204m	67.2m	IT						-	0.025	2.105
Pb-205	1.43E7y	EC						-	0.007	0.002
Pb-209	3.253h	B-						-	0.198	-
Pb-210	22.3y	B-	Bi-210	1.000E+00				-	0.038	0.005
Pb-211	36.1m	B-	Bi-211	1.000E+00				-	0.456	0.051
Pb-212	10.64h	B-	Bi-212	1.000E+00				-	0.176	0.148
Pb-214	26.8m	B-	Bi-214	1.000E+00				-	0.293	0.250
Bismuth										
Bi-200	36.4m	ECB+	Pb-200	1.000E+00				-	0.190	2.393
Bi-201	108m	EC	Pb-201	1.000E+00				-	0.258	1.339
Bi-202	1.67h	ECB+	Pb-202	9.975E-01	Pb-202m	2.500E-03		-	0.109	2.713
Bi-203	11.76h	ECB+	Pb-203	1.000E+00				-	0.080	2.384
Bi-204	11.22h	ECB+	Pb-204m	9.928E-02				-	0.085	3.064
Bi-205	15.31d	ECB+	Pb-205	1.000E+00				-	0.034	1.690
Bi-206	6.243d	EC						-	0.136	3.278
Bi-207	38y	ECB+						-	0.117	1.540
Bi-210m	3.0E6y	A	Tl-206	1.000E+00				4.913	0.047	0.257
Bi-210	5.012d	B-	Po-210	1.000E+00				-	0.389	-
Bi-211	2.14m	A B-	Tl-207	9.972E-01	Po-211	2.800E-03		6.550	0.010	0.047
Bi-212	60.55m	B-A	Po-212	6.407E-01	Tl-208	3.593E-01		2.174	0.472	0.186
Bi-213	45.65m	B-A	Po-213	9.784E-01	Tl-209	2.160E-02		0.126	0.442	0.133
Bi-214	19.9m	B-	Po-214	9.998E-01				-	0.659	1.508
Polonium										
Po-203	36.7m	ECB+	Bi-203	9.989E-01				-	0.164	1.644
Po-205	1.80h	A ECB+	Bi-205	9.990E-01	Pb-201	1.400E-03		0.007	0.060	1.581
Po-207	350m	ECB+	Bi-207	1.000E+00				-	0.052	1.331
Po-209	102y	A EC	Pb-205	9.974E-01				4.867	<	0.003
Po-210	138.38d	A						5.297	<	<
Po-211	0.516s	A						7.442	<	0.008
Po-212	0.305us	A						8.785	-	-
Po-213	4.2us	A	Pb-209	1.000E+00				8.376	-	-
Po-214	164.3us	A	Pb-210	1.000E+00				7.687	<	<
Po-215	0.001780s	A	Pb-211	1.000E+00				7.386	<	<
Po-216	0.15s	A	Pb-212	1.000E+00				6.779	<	<
Po-218	3.05m	A B-	Pb-214	9.998E-01	At-218	2.000E-04		6.001	<	<
Astatine										
At-207	1.80h	ECA	Po-207	9.000E-01	Bi-203	1.000E-01		0.576	0.080	1.325
At-211	7.214h	ECA	Po-211	5.830E-01	Bi-207	4.170E-01		2.446	0.006	0.039
At-215	0.10ms	A	Bi-211	1.000E+00				8.026	<	<
At-216	0.30ms	A	Bi-212	1.000E+00				7.799	<	0.002
At-217	0.0323s	A	Bi-213	1.000E+00				7.067	<	<
At-218	2s	A	Bi-214	1.000E+00				6.697	0.040	0.007
Radon										
Rn-218	35ms	A	Po-214	1.000E+00				7.132	<	<
Rn-219	3.96s	A	Po-215	1.000E+00				6.757	0.006	0.056
Rn-220	55.6s	A	Po-216	1.000E+00				6.288	<	<
Rn-222	3.8235d	A	Po-218	1.000E+00				5.489	<	<

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon	
Francium										
Fr-219	21msA		At-215	1.000E+00				7.313	<	0.003
Fr-220	27.4s A		At-216	1.000E+00				6.637	0.028	0.012
Fr-221	4.8m A		At-217	1.000E+00				6.304	0.010	0.031
Fr-222	14.4m B-		Ra-222	1.000E+00				-	0.731	-
Fr-223	21.8m B-		Ra-223	1.000E+00				-	0.400	0.059
Radium										
Ra-222	38.0s A		Rn-218	1.000E+00				6.546	<	0.009
Ra-223	11.434d A		Rn-219	1.000E+00				5.667	0.076	0.134
Ra-224	3.66d A		Rn-220	1.000E+00				5.674	0.002	0.010
Ra-225	14.8d B-		Ac-225	1.000E+00				-	0.107	0.014
Ra-226	1600y A		Rn-222	1.000E+00				4.774	0.004	0.007
Ra-227	42.2m B-		Ac-227	1.000E+00				-	0.439	0.167
Ra-228	5.75y B-		Ac-228	1.000E+00				-	0.017	<
Actinium										
Ac-223	2.2m A		Fr-219	1.000E+00				6.553	0.015	0.006
Ac-224	2.9h A EC		Ra-224	9.000E-01	Fr-220	1.000E-01		0.611	0.040	0.200
Ac-225	10.0d A		Fr-221	1.000E+00				5.787	0.022	0.018
Ac-226	29h A B-EC		Th-226	8.280E-01	Ra-226	1.720E-01	Fr-222	6.000E-05	<	0.289
Ac-227	21.773y B-A		Th-227	9.862E-01	Fr-223	1.380E-02		0.068	0.016	<
Ac-228	6.13h B-		Th-228	1.000E+00				-	0.475	0.971
Thorium										
Th-226	30.9m A		Ra-222	1.000E+00				6.308	0.021	0.009
Th-227	18.718d A		Ra-223	1.000E+00				5.884	0.053	0.110
Th-228	1.9131y A		Ra-224	1.000E+00				5.400	0.021	0.003
Th-229	7340y A		Ra-225	1.000E+00				4.873	0.116	0.096
Th-230	7.7E4y A		Ra-226	1.000E+00				4.671	0.015	0.002
Th-231	25.52h B-		Pa-231	1.000E+00				-	0.165	0.026
Th-232	1.405E10y A		Ra-228	1.000E+00				3.996	0.012	0.001
Th-234	24.10d B-		Pa-234m	9.980E-01	Pa-234	2.000E-03		-	0.060	0.009
Protactinium										
Pa-227	38.3m ECA		Ac-223	8.500E-01	Th-227	1.500E-01		5.468	0.016	0.022
Pa-228	22h A ECB+		Th-228	9.800E-01	Ac-224	2.000E-02		0.120	0.165	1.141
Pa-230	17.4d A ECB-		Th-230	9.050E-01	U-230	9.500E-02	Ac-226	3.200E-05	<	0.068
Pa-231	3.276E4y A		Ac-227	1.000E+00				4.969	0.065	0.048
Pa-232	1.31d B-		U-232	1.000E+00				-	0.175	0.939
Pa-233	27.0d B-		U-233	1.000E+00				-	0.196	0.204
Pa-234m	1.17m B-IT		U-234	9.987E-01	Pa-234	1.300E-03		-	0.822	0.012
Pa-234	6.70h B-		U-234	1.000E+00				-	0.494	1.919
Uranium										
U-230	20.8d A		Th-226	1.000E+00				5.864	0.022	0.003
U-231	4.2d ECA		Pa-231	1.000E+00	Th-227	5.500E-05		<	0.071	0.082
U-232	72y A		Th-228	1.000E+00				5.302	0.017	0.002
U-233	1.585E5y A		Th-229	1.000E+00				4.817	0.006	0.001
U-234	2.445E5y A		Th-230	1.000E+00				4.758	0.013	0.002
U-235	703.8E6y A		Th-231	1.000E+00				4.396	0.049	0.156
U-236	2.3415E7y A		Th-232	1.000E+00				4.505	0.011	0.002
U-237	6.75d B-		Np-237	1.000E+00				-	0.196	0.143
U-238	4.468E9y SFA		Th-234	1.000E+00	SF	5.400E-05		4.187	0.010	0.001
U-239	23.54m B-		Np-239	1.000E+00				-	0.412	0.053
U-240	14.1h B-		Np-240m	1.000E+00				-	0.138	0.008
Neptunium										
Np-232	14.7m ECB+		U-232	1.000E+00				-	0.106	1.203
Np-233	36.2m EC		U-233	1.000E+00				-	0.014	0.091
Np-234	4.4d ECB+		U-234	1.000E+00				-	0.069	1.442
Np-235	396.1d ECA		U-235	9.999E-01	Pa-231	1.400E-05		<	0.010	0.007
Np-236a	115E3y ECB-		U-236	9.100E-01	Pu-236	8.900E-02		-	0.208	0.136
Np-236b	22.5h B-EC		U-236	5.200E-01	Pu-236	4.800E-01		-	0.087	0.051
Np-237	2.14E6y A		Pa-233	1.000E+00				4.769	0.070	0.035
Np-238	2.117d B-		Pu-238	1.000E+00				-	0.264	0.553
Np-239	2.355d B-		Pu-239	1.000E+00				-	0.260	0.173
Np-240m	7.4m B-		Pu-240	1.000E+00				-	0.683	0.337
Np-240	65m B-		Pu-240	1.000E+00				-	0.528	1.313

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon
Plutonium										
Pu-234	8.8h	A EC	Np-234	9.400E-01	U-230	6.000E-02		0.371	0.011	0.069
Pu-235	25.3m	ECA	Np-235	1.000E+00	U-231	2.700E-05		<	0.021	0.095
Pu-236	2.851y	SFA	U-232	1.000E+00	SF	8.100E-10		5.753	0.013	0.002
Pu-237	45.3d	A EC	Np-237	1.000E+00	U-233	5.000E-05		<	0.016	0.052
Pu-238	87.74y	SFA	U-234	1.000E+00	SF	1.840E-09		5.487	0.011	0.002
Pu-239	24065y	A	U-235	1.000E+00				5.148	0.007	<
Pu-240	6537y	SFA	U-236	1.000E+00	SF	4.950E-08		5.156	0.011	0.002
Pu-241	14.4y	A B-	Am-241	1.000E+00	U-237	2.450E-05		<	0.005	<
Pu-242	3.763E5y	SFA	U-238	1.000E+00	SF	5.500E-06		4.891	0.009	0.001
Pu-243	4.956h	B-	Am-243	1.000E+00				-	0.173	0.026
Pu-244	8.26E7y	SFA	U-240	9.988E-01	SF	1.250E-03		4.575	0.007	0.001
Pu-245	10.5h	B-	Am-245	1.000E+00				-	0.350	0.417
Pu-246	10.85d	B-	Am-246m	1.000E+00				-	0.125	0.140
Americium										
Am-237	73.0m	A EC	Pu-237	9.997E-01	Np-233	2.500E-04		0.002	0.077	0.370
Am-238	98m	ECA	Pu-238	1.000E+00	Np-234	1.000E-06		<	0.052	0.891
Am-239	11.9h	A EC	Pu-239	9.999E-01	Np-235	1.000E-04		<	0.168	0.239
Am-240	50.8h	A EC	Pu-240	1.000E+00	Np-236b	1.900E-06		<	0.075	1.029
Am-241	432.2y	A	Np-237	1.000E+00				5.479	0.052	0.033
Am-242m	152y	A IT	Am-242	9.950E-01	Np-238	4.760E-03		0.025	0.044	0.005
Am-242	16.02h	ECB-	Cm-242	8.270E-01	Pu-242	1.730E-01		-	0.179	0.018
Am-243	7380y	A	Np-239	1.000E+00				5.270	0.022	0.056
Am-244m	26m	B-	Cm-244	1.000E+00				-	0.509	0.002
Am-244	10.1h	B-	Cm-244	1.000E+00				-	0.342	0.807
Am-245	2.05h	B-	Cm-245	1.000E+00				-	0.288	0.032
Am-246m	25.0m	B-	Cm-246	1.000E+00				-	0.498	1.018
Am-246	39m	B-	Cm-246	1.000E+00				-	0.655	0.699
Curium										
Cm-238	2.4h	ECA	Am-238	9.000E-01	Pu-234	1.000E-01		0.652	0.010	0.077
Cm-240	27d	A	Pu-236	1.000E+00				6.247	0.011	0.002
Cm-241	32.8d	A EC	Am-241	9.900E-01	Pu-237	1.000E-02		0.059	0.133	0.502
Cm-242	162.8d	SFA	Pu-238	1.000E+00	SF	6.800E-08		6.102	0.010	0.002
Cm-243	28.5y	A EC	Pu-239	9.980E-01	Am-243	2.400E-03		5.797	0.138	0.134
Cm-244	18.11y	SFA	Pu-240	1.000E+00	SF	1.350E-06		5.795	0.009	0.002
Cm-245	8500y	A	Pu-241	1.000E+00				5.363	0.065	0.096
Cm-246	4730y	SFA	Pu-242	9.997E-01	SF	2.614E-04		5.376	0.008	0.002
Cm-247	1.56E7y	A	Pu-243	1.000E+00				4.949	0.021	0.316
Cm-248	3.39E5y	SFA	Pu-244	9.174E-01	SF	8.260E-02		4.651	0.006	0.001
Cm-249	64.15m	B-	Bk-249	1.000E+00				-	0.284	0.019
Cm-250	6900y	SFA B-	SF	6.100E-01	Pu-246	2.500E-01	Bk-250	1.400E-01	1.296	0.002
Berkelium										
Bk-245	4.94d	A EC	Cm-245	9.990E-01	Am-241	1.200E-03		0.007	0.133	0.234
Bk-246	1.83d	EC	Cm-246	1.000E+00				-	0.054	0.951
Bk-247	1380y	A	Am-243	1.000E+00				5.610	0.061	0.105
Bk-249	320d	SFB-A	Cf-249	1.000E+00	Am-245	1.450E-05	SF	4.700E-10	<	0.033
Bk-250	3.222h	B-	Cf-250	1.000E+00				-	0.293	0.887
Californium										
Cf-244	19.4m	A	Cm-240	1.000E+00				7.200	0.009	0.002
Cf-246	35.7h	SFA	Cm-242	9.997E-01	SF	2.000E-06		6.747	0.006	0.001
Cf-248	333.5d	SFA	Cm-244	1.000E+00	SF	2.900E-05		6.253	0.006	0.001
Cf-249	350.6y	A SF	Cm-245	1.000E+00	SF	5.200E-09		5.831	0.044	0.335
Cf-250	13.08y	SFA	Cm-246	9.992E-01	SF	7.700E-04		6.019	0.006	0.001
Cf-251	898y	A	Cm-247	1.000E+00				5.784	0.198	0.132
Cf-252	2.638y	SFA	Cm-248	9.691E-01	SF	3.092E-02		5.922	0.006	0.001
Cf-253	17.81d	B-A	Es-253	9.969E-01	Cm-249	3.100E-03		0.019	0.079	<
Cf-254	60.5d	SFA	SF	9.969E-01	Cm-250	3.100E-03		0.018	<	<
Einsteinium										
Es-250	2.1h	EC	Cf-250	1.000E+00				-	0.022	0.397
Es-251	33h	ECA	Cf-251	9.950E-01	Bk-247	5.000E-03		0.032	0.052	0.098
Es-253	20.47d	SFA	Bk-249	1.000E+00	SF	8.700E-08		6.628	0.004	0.001
Es-254m	39.3h	A B-	Fm-254	9.800E-01	Bk-250	3.200E-03		0.020	0.256	0.470
Es-254	275.7d	A	Bk-250	1.000E+00				6.423	0.071	0.019

Table A-1 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon	
Fermium										
Fm-252	22.7h	A	Cf-248	1.000E+00				7.034	0.005	0.001
Fm-253	3.00d	ECA	Es-253	8.800E-01	Cf-249	1.200E-01		0.822	0.022	0.083
Fm-254	3.240h	A	Cf-250	1.000E+00				7.182	0.006	0.001
Fm-255	20.07h	A	Cf-251	1.000E+00				7.019	0.098	0.014
Fm-257	100.5d	A	Cf-253	1.000E+00				6.511	0.121	0.111
Mendelevium										
Md-257	5.2h	A EC	Fm-257	9.000E-01	Es-253	1.000E-01		0.707	0.015	0.114
Md-258	55d	A	Es-254	1.000E+00				7.232	0.047	0.006

Table A-2. Summary Information on the Nuclear Transformation of the Radionuclides in MIRD Collection.

Nuclide	T _{1/2}	Decay Mode	Radioactive Decay Products and Fractional Yield						Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon	
Hydrogen											
H-3	12.33y	B-							-	0.006	-
Beryllium											
Be-7	53.29d	EC							-	<	0.050
Carbon											
C-11	20.385m	ECB+							-	0.385	1.020
C-14	5730y	B-							-	0.049	-
Nitrogen											
N-13	9.965m	ECB+							-	0.491	1.020
Oxygen											
O-14	70.599s	ECB+							-	0.777	3.319
O-15	122.24s	ECB+							-	0.734	1.021
O-19	26.91s	B-							-	1.733	0.957
Fluorine											
F-18	109.77m	ECB+							-	0.250	1.022
Neon											
Ne-19	17.22s	ECB+							-	0.963	1.022
Sodium											
Na-22	2.602y	ECB+							-	0.194	2.193
Na-24	15.020h	B-							-	0.554	4.123
Magnesium											
Mg-28	20.91h	B-	Al-28	1.000E+00					-	0.163	1.371
Aluminium											
Al-28	2.240m	B-							-	1.242	1.779
Phosphorus											
P-30	2.498m	ECB+							-	1.436	1.022
P-32	14.26d	B-							-	0.695	-
P-33	25.4d	B-							-	0.077	-
Sulfur											
S-35	87.44d	B-							-	0.049	-
Chlorine											
Cl-38	37.21m	B-							-	1.529	1.488
Argon											
Ar-37	35.02d	EC							-	0.002	<
Potassium											
K-38	7.636m	ECB+							-	1.209	3.187
K-40	1.28E9y	B-EC							-	0.523	0.156
K-42	12.36h	B-							-	1.430	0.276
K-43	22.6h	B-							-	0.309	0.970
Calcium											
Ca-45	163.8d	B-							-	0.077	<
Ca-47	4.536d	B-	Sc-47	1.000E+00					-	0.351	1.047
Ca-49	8.715m	B-	Sc-49	1.000E+00					-	0.870	3.168
Scandium											
Sc-46	83.83d	B-							-	0.112	2.009
Sc-47	3.345d	B-							-	0.163	0.108
Sc-49	57.2m	B-							-	0.818	0.001
Vanadium											
V-48	15.974d	ECB+							-	0.148	2.913
Chromium											
Cr-48	21.56h	ECB+	V-48	1.000E+00					-	0.009	0.432
Cr-51	27.704d	EC							-	0.004	0.033
Manganese											
Mn-51	46.2m	ECB+	Cr-51	1.000E+00					-	0.935	0.998
Mn-52	5.591d	ECB+							-	0.075	3.458
Mn-52m	21.1m	ECB+IT	Mn-52	1.750E-02					-	1.133	2.410
Mn-54	312.5d	EC							-	0.004	0.836
Iron											
Fe-52	8.275h	ECB+	Mn-52m	1.000E+00					-	0.194	0.740
Fe-55	2.73y	EC							-	0.004	0.002
Fe-59	44.496d	B-							-	0.118	1.188

Table A-2 (cont'd).

Nuclide	T _{1/2}	Decay Mode	Radioactive Decay Products and Fractional Yield				Energy (MeV/nt)		
			Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon	
Cobalt									
Co-55	17.53h	ECB+	Fe-55	1.000E+00			-	0.432	1.996
Co-56	78.76d	ECB+					-	0.124	3.580
Co-57	271.80d	EC					-	0.019	0.125
Co-58	70.916d	ECB+					-	0.034	0.976
Co-60	5.2704y	B-					-	0.096	2.505
Nickel									
Ni-57	35.65h	ECB+	Co-57	1.000E+00			-	0.155	1.942
Ni-63	100.1y	B-					-	0.017	-
Copper									
Cu-57	233ms	ECB+	Ni-57	1.000E+00			-	3.622	1.063
Cu-62	9.74m	ECB+					-	1.285	1.007
Cu-64	12.701h	ECB+B-					-	0.122	0.191
Cu-67	61.92h	B-					-	0.156	0.115
Zinc									
Zn-62	9.26h	ECB+	Cu-62	1.000E+00			-	0.033	0.439
Zn-65	243.9d	ECB+					-	0.007	0.583
Zn-69	55.6m	B-					-	0.321	<
Zn-69m	13.76h	B-IT	Zn-69	9.997E-01			-	0.022	0.416
Gallium									
Ga-66	9.49h	ECB+					-	0.983	2.455
Ga-67	3.261d	EC					-	0.034	0.155
Ga-68	68.06m	ECB+					-	0.739	0.947
Ga-72	14.10h	B-					-	0.502	2.724
Germanium									
Ge-68	287d	EC	Ga-68	1.000E+00			-	0.005	0.004
Arsenic									
As-72	26.0h	ECB+					-	1.033	1.776
As-73	80.30d	EC					-	0.060	0.016
As-74	17.76d	B-ECB+					-	0.268	0.759
Selenium									
Se-72	8.40d	EC	As-72	1.000E+00			-	0.023	0.034
Se-73	7.15h	ECB+	As-73	1.000E+00			-	0.389	1.097
Se-73m	39.8m	ECB+IT	Se-73	7.300E-01	As-73	2.700E-01	-	0.171	0.252
Se-75	119.770d	EC					-	0.015	0.392
Se-77m	17.45s	IT					-	0.072	0.088
Bromine									
Br-75	97m	ECB+	Se-75	1.000E+00			-	0.506	1.203
Br-76	16.2h	ECB+					-	0.646	2.790
Br-77	57.036h	ECB+					-	0.010	0.331
Br-80	17.68m	ECB+B-					-	0.727	0.076
Br-80m	4.42h	IT	Br-80	1.000E+00			-	0.062	0.024
Br-82	35.30h	B-					-	0.139	2.642
Krypton									
Kr-77	74.4m	ECB+	Br-77	1.000E+00			-	0.824	1.104
Kr-79	35.04h	ECB+					-	0.024	0.257
Kr-81	2.13E+05y	EC					-	0.005	0.017
Kr-81m	13s	ECIT	Kr-81	9.999E-01			-	0.059	0.130
Kr-83m	1.83h	IT					-	0.039	0.003
Kr-85	10.72y	B-					-	0.251	0.002
Kr-85m	4.480h	B-IT	Kr-85	2.100E-01			-	0.255	0.157
Rubidium									
Rb-77	3.70m	ECB+	Kr-77	1.000E+00			-	1.646	1.831
Rb-79	22.9m	ECB+	Kr-79	1.000E+00			-	0.777	1.438
Rb-81	4.576h	ECB+	Kr-81	1.000E+00			-	0.184	0.645
Rb-82	1.3m	ECB+					-	1.407	1.093
Rb-82m	6.2h	ECB+					-	0.095	2.910
Rb-83	86.2d	EC	Kr-83m	7.620E-01			-	0.015	0.504
Rb-84	32.87d	ECB+B-					-	0.162	0.887
Rb-86	18.66d	B-					-	0.668	0.095

Table A-2 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon
Strontium										
Sr-82	25.0d	EC	Rb-82	1.000E+00				-	0.005	0.008
Sr-83	32.4h	ECB+	Rb-83	1.000E+00				-	0.149	0.801
Sr-85	64.84d	EC						-	0.009	0.513
Sr-85m	67.66m	ECIT	Sr-85	8.730E-01				-	0.013	0.216
Sr-87m	2.81h	ECIT	Rb-87	3.000E-03				-	0.067	0.321
Sr-89	50.5d	B-						-	0.583	<
Sr-90	29.12y	B-	Y-90	1.000E+00				-	0.196	-
Yttrium										
Y-87	80.3h	ECB+	Sr-87m	9.987E-01				-	0.007	0.458
Y-88	106.64d	ECB+						-	0.007	2.692
Y-90	64.0h	B-						-	0.935	<
Zirconium										
Zr-95	64.02d	B-	Nb-95	9.889E-01	Nb-95m	1.110E-02		-	0.118	0.732
Niobium										
Nb-95	35.02d	B-						-	0.045	0.764
Nb-95m	86.6h	B-IT	Nb-95	9.440E-01				-	0.175	0.069
Molybdenum										
Mo-99	65.94h	B-	Tc-99m	8.748E-01	Tc-99	1.252E-01		-	0.393	0.149
Technetium										
Tc-94m	52.0m	ECB+						-	0.755	1.938
Tc-95	20.0h	EC						-	0.007	0.798
Tc-95m	61d	ECB+IT	Tc-95	4.000E-02				-	0.015	0.719
Tc-97m	90.5d	IT	Tc-97	1.000E+00				-	0.087	0.010
Tc-99	2.111E+5y	B-						-	0.101	<
Tc-99m	6.01h	B-IT	Tc-99	1.000E+00				-	0.016	0.127
Ruthenium										
Ru-97	2.9d	EC	Tc-97	9.996E-01	Tc-97m	3.851E-04		-	0.013	0.240
Ru-103	39.26d	B-	Rh-103m	9.836E-01				-	0.067	0.495
Rhodium										
Rh-103m	56.114m	IT						-	0.037	0.002
Palladium										
Pd-103	16.991d	EC	Rh-103m	9.987E-01				-	0.006	0.014
Pd-109	13.427h	B-						-	0.437	0.012
Silver										
Ag-109m	39.6s	IT						-	0.077	0.011
Cadmium										
Cd-109	462.9d	EC						-	0.083	0.026
Indium										
In-109	4.2h	ECB+	Cd-109	1.000E+00				-	0.047	0.672
In-111	2.83d	EC						-	0.035	0.405
In-111m	7.7m	IT	In-111	1.000E+00				-	0.067	0.469
In-113m	1.658h	IT						-	0.134	0.258
In-114	71.9s	ECB-						-	0.776	0.002
In-114m	49.51d	ECIT	In-114	9.570E-01				-	0.143	0.094
In-115m	4.486h	ITB-	In-115	9.510E-01				-	0.172	0.161
Tin										
Sn-113	115.09d	EC	In-113m	1.000E+00				-	0.006	0.023
Sn-117m	13.61d	IT						-	0.161	0.158
Antimony										
Sb-118	3.6m	ECB+						-	0.896	0.811
Sb-118m	5.00h	ECB+						-	0.040	2.585
Tellurium										
Te-123	1E+13y	EC						-	0.003	<
Te-123m	119.7d	IT	Te-123	1.000E+00				-	0.102	0.148
Iodine										
I-122	3.62m	ECB+						-	1.055	0.946
I-123	13.2h	EC	Te-123	1.000E+00	Te-123m	4.442E-05		-	0.028	0.173
I-124	4.18d	ECB+						-	0.196	1.083
I-125	60.14d	EC						-	0.019	0.042
I-126	13.02d	ECB+B-						-	0.146	0.433
I-129	1.57E7y	B-						-	0.063	0.024

Table A-2 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode	Radioactive Decay Products and Fractional Yield				Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec.	Photon
Iodine, cont'd										
I-130	12.36h	B-						-	0.297	2.139
I-131	8.04d	B-	Xe-131m	1.110E-02				-	0.192	0.382
I-132	2.30h	B-						-	0.495	2.280
I-132m	83.6m	ITB-	I-132	8.600E-01				-	0.156	0.321
I-133	20.8h	B-	Xe-133	9.710E-01	Xe-133m	2.900E-02		-	0.411	0.807
Xenon										
Xe-122	20.1h	EC	I-122	1.000E+00				-	0.010	0.068
Xe-123	2.08h	ECB+	I-123	1.000E+00				-	0.188	0.641
Xe-127	36.4d	EC						-	0.032	0.280
Xe-129m	8.89d	IT						-	0.185	0.051
Xe-131m	11.9d	IT						-	0.144	0.020
Xe-133	5.245d	B-						-	0.136	0.046
Xe-133m	2.186d	IT	Xe-133	1.000E+00				-	0.192	0.041
Cesium										
Cs-128	3.62m	ECB+						-	0.870	0.890
Cs-129	32.06h	EC						-	0.018	0.281
Cs-130	29.9m	ECB+						-	0.401	0.517
Cs-131	9.69d	EC						-	0.007	0.023
Cs-132	6.475d	ECB+B-						-	0.014	0.705
Cs-134	2.062y	ECB-						-	0.164	1.555
Cs-134m	2.91h	IT	Cs-134	1.000E+00				-	0.112	0.027
Cs-137	30.0	B-	Ba-137m	9.443E-01				-	0.187	-
Barium										
Ba-128	2.43d	EC	Cs-128	1.000E+00				-	0.009	0.066
Ba-131m	14.6m	IT	Ba-131	1.000E+00				-	0.109	0.077
Ba-133	10.74y	EC						-	0.054	0.402
Ba-135m	28.7h	IT						-	0.208	0.060
Ba-137m	2.552m	IT						-	0.065	0.587
Lanthanum										
La-134	6.45m	ECB+						-	0.759	0.716
La-140	40.272h	B-						-	0.535	2.316
Cerium										
Ce-134	75.9h	EC	La-134	1.000E+00				-	0.008	0.028
Ce-138	137.66d	EC						-	0.036	0.159
Ce-141	32.50d	B-						-	0.171	0.077
Promethium										
Pm-145	17.7y	EC						-	0.013	0.031
Pm-147	2.6234y	B-	Sm-147	1.000E+00				-	0.062	<
Samarium										
Sm-145	340d	EC	Pm-145	1.000E+00				-	0.031	0.064
Sm-153	46.7h	B-						-	0.270	0.062
Europium										
Eu-154	8.8y	ECB-						-	0.292	1.242
Gadolinium										
Gd-153	241.6d	EC						-	0.042	0.101
Dysprosium										
Dy-157	8.1h	EC	Tb-157	1.000E+00				-	0.014	0.341
Dy-159	144.4d	EC						-	0.013	0.045
Dy-165	2.334h	B-						-	0.449	0.026
Erbium										
Er-165	10.36h	EC						-	0.008	0.038
Er-167m	2.28s	IT						-	0.111	0.097
Er-171	7.52h	B-	Tm-171	1.000E+00				-	0.420	0.373
Thulium										
Tm-167	9.24d	EC						-	0.128	0.146
Tm-170	128.6d	ECB-						-	0.331	0.005
Tm-171	1.92y	B-						-	0.026	<
Ytterbium										
Yb-169	32.022d	EC						-	0.123	0.311
Tantalum										
Ta-177	56.6h	EC						-	0.024	0.067

Table A-2 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha	Elec.
Tantalum, cont'd										
Ta-178	9.31m	EC						-	0.034	0.109
Ta-179	864.9d	EC						-	0.008	0.032
Ta-182	115.0d	B-						-	0.217	1.294
Wolfram										
W-177	135m	ECB+	Ta-177	1.000E+00				-	0.104	0.903
W-178	21.7d	EC	Ta-178	1.000E+00				-	0.007	0.014
W-181	121.2d	EC						-	0.014	0.040
W-188	69.4d	B-	Re-188	1.000E+00				-	0.100	0.002
Rhenium										
Re-186	90.64h	B-EC						-	0.345	0.021
Re-188	16.98h	B-						-	0.780	0.058
Osmium										
Os-190m	9.9m	IT						-	0.117	1.589
Os-191	15.4d	B-						-	0.133	0.075
Os-191m	13.10h	IT	Os-191	1.000E+00				-	0.065	0.009
Iridium										
Ir-190	11.78d	EC						-	0.076	1.503
Ir-190m	1.2h	IT	Ir-190	1.000E+00				-	0.024	0.002
Ir-190m	3.2h	ECIT	Ir-190m	5.600E-02				-	0.126	1.548
Ir-191m	4.94s	IT						-	0.096	0.075
Ir-192	73.831d	ECB-						-	0.217	0.815
Platinum										
Pt-195m	4.02d	IT						-	0.183	0.076
Gold										
Au-195	183d	EC						-	0.051	0.085
Au-195m	30.5s	IT	Au-195	1.000E+00				-	0.117	0.201
Au-198	2.696d	B-						-	0.327	0.404
Au-199	3.139d	B-						-	0.143	0.089
Mercury										
Hg-195	9.9h	EC	Au-195	1.000E+00				-	0.065	0.204
Hg-195m	41.6h	ITEC	Hg-195	5.420E-01	Au-195	4.580E-01		-	0.150	0.214
Hg-197	64.1h	EC						-	0.066	0.070
Hg-197m	23.8h	ECIT	Hg-197	9.300E-01				-	0.216	0.094
Hg-203	46.612d	B-						-	0.099	0.238
Hg-206	8.15m	B-	Tl-206	1.000E+00				-	0.428	0.106
Thallium										
Tl-200	26.1h	ECB+						-	0.040	1.311
Tl-201	73.1h	EC						-	0.043	0.093
Tl-202	12.23d	ECB+						-	0.023	0.468
Tl-206	4.20m	B-						-	0.537	<
Tl-208	3.053m	B-						-	0.611	3.360
Tl-210	1.30m	B-	Pb-210	1.000E+00				-	1.273	2.736
Lead										
Pb-201	9.4h	ECB+	Tl-201	1.000E+00				-	0.060	0.758
Pb-203	51.873h	EC						-	0.053	0.314
Pb-204m	67.2m	IT						-	0.025	2.105
Pb-210	22.3y	A B-	Bi-210	1.000E+00	Hg-206	1.900E-08		<	0.038	0.005
Pb-212	10.64h	B-	Bi-212	1.000E+00				-	0.175	0.145
Pb-214	26.8m	B-	Bi-214	1.000E+00				-	0.293	0.250
Bismuth										
Bi-204	11.22h	ECB+	Pb-204m	9.928E-02				-	0.085	3.064
Bi-206	6.243d	EC						-	0.136	3.278
Bi-210	5.013d	A B-	Po-210	1.000E+00	Tl-206	1.320E-06		<	0.389	-
Bi-212	60.55m	A B-	Po-212	6.406E-01	Tl-208	3.594E-01		2.175	0.504	0.106
Bi-214	19.9m	A B-	Po-214	9.998E-01	Tl-210	2.100E-04		0.001	0.659	1.508
Polonium										
Po-209	102y	A EC	Pb-205	9.974E-01				4.867	<	0.003
Po-210	138.376d	A						5.305	<	<
Po-211	0.516s	A						7.442	<	0.008
Po-212	0.298us	A						8.784	-	-
Po-214	164.3us	A	Pb-210	1.000E+00				7.687	<	<

Table A-2 (cont'd).

Radioactive Decay Products and Fractional Yield										
Nuclide	T _{1/2}	Decay Mode					Energy (MeV/nt)			
			Nuclide	Fraction	Nuclide	Fraction	Nuclide	Fraction	Alpha Elec. Photon	
Polonium, cont'd										
Po-216	0.145s	A	Pb-212	1.000E+00				6.778	-	-
Po-218	3.05m	A B-	Pb-214	9.998E-01	At-218	2.000E-04		6.001	<	-
Astatine										
At-211	7.214h	A EC	Po-211	5.830E-01	Bi-207	4.170E-01		2.446	0.006	0.039
At-218	2s	A	Bi-214	9.990E-01				6.697	0.040	0.007
Radon										
Rn-220	55.6s	A	Po-216	1.000E+00				6.288	<	<
Rn-222	3.8235d	A	Po-218	1.000E+00				5.489	<	<
Radium										
Ra-224	3.66d	A	Rn-220	1.000E+00				5.674	0.002	0.010
Ra-226	1600y	A	Rn-222	1.000E+00				4.774	0.004	0.007
Americium										
Am-241	432.2y	A	Np-237	1.000E+00				5.479	0.059	0.034
Californium										
Cf-252	2.638y	SFA	Cm-248	9.691E-01	SF	3.092E-02		5.922	0.006	0.001

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