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(ENDF-210)

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Aerojet Nuclear Company

NATIONAL REACTOR TESTING STATION

Idaho Falls, Idaho — 83401

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PREPARED FOR THE

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ABSTRACT

A file of radioactive-nuclide decay data for ENDF/B has been established. The information is stored on magnetic tape in a readable, card-image format. For each nuclide (or isomeric state) the atomic number, mass number and half-life are given, together with the observed decay modes (including β^-, β^+, electron-capture, isomeric-transition, α, delayed-neutron and spontaneous-fission decay). For each decay mode the associated branching ratio and the available decay energy (where defined) are listed. For each radiation type, the energies and intensities of the individual transitions are given, together with a normalization factor to convert relative intensities to absolute intensities. In addition, intensity-weighted average energies are included for β , γ and α transitions. For the individual γ-ray transitions, provision is made for inclusion of their total internal-conversion coefficients. Uncertainties for all the measured quantities are also given. Documentation of the sources from which the data were taken and other pertinent information are included as comments for each nuclide. The format in which the data are prepared (and from which they are translated into the ENDF/B format) is presented and discussed. A list of the 198 nuclides for which decay data are included in this file as of June, 1974, and in Version IV of ENDF/B is given.

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I. INTRODUCTION

Historically, the study of the decay properties of radioactive nuclides has proved to be a highly productive source of important information of both a basic and an applied character. In the area of basic nuclear physics, such studies have provided much of the experimental basis for our present understanding of the nucleus, as embodied in current models of nuclear structure. In their application to other areas, radioactive-nuclide decay data are directly relevant to and of vital importance in a wider range of disciplines and applied areas than is any other category of nuclear data.

In recognition of the pressing need for nuclear decay data in a variety of reactor-related applications, the scope of the Evaluated Nuclear Data File (ENDF/B) has recently been expanded to include such information. The impetus for this expansion was provided by the need for a reliable and common data base to be used in computer codes developed to carry out "summation" calculations of the decay-heat source term in reactor cores. (See references 1-3 for descriptions of three computer codes currently used to carry out such calculations, as well as for discussions of the summation method itself.) The Fission-Product File of ENDF/B-IV was to constitute this data base; and, consequently, the first phase of this file-expansion effort was directed toward providing radioactive-nuclide decay data for inclusion in the Fission-Product File. The responsibility for preparing the Fission-Product File was assigned to a specially designated ad-hoc group - the Decay-Heat Task Force - set up under the Fission-Product Subcommittee of the Cross-Sections Evaluation Work Group (CSEWG). The Fission-Product File set up for ENDF/B-IV as a result of this effort contained entries for 825 nuclides, 712 of which were radioactive, deemed to be of importance for the decay-heat problem.

Our involvement in the nuclide decay-data aspect of the work of the Decay-Heat Task Force had two principal emphases:

1. to establish the categories of decay data to be included in ENDF/B and to set up a format within which these data could be organized (and from which they could be translated into the ENDF/B format); and
2. to evaluate the experimental decay data and prepare a file containing such data (where they are sufficiently detailed) for a number of fission-product nuclides of priority interest in the decay-heat problem for inclusion in ENDF/B.

In this report we give a description of the organization and content of the nuclide decay-data file we have set up as a result of our involvement in the Decay-Heat Task Force. Section II contains a discussion of the types of data included in the file, the format in which we prepare these data and a list of those nuclides for which experimental data are presently (as of June, 1974) incorporated into the file. Section III gives a discussion of specific aspects of the included data as a guide to their use. Section IV deals with modifications to the file data which will probably be made in future versions.

II. DATA CONTENT AND INPUT FORMAT FOR THE DECAY-DATA FILE

1. Data Content of the File

The impetus for the preparation of the file was the need for a reliable (and commonly available) data base for "summation" calculations of the decay-heat source term in reactor cores. For these calculations one needs only the following decay information: half-life; average beta-ray energy, $\langle E_\beta \rangle$, emitted per decay; and average gamma-ray energy, $\langle E_\gamma \rangle$, emitted per decay†. Consequently, a nuclide decay-data file adequate only for the needs of the decay-heat source-term problem could be set up with a relatively small data content.

However, nuclide-decay data are important for any measurement problem involving precise assay of radioactivity and hence are required in a wide variety of applied areas and basic disciplines. A few examples of such areas are the following: fuel-burnup studies in reactor systems; precise fission-rate-determination studies in fast reactors; shielding requirements for storage of spent fuel elements, control-rod sections and structural materials in reactor cores; radioactivity hazards assessment in CTR systems; and environmental monitoring of nuclear power plants. Consequently, it was decided to set up at the outset a data file of much broader flexibility and scope than the minimum required for the decay-heat problem alone. Once done, this would make the file readily expandable (simply by the inclusion of additional nuclides) without the need for continual revision of the format (to incorporate additional categories of information) as its use was extended to include other applications.

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†Also required, of course, are the fission yields and capture cross sections, but these are not considered here since they are not classified as "decay" data.

The content and structure proposed for the decay-data file was formally adopted by the relevant subcommittees of CSEWG at the May, 1973 meeting at Brookhaven National Laboratory (BNL). On the file, the nuclides are arranged in order of increasing atomic number (Z). For a given Z-value, the nuclides are arranged in order of increasing mass number (A). Isomers (arbitrarily restricted to excited states with half-lives $\gtrsim$ 0.1 sec) are treated as separate cases and appear on the file immediately following their associated ground state (when the latter are radioactive). In addition to Z, the chemical symbol, A, and an "isomer tag", the following information is given for each nuclide. A number of comment cards are included which give references from which the listed data were taken together with relevant remarks concerning specific aspects of the data and/or how they were treated. The half-life, its uncertainty and the various decay modes of the nuclide are given. These modes presently include β^-, β^+ and/or electron-capture, isomeric-transition, alpha-particle, delayed-neutron and spontaneous-fission decay. For each such mode, the associated total branching ratio and its uncertainty as well as the available decay energy (where defined) and its uncertainty are listed. For each radiation type, the energies and intensities (and their uncertainties) of the individual transitions are given, together with a normalization factor to convert relative intensities to absolute intensities. In addition, intensity-weighted average energies and their uncertainties are included for β , γ and α transitions. For the individual γ-ray transitions, provision is made for inclusion of their total internal-conversion coefficients and uncertainties.

2. Card Format of the Decay-Data File

The standard punched-card format in which these data are entered into the laboratory working file is given in Table I. This "people-readable" format differs considerably from that in which the data are stored in ENDF/B. A program which translates the data from this format into that of ENDF/B has been written by personnel at the National Neutron Cross-Section Center at BNL[4].

A typical example of decay data arranged in this format is given, for the nuclide ^{125}Sb, in Table II.

3. Present Status of Decay Data on ENDF/B-IV

Up to the present time (June, 1974), we have prepared experimental decay data for 198 radioactive nuclides for inclusion in ENDF/B-IV. A list of these is given in Table III. Fission-product nuclides account for 180 of these entries; and their decay data will be included in the Fission-Product File.

As noted in Section I above, there are 712 radioactive nuclides for which decay information is required for the calculation of the fission-product decay-heat source term. The choice of the 180 fission-product nuclides presently included in our file was determined primarily by the relative importance of their predicted contribution to the decay-heat source term and by the availability of sufficiently detailed decay information to permit a realistic calculation of their $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values to be made. Reliable decay data exist for a number of the remaining $\approx$ 530 nuclides, but limitations of time and manpower precluded their being included in this version of ENDF/B; it is planned to include them in subsequent versions. However, the large majority of these remaining, nonincluded nuclides fall into one of two categories. Nuclides

TABLE I

CARD FORMAT FOR INPUT TO THE NUCLIDE DECAY-DATA FILE

All energy values are given in keV and all intensities are given in percent of decays.

Card Type	Column(s)	Description
1	Nuclide Identification (one card)	
	1-3	Z (Atomic Number) (Right Adjusted)
	4-6	A (Mass Number) (Right Adjusted)
	7	Isomer Tag: Blank (or zero) indicates the ground state; 1 indicates the first isomeric state; 2 indicates the second isomeric state, etc.
	31-40	Number of Comment Cards to follow (right adjusted)
2	Comment Cards (any number of cards)	
	1-66	These include any desired comments on the decay information. They should contain the month/year the information was prepared and the references from which it was obtained.
3	Half-Life (one card)	
	1-10	Half-life
	11-20	Its uncertainty
	30	Units for half-life (one letter: S, M, H, D, Y).
	40	Number of decay modes of the parent state. [This is equal to the number of decay-mode cards (type 4).]
	50	Number of "spectra", or data lists, to follow. (e.g., 0 indicates no data lists, 2 indicates two such lists, etc.)
4	Decay Modes (one card for each mode; any number of cards)	
	10	Mode of decay: 1 = β^- 2 = β^+ 3 = Isomeric transition

TABLE I (Continued)

Card Type	Column(s)	Description
4	Decay Modes (Continued)	
		4 = alpha particle 5 = delayed neutron 6 = spontaneous fission
	20	Is an isomeric state in the daughter nucleus fed? 0 = no 1 = first isomeric state in daughter is fed 2 = second isomeric state in daughter is fed, etc.
	21-30	Q-value of the decay. For isomeric-transition decay, this will be the energy of the isomeric state.
	31-40	Uncertainty (in keV) in this Q-value.
	41-50	Percentage branching of this decay mode.
	51-60	Uncertainty in this branching.
	NOTE:	If both an isomeric state and the ground state in the daughter nucleus are fed in the decay, separate cards for each should be prepared.
5	Average Energy (one card)	
	1-10	Average beta energy
	11-20	Its uncertainty
	21-30	Average gamma energy
	31-40	Its uncertainty
	41-50	Average alpha energy
	51-60	Its uncertainty
6.	Intensity Normalization and Radiation Type	(one type-6 card to be followed by any number of type-7 cards; any number of such groups)
	1-10	Normalization factor (absolute intensity/relative intensity) for the list to follow in type-7 cards.
	11-20	Uncertainty in the normalization factor.
	21-30	Number of transitions of this type to be listed (right adjusted).
	40	Radiation type (same numerical designation as in column 10 of card 4).

TABLE I (Continued)

Card Type	Column(s)	Description
7	Energy and Intensity Information (one per card in order of increasing energy of each individual transition of the radiation type given on card 6; any number of cards)	
	1-10	Energy of transition (gamma radiation excluded)
	11-20	Uncertainty (in keV) of the energy.
	21-30	Intensity of this transition.
	31-40	Uncertainty in this intensity value.
8	Gamma-ray Data (one type-8 card followed by any number of type-9 cards)	
	1-10	Normalization factor (absolute intensity/relative intensity) for the gamma rays listed on the type-9 cards to follow.
	11-20	Uncertainty in the normalization factor.
	21-30	Number of gamma rays included in the list. This is equal to the number of type-9 cards to follow. (right adjusted)
	40	0, radiation-type designation for gamma radiation.
9	Gamma-ray Energy and Intensity Data (any number of cards, in order of increasing gamma-ray energy)	
	1-10	Gamma-ray energy (E_γ)
	11-20	Uncertainty in E_γ
	21-30	Gamma-ray intensity (I_γ)
	31-40	Uncertainty in I_γ
	41-50	Internal-conversion coefficient, ICC. (Generally given only for isomeric transitions or for highly converted gamma rays.)
	51-60	Uncertainty in ICC.
	NOTE:	If an isomeric state in the daughter nucleus is fed, do not include in this list any transitions which result from the decay of this daughter isomer.

TABLE II

Sample file entry showing the format in which the nuclide-decay data are prepared before transformation to the ENDF/B format.

```
511250    SB                                    7
PREPARED FOR FILE : 12/73                                   CWR
REFERENCES: Q- 1973 REVISION OF WAPSTRA-GOVE MASS TABLE
            HALF-LIFE  N.E.HOLDEN, CHART OF THE NUCLIDES (1973);
                       AND PRIVATE COMMUNICATION (SEPT.,1973)
            OTHER- NUCLEAR DATA SHEETS B 7, NO.5, 465 (1972).
  NOTE: FIRST-FORBIDDEN,UNIQUE SHAPE CORRECTION CONSIDERED IN
        DERIVING <E-BETA> FOR HIGHEST-ENERGY BETA TRANSITION
     2.73      0.03          Y          2         2
        1         0       766.         2.       77.
        1         1       621.         2.       23.
    86.86       0.0     452.07         0.0
      1.0                    7          1
     94.                 13.5
    124.                  5.7
    130.                 18.1
    241.                  1.5
    302.                 40.2
    445.                  7.15
    621.                 13.5
    0.302                   17          0
    35.46      0.03     14.2                     14.0
   116.94      0.05      1.13        0.11        0.074
   172.60      0.05      0.89        0.10
   176.29      0.02     22.7         0.9         0.155
   204.07      0.04      0.93        0.09
   208.0       0.2       0.63        0.06
   227.7       0.2       0.39        0.04
   321.0       0.2       1.52        0.15
   380.5       0.2       5.1         0.3         0.016
   408.0       0.2       0.45        0.05
   427.9       0.2     100.                      0.012
   443.3       0.3       1.0         0.2
   463.4       0.3      35.0         1.5
   600.6       0.2      59.8         2.5
   606.7       0.2      16.4         0.8
   636.0       0.2      38.4         1.9
   671.5       0.2       5.83        0.30
```

TABLE III

List of nuclides (as of June, 1974) for which decay data have been prepared for inclusion in ENDF/B-IV.

#	Z	A	#	Z	A	#	Z	A
1	1	H- 3	2	32	GE- 79	3	33	AS- 80
4	33	AS- 81	5	33	AS- 82	6	33	AS- 82M
7	34	SE- 83	8	34	SE- 83M	9	34	SE- 84
10	35	BR- 84	11	35	BR- 84M	12	35	BR- 85
13	35	BR- 86	14	35	BR- 87	15	36	KR- 85
16	36	KR- 85M	17	36	KR- 87	18	36	KR- 88
19	36	KR- 89	20	36	KR- 90	21	36	KR- 91
22	36	KR- 92	23	37	RB- 88	24	37	RB- 89
25	37	RB- 90	26	37	RB- 90M	27	37	RB- 91
28	37	RB- 92	29	38	SR- 89	30	38	SR- 90
31	38	SR- 91	32	38	SR- 92	33	38	SR- 93
34	38	SR- 94	35	39	Y- 90	36	39	Y- 90M
37	39	Y- 91	38	39	Y- 91M	39	39	Y- 92
40	39	Y- 93	41	39	Y- 94	42	39	Y- 95
43	39	Y- 97	44	40	ZR- 90M	45	40	ZR- 95
46	40	ZR- 97	47	40	ZR- 99	48	41	NB- 95
49	41	NB- 95M	50	41	NB- 97	51	41	NB- 97M
52	41	NB- 98	53	41	NB- 98M	54	41	NB- 99
55	41	NB- 99M	56	41	NB-100	57	41	NB-101
58	42	MO- 99	59	42	MO-101	60	42	MO-102
61	43	TC- 99M	62	43	TC-101	63	43	TC-102
64	43	TC-102M	65	43	TC-104	66	44	RU-103
67	44	RU-105	68	44	RU-106	69	44	RU-107
70	44	RU-108	71	45	RH-103M	72	45	RH-104
73	45	RH-104M	74	45	RH-105	75	45	RH-105M
76	45	RH-106	77	45	RH-106M	78	45	RH-107
79	45	RH-108	80	45	RH-108M	81	45	RH-110
82	45	RH-110M	83	46	PD-109	84	46	PD-109M
85	46	PD-111	86	46	PD-111M	87	47	AG-109M
88	47	AG-111	89	47	AG-111M	90	47	AG-112
91	49	IN-118	92	49	IN-118M	93	49	IN-120
94	49	IN-120M	95	50	SN-125	96	50	SN-125M
97	50	SN-127	98	50	SN-127M	99	50	SN-128
100	50	SN-132	101	51	SB-125	102	51	SB-127
103	51	SB-128	104	51	SB-128M	105	51	SB-129
106	51	SB-130	107	51	SB-130M	108	51	SB-131
109	51	SB-132	110	51	SB-132M	111	51	SB-133
112	51	SB-134	113	51	SB-134M	114	52	TE-125M
115	52	TE-127	116	52	TE-129	117	52	TE-129M
118	52	TE-131	119	52	TE-131M	120	52	TE-132
121	52	TE-133	122	52	TE-133M	123	52	TE-134
124	53	I-131	125	53	I-132	126	53	I-133
127	53	I-134	128	53	I-134M	129	53	I-135
130	53	I-136	131	53	I-136M	132	54	XE-131M
133	54	XE-133	134	54	XE-133M	135	54	XE-135
136	54	XE-135M	137	54	XE-137	138	54	XE-138
139	54	XE-139	140	55	CS-134	141	55	CS-134M
142	55	CS-136	143	55	CS-137	144	55	CS-138
145	55	CS-138M	146	55	CS-139	147	55	CS-140
148	56	BA-137M	149	56	BA-139	150	56	BA-140
151	56	BA-141	152	56	BA-142	153	57	LA-140
154	57	LA-141	155	57	LA-142	156	58	CE-141
157	58	CE-143	158	58	CE-144	159	58	CE-145
160	58	CE-146	161	59	PR-143	162	59	PR-144
163	59	PR-144M	164	59	PR-145	165	59	PR-146
166	59	PR-147	167	59	PR-148	168	59	PR-149
169	60	ND-147	170	60	ND-149	171	60	ND-151
172	61	PM-147	173	61	PM-148	174	61	PM-148M
175	61	PM-149	176	61	PM-151	177	61	PM-152
178	61	PM-152M	179	61	PM-153	180	62	SM-153
181	63	EU-156	182	75	RE-187	183	90	TH-232
184	91	PA-233	185	92	U-233	186	92	U-234
187	92	U-235	188	92	U-236	189	92	U-238
190	93	NP-237	191	94	PU-238	192	94	PU-239
193	94	PU-240	194	94	PU-241	195	94	PU-242
196	95	AM-241	197	95	AM-243	198	96	CM-244

in the first of these categories represent cases for which, although there exist extensive decay data, the lack of only one (or a few) key piece(s) of information makes a determination of their $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values impossible. [The most common example of this is the existence of precise γ-ray energy and relative-intensity data but the lack of absolute intensities (i.e., branching ratios).] Nuclides in the second category are those for which essentially no relevant decay data presently exist. These latter nuclides are generally those with short half-lives ($T_{1/2}$ < a few minutes) whose study using conventional radiochemical techniques is difficult.

In addition to the 180 fission-product nuclides, the file contains data on 18 nonfission products. These 18 nuclides are, with the exception of ^{3}H and ^{187}Re, isotopes of the actinide elements. Decay data on these nuclides were prepared at the request of personnel of the National Neutron Cross Section Center at BNL. These data will be included in the Version-IV General-Purpose File of ENDF/B.

III. COMMENTS ON THE CONTENT OF THE DECAY-DATA FILE

To assist in the use of the data contained in the file, some remarks detailing the considerations involved in their preparation are appropriate. (It may be helpful in the following discussion to refer to the sample data set given in Table II.)

The "Comment Cards" contain references to the sources from which the data are taken. In many instances, these cards also give pertinent information about specific features of the data and/or the manner in which they were treated in preparing them for inclusion in the file. In some cases, fairly recent evaluations of data from a number of different experiments exist. In many of these cases we have incorporated the results of these evaluations. For some nuclides, the cryptic reference "French File" is given. This indicates that the associated data have been taken from the March, 1973 version of the fission-product decay-data library of Blachot and de Tourreil[5,6]. For those cases where evaluated data sets were not used, we have adopted a policy for this version of ENDF/B of selecting for each nuclide only a single "best" reference for each data type rather than of averaging the results of many studies (where they exist).

The majority of the half-life values has been taken from the compilation by Holden[7]. These values are generally the same as those listed on the Eleventh Edition of the Chart of the Nuclides. Their uncertainties are not given on the Chart; but they have been supplied to us by Holden[7]. The recent evaluation by Rudstam _et al_.[8] of half-lives of short-lived fission-product nuclides has also been used as a source of half-life information. In several cases, the results of quite recent measurements, not contained in these two compilations[7,8] have appeared and have been included in the file.

The decay energies, or Q-values, for the various decay modes are generally taken from the "1973" revision[9] of the Wapstra-Gove mass tables. As yet unpublished, this compilation represents an updating of the 1971 mass table previously published by these authors[10]. In some cases data more recent than those included in this compilation are available; these have generally been incorporated in the file. Where the β-decay Q-values are not known, the theoretical values given by Garvey et al.[11] have been used. No Q-values are given for the spontaneous-fission decay mode. In decays in which the ground-state and an isomeric state of a daughter nucleus are both populated, the Q-value given for the latter process is simply the difference of the Q-value for the ground-state decay and the energy of the isomeric state.

It should be pointed out that all intensity values are given in percent (of decays) and that all energy values are given in keV.

The $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values are intensity weighted, that is,

$$\langle E_\beta \rangle = \frac{1}{100} \; F_\beta \sum_i E_{\beta i} \, I_{\beta i} \, f_i \, (E_\beta) \qquad (1a)$$

and

$$\langle E_\gamma \rangle = \frac{1}{100} \; F_\gamma \sum_i E_{\gamma i} \, I_{\gamma i} \quad . \qquad (1b)$$

The summations in eqs. (1) are over all the individual transitions (of energy E_i and intensity I_i). The factors F_β and F_γ are the factors which convert the listed relative intensities to absolute values (see Table I). The factor $f_i(E_\beta)$ is defined as the ratio of the average β energy released by the i^{th} β group to the transition (i.e., endpoint) energy, $E_{\beta i}$. This factor takes into account the fact that a major portion of the energy released in the β-decay process is carried by neutrinos. We have calculated these f_i values from the expression[12]

$$f_i(E_\beta) = \frac{1}{4}\left\{\frac{10 + 8x + 2x^2}{10 + 5x + x^2}\right\}, \qquad (2)$$

where $x(\equiv E_{\beta_i}/511.)$ is the β-ray endpoint energy (in m_oc^2 units). (This relation represents a re-casting of a similar one derived[13] from an equation[14] for the density of β particles per unit energy which accounts approximately for the nuclear charge.) The values for $f_i(E_\beta)$ given by the expression in eq. (2) agree to within a few (2-3) percent with those given by the exact formula for allowed and first-forbidden transitions in the range of nuclides and energies of interest here. For first-forbidden, unique transitions, f values obtained from values given in ref. (15) have been used. These latter cases are few in number and are indicated in the "Comment Cards". (See, e.g., Table II.)

It should be recognized that, in decay-scheme studies, β-ray energies and intensities are frequently not measured directly. Rather, they are generally deduced from the γ-ray energies and transition intensities together with the Q_β-value. Where the β-ray spectrum is studied directly, the usual results consist of an end-point energy and an intensity for one, or at most a few, of the more intense components. This should be borne in mind in assessing the β-ray energy and intensity values in this (or any) collection of such information.

For a few of the nuclides whose data were taken from the "French File", there are inconsistencies between the energies and intensities of the β-ray transitions and those of the γ rays. These cases occur when the γ-ray energies and (relative) intensities are known but when there is no information on the β-ray transitions. In these cases, the β-energy and intensities values given in the French File (and hence in this one) represent arbitrary choices, chosen so that the resultant $\langle E_\beta \rangle$ value would correspond to a desired fraction of the Q_β value. Since $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ are constrained by the requirement that

$$\langle E_\beta \rangle + \langle E_\nu \rangle + \langle E_\gamma \rangle = Q_\beta \quad ,$$

where $\langle E_\nu \rangle$ is the average neutrino energy, the $\langle E_\gamma \rangle$ values (and hence the <u>absolute</u> γ-ray intensities) for these cases are also uncertain.

The manner of listing the γ-ray intensity data, namely in the form of relative-intensity values together with a normalization factor to convert to absolute intensities, was chosen for several reasons. The relative intensities are generally the quantities that are directly measured experimentally, and the estimation of their uncertainties is a reasonably straightforward and well-defined (at least in principle) procedure. The absolute intensities, however, are usually derived from other data (e.g., a measurement of the branching ratios of one or more prominent γ rays) and have associated uncertainties which are independent of, and frequently quite different from, those of the relative intensities. Hence, with the adopted system, it is possible to formally separate these two sources of uncertainty and to treat them independently. Another advantage of this method is related to updating the data. Generally the relative intensities are less subject to change than are the absolute intensities. As improved measurements of absolute gamma-ray branching ratios become available, the resultant changes in absolute intensity values can be incorporated simply by changing the normalization factor instead of revising the entire listing of intensity values.

The inclusion of the total internal-conversion coefficients in the file makes possible the splitting up of the decay energy of a γ-ray transition into a photon and a conversion-electron component. This may be useful in some applications (such as, e.g., shielding and dosimetry).

The listing of the internal-conversion data in this version of the file is by no means complete, and will be expanded in future versions. In this connection, it is essential to distinguish between photon intensities and transition intensities, the former referring to γ-ray emission while the latter includes the internal-conversion electrons emitted in the transition process.† The intensity values given for the γ rays are generally photon intensities. For those nuclides taken from the French File, however, the intensity values given for isomeric transitions (in which a significant fraction of the transition strength is carried by the internal-conversion electrons) are frequently transition intensities. Since we have adopted the policy of using the transition-intensity values in the calculation of $\langle E_\gamma \rangle$ (thereby including in this quantity both the γ-ray and conversion-electron contributions), this aspect of the French File data creates no problems. However, one should avoid using these intensity data in applications where only the photon intensities are needed. In a few cases, the listed γ-ray intensities are so small and the associated internal-conversion coefficients so large, compared with the other entries, that they are obviously anomalous. These correspond to transitions which take place largely, or entirely, by internal conversion and for which the photon intensity and internal-conversion coefficients are unknown. The values listed for these two quantities were chosen such that their product, $I_\gamma(1+\alpha)$, gives the observed transition intensity. With the data treated in this manner, the energy and transition intensity (mostly conversion electron) are correctly given, and the photon intensity is sufficiently small that it has no influence in any photon-related applications.

†If the photon intensity is denoted by I_γ, then the associated transition intensity is given by the relation $I_T = I_\gamma(1+\alpha)$, where α is the total internal-conversion coefficient of the transition.

In a number of cases, decay of a given nuclide leads to the population of one (or more) isomeric state(s) in the daughter nucleus. Generally, the energy released in the decay of the isomeric state is characterized by a half-life different from that of the parent nucleus and the relative intensity of the radiation emitted in the two decays is time dependent. Consequently, in the listing of energy and intensity values, we have not included those for radiation associated with the decay of any daughter-nuclide isomeric states which may be formed. Those data are included in the file entry corresponding to the isomeric state. For example, in the decay of ^{125}Sb (see Table II) an isomeric state at 144.7 keV in ^{125}Te is fed in 23% of the decays. This isomeric state ($T_{1/2}$ = 58 days) decays via two γ-ray transitions. The data on these two transitions are given in the entry for ^{125m}Te and not for ^{125}Sb.

The uncertainties in the tabulated quantities form an important part of any compilation of experimental data; and provision was made for including them for each quantity in this file. In the present version, the uncertainties, where given, have been taken directly from the indicated references. It should be recognized that these uncertainties are of uneven quality. Those for the Q-values which are taken from the Wapstra-Gove mass tables, for example, are derived in a consistent and well documented[9,10] manner and their meaning is clear. At the other extreme, those for the γ-ray intensities constitute a quite different situation. While the uncertainties given for these quantities by some authors can indeed be treated as being standard deviations for purposes of error propagation, in many cases the uncertainties are, at best, qualitative. (For example, one frequently encounters phrases such as

'The errors in the γ-ray intensities are estimated to be X% for the strong γ rays and Y% for the weak ones'.) In such cases, the uncertainties certainly do not represent standard deviations in the statistical sense; and their use as such is probably not justified. However, they are useful in providing some indication of the general quality of the data and for this reason we have included them.

IV. POSSIBLE MODIFICATIONS FOR FUTURE VERSIONS OF THE DECAY-DATA FILE

As a result of our experience thus far with the decay-data file and in anticipation of additional uses for these decay data, we have identified a number of areas where modifications for future versions of the file can lead to increased utility. Among these, we include the following items.

A different way of giving average energy values associated with the various decay modes seems called for. Because of the emphasis of the decay-heat problem, the $\langle E_{\beta^-} \rangle$ and $\langle E_\gamma \rangle$ values were singled out for special attention. However, with the inclusion of additional nuclides for which decay modes other than β^- exist, it will be desirable to include the average energy values for these other decay modes on an equal footing with that for β^- decay. Also, the problems of how the annihilation radiation (two γ rays of energy 511 keV) associated with β^+ decay and the x-rays associated with electron-capture decay are to be treated in a consistent and complete manner need to be addressed.

The treatment of internal conversion should be extended to include the various atomic electron subshells. One means of accomplishing this might involve listing the multipolarity for each gamma ray. From this, the internal-conversion coefficients for all the relevant subshells could be generated theoretically and the split of the associated energy into an x-ray (i.e., photon) and a conversion-electron component could be carried out theoretically, using separate computer programs. These multipolarities need not be incorporated into the ENDF/B data file (unless desired). It might prove to be more feasible to incorporate them in our file only and to include in ENDF/B only the relevant results obtained from the theoretical calculations based on them.

A necessary modification, and one which is currently being carried out, is the replacement of the approximate relationship, eq. (2), for $f_i(E_\beta)$ by an exact expression [see, e.g., ref. (16)] to permit more accurate calculation of $\langle E_\beta \rangle$ values. An additional modification which might be useful is the inclusion of a means of indicating the multipolarity of the individual β^- and β^+ transitions. This would enable the average energy of such transitions to be calculated using the theoretical spectrum shape for the particular transition type (e.g., first-forbidden unique). Again, this chracterization would not necessarily have to be included in ENDF/B; it might be included only in our file, with only the relevant quantities derived from it appearing in ENDF/B.

Provision needs to be made for incorporating the average number of neutrons emitted in the spontaneous-fission decay of nuclides. In addition, the treatment of particle (e.g., proton, neutron or fission-fragment) emission from excited states of nuclei needs to be expanded. A concise yet complete treatment of this problem may become quite complex, since such particle emission is generally preceded by other radiations, which excite a variety of these states.

The number of nuclides for which experimental data are included on the file is expected to increase both as more data become available and as decay-data needs in other areas are defined.

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