ORNL/TM-12350

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# Nuclear Decay Data Files of the Dosimetry Research Group

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R. J. Westfall
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M. Cristy



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FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-12350
Dist. Category UC-407

Health Sciences Research Division

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December 1993

Research sponsored by the Office of Health and Environmental Research, U. S. Department of Energy, Washington, DC 20545, and the Office of Radiation and Indoor Air, U. S. Environmental Protection Agency, Washington DC, 20460, under Interagency Agreement 1824-C148-A1, EPA NO. DW89934657-3.

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
Martin Marietta Energy Systems, Inc.
for the
U. S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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## ACKNOWLEDGEMENTS

This report represents a culmination of efforts by various members of the "Oak Ridge" dosimetry group undertaken during the preparation of Publication 30 of the International Commission on Radiological Protection. The authors wish to acknowledge the earlier efforts of M. R. Ford and S. B. Watson in assembling these data on the ORNL mainframe computers. Particular appreciation is extended to Prof. L. T. Dillman, Ohio Wesleyan University, whose technical expertise served the nuclear decay data needs of the "Oak Ridge" dosimetry group for many years.

Preparation of this report was funded by the Environmental Protection Agency. The development of the underlying methodologies were supported by the Office of Health and Environmental Research, U. S. Department of Energy. R. J. Westfall was supported by the Internship Program of the Oak Ridge Associated Universities.

## 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 calculations[1-4]. 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 Dillman[7], 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 Laboratory[8]. 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 Jones[14]. The nuclear decay data used in the dosimetric calculations for Publication 30[9] of the International Commission on Radiological Protection (ICRP) were derived from EDISTR and were subsequently published, in an abridged format, in ICRP Publication 38[3]. 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 | | |

monograph[4] 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 monograph[4]. 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 Jones[14]. Our interest here is limited to the following data elements of the EDISTR output:

a. the complete listing of the emitted radiations, their types, energies, and absolute intensities for the radionuclide, and

b. 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.

| | Energy/nuclear transformation (MeV/nt) | | | | | | Ratio MIRD/ICRP | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICRP38 collection | | | MIRD collection | | | | | |
| Nuclide | alpha | elec. | photon | alpha | elec. | photon | alpha | elec. | photon |
| Am-241 | 5.4791 | .0520 | .0325 | 5.4791 | .0585 | .0340 | 1 | 1.13** | 1.05 |
| As-72 | | 1.0257 | 1.7938 | | 1.0332 | 1.7763 | | 1.01 | .99 |
| As-73 | | .0603 | .0160 | | .0603 | .0160 | | 1 | 1 |
| At-218 | 6.6969 | .0399 | .0067 | 6.6969 | .0398 | .0066 | 1 | 1 | .99 |
| Au-198 | | .3274 | .4051 | | .3269 | .4043 | | 1 | 1 |
| Ba-128 | | .0094 | .0761 | | .0088 | .0659 | | .94 | .87** |
| Ba-133 | | .0542 | .4019 | | .0535 | .4018 | | .99 | 1 |
| Be-7 | | | .0493 | | | .0496 | | | 1.01 |
| Bi-210 | | .3889 | | | .3888 | | | 1 | |
| Bi-212 | 2.1741 | .4720 | .1855 | 2.1746 | .5035 | .1062 | 1 | 1.07 | .57** |
| Bi-214 | | .6593 | 1.5082 | .0011 | .6593 | 1.5082 | .0011/0 | 1 | 1 |
| Br-75 | | .5241 | 1.2157 | | .5062 | 1.2027 | | .97 | .99 |
| Br-76 | | .6906 | 2.6329 | | .6456 | 2.7904 | | .93 | 1.06 |
| Br-77 | | .0092 | .3208 | | .0095 | .3314 | | 1.03 | 1.03 |
| Br-80 | | .7236 | .0796 | | .7266 | .0758 | | 1 | .95 |
| Br-80m | | .0603 | .0240 | | .0615 | .0242 | | 1.02 | 1.01 |
| C-11 | | .3846 | 1.0195 | | .3846 | 1.0195 | | 1 | 1 |
| Ca-45 | | .0772 | | | .0772 | | | 1 | |
| Ca-47 | | .3448 | 1.0627 | | .3505 | 1.0471 | | 1.02 | .99 |
| Ca-49 | | .8695 | 3.1646 | | .8699 | 3.1675 | | 1 | 1 |
| Cd-109 | | .0826 | .0263 | | .0825 | .0259 | | 1 | .98 |
| Ce-134 | | .0069 | .0262 | | .0084 | .0278 | | 1.22** | 1.06 |
| Ce-139 | | .0355 | .1595 | | .0355 | .1587 | | 1 | .99 |
| Ce-141 | | .1705 | .0762 | | .1707 | .0765 | | 1 | 1 |
| Cf-252 | 5.9223 | .0056 | .0012 | 5.9223 | .0056 | .0012 | 1 | 1 | 1 |
| Co-55 | | .4294 | 1.9942 | | .4315 | 1.9961 | | 1 | 1 |
| Co-57 | | .0186 | .1252 | | .0186 | .1252 | | 1 | 1 |
| Co-58 | | .0341 | .9756 | | .0341 | .9757 | | 1 | 1 |
| Co-60 | | .0965 | 2.5043 | | .0964 | 2.5045 | | 1 | 1 |
| Cr-48 | | .0084 | .4358 | | .0086 | .4321 | | 1.02 | .99 |
| Cr-51 | | .0038 | .0325 | | .0038 | .0333 | | 1 | 1.02 |
| Cs-128 | | .8455 | .9004 | | .8701 | .8895 | | 1.03 | .99 |
| Cs-129 | | .0179 | .2815 | | .0178 | .2812 | | .99 | 1 |
| Cs-134 | | .1636 | 1.5551 | | .1642 | 1.5552 | | 1 | 1 |
| Cs-134m | | .1117 | .0267 | | .1124 | .0270 | | 1.01 | 1.01 |
| Cs-137 | | .1870 | | | .1874 | | | 1 | |
| Cu-62 | | 1.2848 | 1.0067 | | 1.2848 | 1.0069 | | 1 | 1 |
| Cu-64 | | .1226 | .1906 | | .1224 | .1907 | | 1 | 1 |
| Cu-67 | | .1553 | .1153 | | .1558 | .1153 | | 1 | 1 |

| | Energy/nuclear transformation (MeV/nt) | | | | | | Ratio MIRD/ICRP | | |
|---|---|---|---|---|---|---|---|---|---|
| | ICRP38 collection | | | MIRD collection | | | | | |
| Nuclide | alpha | elec. | photon | alpha | elec. | photon | alpha | elec. | photon |
| Dy-157 | | .0134 | .3565 | | .0138 | .3405 | | 1.03 | .96 |
| Dy-159 | | .0128 | .0450 | | .0131 | .0451 | | 1.02 | 1 |
| Er-171 | | .4218 | .3812 | | .4200 | .3727 | | 1 | .98 |
| Fe-52 | | .1935 | .7404 | | .1935 | .7404 | | 1 | 1 |
| Fe-55 | | .0042 | .0016 | | .0042 | .0016 | | 1 | 1 |
| Fe-59 | | .1176 | 1.1888 | | .1177 | 1.1883 | | 1 | 1 |
| Ga-66 | | .9699 | 2.4733 | | .9833 | 2.4545 | | 1.01 | .99 |
| Ga-67 | | .0355 | .1580 | | .0343 | .1548 | | .97 | .98 |
| Ga-68 | | .7392 | .9507 | | .7393 | .9474 | | 1 | 1 |
| Ga-72 | | .4969 | 2.7110 | | .5020 | 2.7241 | | 1.01 | 1 |
| Gd-153 | | .0439 | .1055 | | .0415 | .1010 | | .95 | .96 |
| Ge-68 | | .0049 | .0041 | | .0049 | .0041 | | 1 | 1 |
| H-3 | | .0056 | | | .0056 | | | 1 | |
| Hg-197 | | .0664 | .0700 | | .0664 | .0703 | | 1 | 1 |
| Hg-197m | | .2146 | .0943 | | .2161 | .0942 | | 1.01 | 1 |
| Hg-203 | | .0988 | .2381 | | .0989 | .2380 | | 1 | 1 |
| I-123 | | .0281 | .1717 | | .0283 | .1726 | | 1.01 | 1.01 |
| I-124 | | .1937 | 1.0982 | | .1955 | 1.0832 | | 1.01 | .99 |
| I-125 | | .0193 | .0420 | | .0194 | .0419 | | 1.01 | 1 |
| I-126 | | .1573 | .4548 | | .1459 | .4329 | | .93 | .95 |
| I-129 | | .0638 | .0246 | | .0632 | .0244 | | .99 | .99 |
| I-132 | | .4953 | 2.2804 | | .4953 | 2.2804 | | 1 | 1 |
| I-132m | | .1588 | .3222 | | .1563 | .3207 | | .98 | 1 |
| In-109 | | .0468 | .6722 | | .0468 | .6722 | | 1 | 1 |
| In-111 | | .0344 | .4053 | | .0347 | .4049 | | 1.01 | 1 |
| In-113m | | .1339 | .2576 | | .1339 | .2576 | | 1 | 1 |
| In-114 | | .7714 | .0027 | | .7760 | .0023 | | 1.01 | .85** |
| In-114m | | .1430 | .0944 | | .1430 | .0944 | | 1 | 1 |
| In-115m | | .1723 | .1611 | | .1724 | .1611 | | 1 | 1 |
| Ir-190 | | .1288 | 1.4427 | | .0758 | 1.5030 | | .59** | 1.04 |
| Ir-190m | | .0243 | .0019 | | .0243 | .0019 | | 1 | 1 |
| Ir-190n | | .1255 | 1.5546 | | .1263 | 1.5479 | | 1.01 | 1 |
| Ir-192 | | .2173 | .8179 | | .2172 | .8153 | | 1 | 1 |
| Kr-77 | | .6420 | 1.0160 | | .8243 | 1.1044 | | 1.28** | 1.09 |
| Kr-79 | | .0243 | .2574 | | .0244 | .2571 | | 1 | 1 |
| Kr-81 | | .0051 | .0117 | | .0051 | .0168 | | 1 | 1.44** |
| Kr-81m | | .0594 | .1308 | | .0590 | .1300 | | .99 | .99 |
| Kr-83m | | .0387 | .0026 | | .0387 | .0026 | | 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 | ICRP38 collection alpha | ICRP38 elec. | ICRP38 photon | MIRD collection alpha | MIRD elec. | MIRD photon | Ratio MIRD/ICRP alpha | Ratio elec. | Ratio photon |
|---|---|---|---|---|---|---|---|---|---|
| La-134 | | .7386 | .6978 | | .7591 | .7164 | | 1.03 | 1.03 |
| La-140 | | .5370 | 2.3149 | | .5351 | 2.3159 | | 1 | 1 |
| Mn-51 | | .9344 | .9977 | | .9347 | .9977 | | 1 | 1 |
| Mn-52 | | .0748 | 3.4576 | | .0748 | 3.4576 | | 1 | 1 |
| Mn-52m | | 1.1318 | 2.4088 | | 1.1326 | 2.4102 | | 1 | 1 |
| Mn-54 | | .0042 | .8360 | | .0042 | .8360 | | 1 | 1 |
| Mo-99 | | .3922 | .1500 | | .3926 | .1492 | | 1 | .99 |
| Na-22 | | .1941 | 2.1925 | | .1941 | 2.1925 | | 1 | 1 |
| Na-24 | | .5535 | 4.1212 | | .5535 | 4.1231 | | 1 | 1 |
| Nb-95 | | .0444 | .7658 | | .0445 | .7643 | | 1 | 1 |
| Nb-95m | | .1663 | .0683 | | .1745 | .0686 | | 1.05 | 1 |
| Ni-57 | | .1431 | 1.9219 | | .1550 | 1.9421 | | 1.08 | 1.01 |
| Ni-63 | | .0171 | | | .0171 | | | 1 | |
| Os-190m | | .1163 | 1.5884 | | .1168 | 1.5886 | | 1 | 1 |
| Os-191 | | .1353 | .0795 | | .1330 | .0748 | | .98 | .94 |
| Os-191m | | .0650 | .0091 | | .0652 | .0089 | | 1 | .98 |
| P-30 | | 1.4363 | 1.0219 | | 1.4362 | 1.0220 | | 1 | 1 |
| P-32 | | .6946 | | | .6946 | | | 1 | |
| Pb-201 | | .0575 | .7580 | | .0599 | .7576 | | 1.04 | 1 |
| Pb-203 | | .0523 | .3118 | | .0527 | .3141 | | 1.01 | 1.01 |
| Pb-210 | | .0379 | .0048 | | .0379 | .0048 | | 1 | 1 |
| Pb-212 | | .1755 | .1483 | | .1754 | .1451 | | 1 | .98 |
| Pb-214 | | .2932 | .2497 | | .2932 | .2497 | | 1 | 1 |
| Pd-103 | | .0058 | .0144 | | .0058 | .0144 | | 1 | 1 |
| Pd-109 | | .4374 | .0117 | | .4374 | .0117 | | 1 | 1 |
| Pm-145 | | .0140 | .0310 | | .0126 | .0309 | | .90** | 1 |
| Po-210 | 5.2970 | | | 5.3045 | | | 1 | | |
| Po-211 | 7.4421 | .0001 | .0078 | 7.4423 | .0001 | .0077 | 1 | 1 | .99 |
| Po-212 | 8.7848 | | | 8.7843 | | | 1 | | |
| Po-214 | 7.6871 | | | 7.6871 | | | 1 | | |
| Po-216 | 6.7786 | | | 6.7786 | | | 1 | | |
| Ra-224 | 5.6739 | .0022 | .0099 | 5.6739 | .0022 | .0099 | 1 | 1 | 1 |
| Ra-226 | 4.7743 | .0035 | .0067 | 4.7743 | .0035 | .0067 | 1 | 1 | 1 |
| Rb-79 | | .8201 | 1.3578 | | .7770 | 1.4381 | | .95 | 1.06 |
| Rb-81 | | .1965 | .6233 | | .1842 | .6448 | | .94 | 1.03 |
| Rb-82m | | .0954 | 2.9099 | | .0954 | 2.9099 | | 1 | 1 |
| Rb-83 | | .0146 | .5044 | | .0146 | .5044 | | 1 | 1 |
| Rb-84 | | .1548 | .9187 | | .1615 | .8865 | | 1.04 | .96 |
| Re-188 | | .7800 | .0576 | | .7800 | .0577 | | 1 | 1 |
| Rh-103m | | .0379 | .0017 | | .0371 | .0017 | | .98 | 1 |

| Nuclide | ICRP38 collection alpha | ICRP38 elec. | ICRP38 photon | MIRD collection alpha | MIRD elec. | MIRD photon | Ratio MIRD/ICRP alpha | Ratio elec. | Ratio photon |
|---|---|---|---|---|---|---|---|---|---|
| Ru-103 | | .0748 | .4687 | | .0665 | .4947 | | .89** | 1.06 |
| Ru-97 | | .0133 | .2399 | | .0130 | .2404 | | .98 | 1 |
| Sc-47 | | .1625 | .1083 | | .1628 | .1082 | | 1 | 1 |
| Sc-49 | | .8223 | .0010 | | .8177 | .0010 | | .99 | 1 |
| Se-73 | | .3855 | 1.0873 | | .3894 | 1.0965 | | 1.01 | 1.01 |
| Se-73m | | .1779 | .2439 | | .1710 | .2519 | | .96 | 1.03 |
| Se-75 | | .0145 | .3942 | | .0146 | .3916 | | 1.01 | .99 |
| Sm-145 | | .0319 | .0652 | | .0310 | .0640 | | .97 | .98 |
| Sm-153 | | .2726 | .0619 | | .2702 | .0619 | | .99 | 1 |
| Sn-113 | | .0063 | .0228 | | .0063 | .0227 | | 1 | 1 |
| Sr-83 | | .1494 | .8013 | | .1494 | .8013 | | 1 | 1 |
| Sr-85 | | .0089 | .5118 | | .0089 | .5133 | | 1 | 1 |
| Sr-85m | | .0122 | .2195 | | .0131 | .2160 | | 1.07 | .98 |
| Sr-87m | | .0669 | .3203 | | .0670 | .3210 | | 1 | 1 |
| Ta-177 | | .0238 | .0671 | | .0238 | .0671 | | 1 | 1 |
| Ta-178a | | .0335 | .1086 | | .0335 | .1086 | | 1 | 1 |
| Ta-182 | | .2169 | 1.2943 | | .2169 | 1.2943 | | 1 | 1 |
| Tc-94m | | .7558 | 1.8589 | | .7546 | 1.9382 | | 1 | 1.04 |
| Tc-95 | | .0068 | .7964 | | .0068 | .7979 | | 1 | 1 |
| Tc-95m | | .0155 | .6750 | | .0154 | .7191 | | .99 | 1.07 |
| Tc-97m | | .0868 | .0095 | | .0867 | .0095 | | 1 | 1 |
| Tc-99 | | .1012 | | | .1012 | | | 1 | |
| Tc-99m | | .0162 | .1263 | | .0161 | .1265 | | .99 | 1 |
| Te-123 | | .0063 | .0197 | | .0028 | .0001 | | .44** | .01** |
| Te-123m | | .0993 | .1480 | | .1024 | .1482 | | 1.03 | 1 |
| Tl-201 | | .0434 | .0934 | | .0434 | .0934 | | 1 | 1 |
| Tl-208 | | .5976 | 3.3745 | | .6109 | 3.3601 | | 1.02 | 1 |
| Tm-171 | | .0255 | .0006 | | .0255 | .0006 | | 1 | 1 |
| V-48 | | .1488 | 2.9141 | | .1478 | 2.9127 | | .99 | 1 |
| W-181 | | .0108 | .0404 | | .0136 | .0398 | | 1.26** | .99 |
| W-188 | | .0996 | .0019 | | .0996 | .0019 | | 1 | 1 |
| Xe-123 | | .1837 | .6336 | | .1876 | .6410 | | 1.02 | 1.01 |
| Xe-127 | | .0325 | .2802 | | .0324 | .2800 | | 1 | 1 |
| Xe-129m | | .1847 | .0512 | | .1847 | .0512 | | 1 | 1 |
| Xe-133 | | .1357 | .0461 | | .1357 | .0461 | | 1 | 1 |
| Y-87 | | .0070 | .4572 | | .0071 | .4579 | | 1.01 | 1 |
| Yb-169 | | .1247 | .3097 | | .1232 | .3114 | | .99 | 1.01 |
| Zn-62 | | .0326 | .4389 | | .0326 | .4389 | | 1 | 1 |
| Zn-65 | | .0068 | .5842 | | .0068 | .5832 | | 1 | 1 |
| Zn-69 | | .3209 | | | .3209 | | | 1 | |
| Zn-69m | | .0222 | .4166 | | .0222 | .4164 | | 1 | 1 |
| Zr-95 | | .1163 | .7388 | | .1179 | .7321 | | 1.01 | .99 |

Energy/nuclear transformation (MeV/nt)

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

** Difference between MIRD and ICRP38 > 10%.
Note: Ratios 1.00 shown as 1.

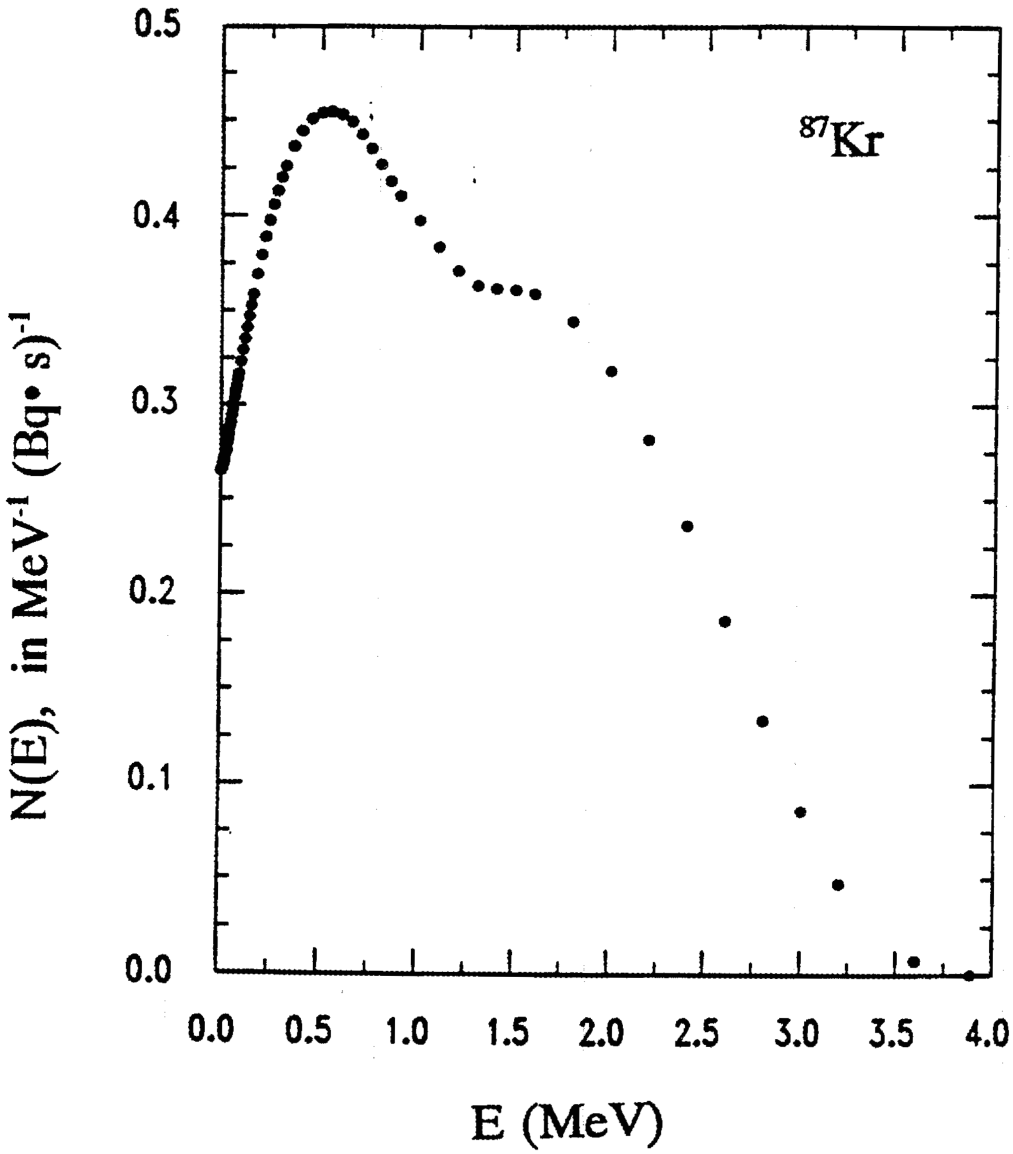


Figure 1. Composite Beta Spectrum for $^{87}Kr$. Each point represents a tabulated value.

## 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 30[9]. Our computer program for computing SEEs, SEECAL, is documented by Cristy and Eckerman[10], 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 38[3] nor in the MIRD monograph[4], but the former data were used in the calculations of the derived air concentration (DAC) for submersion exposure given in ICRP Publication 30[9]. Note: if your only interest in DEXRAX is extracting data to compute SEEs with SEECAL[10], 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 manual[2] 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 MIRD.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 | Halflife & units | Decay Modes | Index, Radiat. | # Rec | Index, Beta | # 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- | 45518 | 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 | h- | 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 | Notes |
|---|---|
| H-3    12.35 y            1 | Header record for H-3. |
| 5 1.00000E+02 5.68276E-03 | First (and only) data record for H-3. |
| Be-7   53.3 d             4 | Header record for Be-7. |
| 1 1.03400E+01 4.77605E-01 | ICODE, intensity, and energy. |
| 6 8.04306E-06 4.77550E-01 | |
| 6 1.18019E-07 4.77605E-01 | Intensity of radiation is in percent |
| 2 1.63500E-02 5.47500E-05 | (i.e., radiations per 100 decays). |
| Be-10   1.600E 06 y      1 | Unique or average energy is in MeV. |
| 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 | |

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 |

[a]Input file refers to standard file ICRP38.RAD or MIRD.RAD. Output file refers to DEXRAX radiations output file (see Tables 8-9).

[b]Mnemonic 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 EDISTR[7] 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

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

and the average energy of the spectrum is

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

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 ic
6 4.44315E-01 6.67000E-03 ic
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    1.0000E 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 SEECAL[10]; 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 elsewhere[11].

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 Eckerman[10].

## 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:

| File | Directory |
|---|---|
| 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

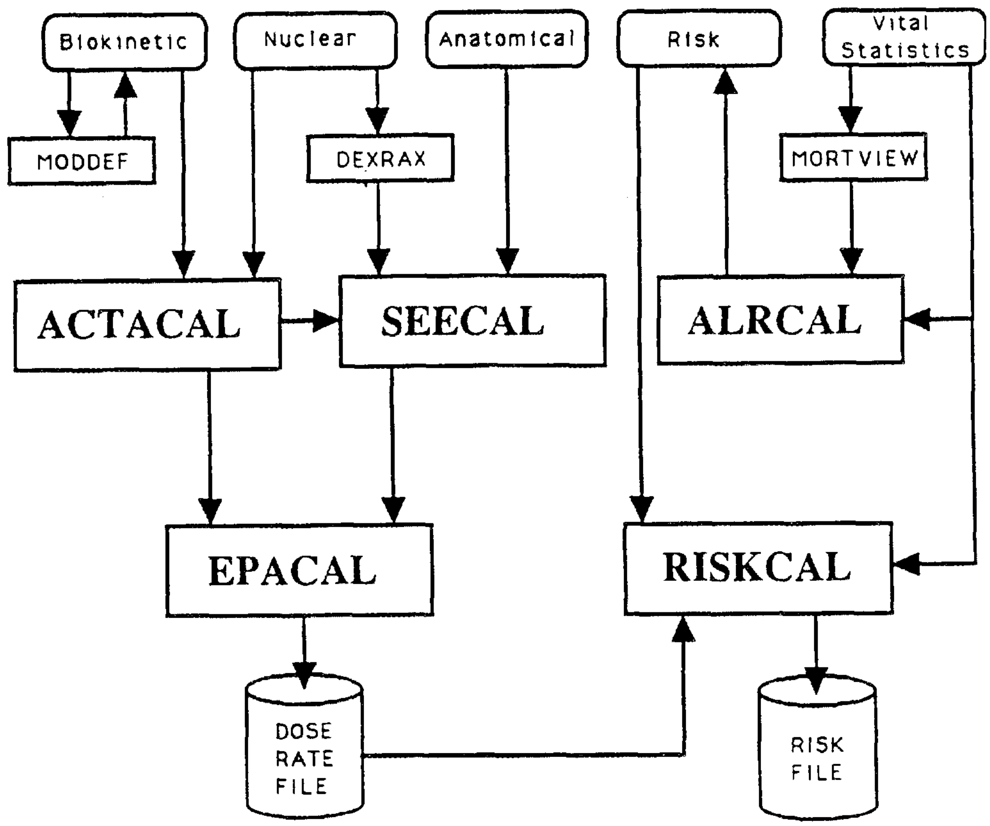


Figure 2. Schematic showing the programs, input data, and flow in the DCAL dosimetric system. The major data elements of the system are shown at the top of the figure (in the rectangles with rounded corners). The two cylinders at the bottom denote the repositories of dosimetric and risk data. Major computation 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 |

<u>Input</u>

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.

<u>Output</u>

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. Ward[12], and DEXRAX uses a C language routine[13] 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, FRWARD and RECVER, 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 FRWARD to read a linear chain, noting the occurrence of any branches and their convergence, when processing previously detected branches. CHAIN calls RECVER to recover the location of any branches detected by FRWARD 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

                                        Emitted Energy (MeV/nt)
Nuclide      T-1/2  DecMode  # rad.   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 usA             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 \$DCAL\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

                                          Emitted Energy (MeV/nt)
 Nuclide     T-1/2    DecMode  # rad.   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 usA           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>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)? o
Log file Dexrax.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

                                         Emitted Energy (MeV/nt)
Nuclide     T-1/2    DecMode  # rad.   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 usA           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

                                           Emitted Energy (MeV/nt)
 Nuclide     T-1/2    DecMode  # rad.  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 usA           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>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)? o
Log file Dexrax.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

                 Radiations data only
                 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-24
Nuclide # 2: k-40
Nuclide # 3: Sr-90
Nuclide # 4: TC-99M
Nuclide # 5: I-131
Nuclide # 6: Cs-237
   Entry error or unlisted nuclide Cs-237
Nuclide # 6: Cs-137
Nuclide # 7: Np-237
Nuclide # 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-236a
Nuclide # 9: Am-241
Nuclide #10: Eu-150a
Nuclide #11: Eu-150b
Nuclide #12: Cf252
   Entry error or unlisted nuclide Cf252
Nuclide #12: Cf-252
Nuclide #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: n
Nuclide #14: Ir-190n
Nuclide #15: Cf-252
Nuclide #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 Convention[1]

| 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 Jones[14], 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

                                      Emitted Energy (MeV/nt)
Nuclide    T-1/2    DecMode  # rad.   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

                                           Emitted Energy (MeV/nt)
 Nuclide     T-1/2    DecMode  # rad.   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 | $0.75 + 0.65\ (\bar{\nu} + 1)^{1/2}$ | $\bar{\nu} f_{SF}$ |
| Fission fragments | $0.0698Z^2 / A^{1/3} - 10.988$ | $2f_{SF}$ |
| Prompt gamma rays | 0.8847 | $8.636f_{SF}$ |
| Delayed gamma rays | 0.9578 | $0.2102m^2 f_{SF}$ |
| Beta particles | $0.2058m$ | $mf_{SF}$ |

[a]Methods of Dillman and Jones[14], as given by Dillman[7]

[b]In 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.**

<u>Radiations Data for Cf-252, as Given in ICRP38.RAD</u>

```
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.
```

<u>Radiations Data for Cf-252, as Given in RAD Output File</u>

```
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
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
```

```
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.
```

## 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

1. Dillman, L. T., and Von der Lage, F. C. *Radionuclide Decay Schemes and Nuclear Parameters for Use in Radiation-Dose Estimation*, MIRD Pamphlet No. 10, 1975.

2. Kocher, D. C. *Radioactive Decay Data Tables*, DOE/TIC-11026, 1981.

3. International Commission on Radiological Protection. *Radionuclide Transformations: Energy and Intensity of Emissions*, ICRP Publication 38, 1983.

4. Weber, D. A., Eckerman, K. F., Dillman, L. T., and Ryman, J. C. *MIRD: Radionuclide Data and Decay Schemes* (Society of Nuclear Medicine, New York), 1989.

5. Lederer, C. M., Hollander, J. M., and Perlman, I. *Table of Isotopes*, 6th ed. (John Wiley & Sons, New York), 1967.

6. National Council on Radiation Protection and Measurements. *A Handbook of Radioactivity Measurements Procedures*, 2nd ed., NCRP Report No. 58, 1985.

7. Dillman, L. T. *EDISTR - A Computer Program to Obtain a Nuclear Decay Data Base for Radiation Dosimetry*, ORNL/TM-6689, 1980.

8. National Nuclear Data Center, Brookhaven National Laboratory. *ENSDF: The Evaluated Nuclear Structure Data File*, (ENSDF Formats: Tuli, J. K., Evaluated Nuclear Structure Data File, BNL-NCS-51655), 1987.

9. International Commission on Radiological Protection. *Limits for Intakes of Radionuclides by Workers*, ICRP Publication 30, Parts 1-4, 1979-1988.

10. Cristy, M., and Eckerman, K. F. *SEECAL: Program to Calculate Age-dependent Specific Effective Energies*, ORNL/TM-12351, 1993.

11. Eckerman, K. F., Leggett, R. W., Cristy, M., Ward, R. C., Sjoreen, A. L., Ryman, J. C., and Nelson, C. B. *DCAL: Radiation Dose and Risk Calculational System*, ORNL/TM-12431, in preparation.

12. Ward, R. C. *FASTPLOT- An Interface to Microsoft FORTRAN Graphics*, ORNL/TM-12373, in preparation.

13. J. C. Ryman, private communication.

14. Dillman, L. T., and Jones, T. D. Internal Dosimetry of Spontaneously Fissioning Nuclides, *Health Phys. 29*: 111-123, 1975.

# 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 μs 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 photons[1] (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

---

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

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

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

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

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 that 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 $^{114m}$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 $^{124n}$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.**

| | | | Radioactive Decay Products and Fractional Yield | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Decay | | | | | | | Energy (MeV/nt) | | |
| Nuclide | $T_{1/2}$ | Mode | 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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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 | | | - | 0.656 | 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).**

| Nuclide | $T_{1/2}$ | Decay Mode | Radioactive Decay Products and Fractional Yield | | | | | | 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-109 | 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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | Nuclide | Fraction | Nuclide | Fraction | Nuclide | Fraction | Alpha | Elec. | Photon |
| **Cadium**, 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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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 | 9.760E-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 | 9.09h | 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 | 29.9m | 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-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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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 | 0.916 |
| **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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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).**

| Nuclide | T½ | Decay Mode | Radioactive Decay Products and Fractional Yield: 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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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).**

| Nuclide | $T_{1/2}$ | Decay Mode | Radioactive Decay Products and Fractional Yield | | | | | | 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-189m | 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 | | | | | - | 0.096 | 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).**

| Nuclide | $T_{1/2}$ | Decay Mode | Radioactive Decay Products and Fractional Yield | | | | | | 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).

| Nuclide | $T_{1/2}$ | Decay Mode | Radioactive Decay Products and Fractional Yield | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Nuclide | Fraction | Nuclide | Fraction | Nuclide | Fraction | Alpha | Elec. | Photon |
| **Francium** | | | | | | | | | | | |
| Fr-219 | 21ms | A | 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 | 0.130 |
| 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 | 0.652 |
| 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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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).**

| Nuclide | $T_{½}$ | Decay Mode | Radioactive Decay Products and Fractional Yield | | | | | | 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.**

| | | | Radioactive Decay Products and Fractional Yield | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | 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: Nuclide | Fraction | Nuclide | Fraction | Nuclide | Fraction | Energy (MeV/nt): 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).**

| Nuclide | $T_{1/2}$ | Decay Mode | Radioactive Decay Products and Fractional Yield | | | | | | 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 | 9.997E-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).**

| 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 | 0.607 |
| **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 | 2.188d | 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 | 0.597 |
| **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-139 | 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).**

| Nuclide | $T_{1/2}$ | Decay Mode | Radioactive Decay Products and Fractional Yield: Nuclide | Fraction | Nuclide | Fraction | Nuclide | Fraction | Energy (MeV/nt): ALpha | Elec. | Photon |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tantalum**, cont'd | | | | | | | | | | | |
| Ta-178 | 9.31m | EC | | | | | | | - | 0.034 | 0.109 |
| Ta-179 | 664.9d | 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-190n | 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 | | | | | | Energy (MeV/nt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclide | $T_{1/2}$ | Decay Mode | Nuclide | Fraction | Nuclide | Fraction | Nuclide | Fraction | Alpha | Elec. | Photon |
| **Polonium**, cont'd | | | | | | | | | | | |
| Po-216 | 0.145s | 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-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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