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# RADIOACTIVE-NUCLIDE DECAY DATA IN SCIENCE AND TECHNOLOGY[†]

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The scope of ENDF/B has recently been expanded to include radioactive-nuclide decay data. In this paper, the content and organization of the decay data which are included in ENDF/B are presented and discussed. The application of decay data in a wide variety of nuclear-related activities is illustrated by a number of examples. Two items pointed up by the ENDF/B decay-data compilation effort are treated: the identification of deficiencies in the data; and the importance of a radioactive-nuclide metrology effort oriented toward supplying these needs in a systematic fashion.

(ENDF/B-IV decay-data file; applications of decay data)

## Introduction

Historically, the study of the radiation emitted in the decay of radioactive nuclei has been a highly productive source of important information in many basic scientific disciplines as well as in many areas of applied technology. In basic nuclear physics, for example, 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 impact in other areas, radioactive-nuclide decay data are directly relevant to and of vital importance in a wider range of disciplines and areas of applied technology than is perhaps any other category of nuclear data.

Major advances in the study and application of the decay of radioactive nuclides have been made in the past 5-10 years as the result of a number of developments. In the area of data acquisition and analysis, the impact of the Ge(Li) γ-ray detector has been especially significant. With its excellent energy-resolution characteristics, it has provided great improvements in the quality of γ-ray spectral data over that which was previously available from NaI(Tl) scintillation spectrometers. The potential of these solid-state devices as radiation detectors has been enhanced as a result of developments which have taken place in the associated low-noise electronic circuitry and multichannel pulse-height analyzers as well as in the use of computer-based systems for data acquisition and analysis.[1] Another facet of the effort related to these detectors is the large amount of work which has been directed toward making them capable of intensity and energy measurements of high precision. At present, for example, γ-ray intensity measurements with a precision of ~ 1-2% have been reported for some cases, and γ-ray energy values suitable for use as energy-calibration standards have been measured with precisions of a few tens of eV at ~ 1 MeV.

Improvements in the capabilities of particle accelerators have also had a significant impact on the field of radioactive-nuclide decay studies. The increasing energies and intensities of the particle beams which can be obtained from these machines, together with the increasingly wide range of nuclei (e.g., heavy ions) which are being used as projectiles, provide an ever expanding number of radioactive nuclides which can be produced for detailed study. The continuing development of techniques for fast radiochemical separations and the increasing use of isotope separators to produce samples of high chemical and isotopic purity have materially increased the wealth of detail which can be extracted from the experiments. The development which represents perhaps the most significant tool for future work in this field is the use of isotope separators "on-line" at accelerators and nuclear reactors. This combination makes feasible the extension of the conventional techniques for studying decay schemes to nuclides whose half-lives are as short as 1 sec or so. This capability constitutes a significant extension of the "off-line" studies, which were effectively limited to the half-life range ≳ 1 h. The importance of this technique in basic nuclear-physics studies has been discussed at a number of international conferences.[2-4] Of particular relevance to the subject matter of this conference is the fact that, through the use of "on-line" isotope separation, a varied and ever increasing body of decay data on the short-lived fission products is being generated.

The use of radioactivity is continuing to increase in a number of areas such as, e.g., nuclear medicine, industrial applications and all aspects of the nuclear industry. This has necessitated development of techniques for isotopic analysis and a more detailed characterization of the radiation emitted by radioactive nuclides. There presently exists a large and varied "community" of radioactive-nuclide users, with a number of different requirements for nuclear decay data. This has created a need for re-examining the status of decay data in the light of the needs of these users. Involved in this re-examination are not only the quality of the data and how they are to be used but also improved access to these data and the necessity for having them available in a form useful for special needs.

## Nuclear Data Derived from Radioactive-Decay Studies

The category of "Nuclear-Decay Data" is a broad one and is perhaps most simply discussed by reference to a specific case. As an example, in Fig. 1 we show the decay scheme of $^{144}$Ce, as given in Ref. 5.

Two types of properties are present in this decay scheme. The first are those associated with the energy levels and include the following: atomic number (Z); mass number (A); mass; half-life; energy (for excited states); total angular momentum (spin); parity; and one or more static electromagnetic moments (and, for excited states, a number of transition moments, too). The second are those associated with the radiations which represent transitions between the individual levels and include the following: the radiation type (e.g., β, γ); energy; intensity; and total angular momentum and parity (multipolarity). It is generally the properties of the radiations rather than those of the levels that are of interest in the applications of decay data, the level-related data being of interest primarily in nuclear

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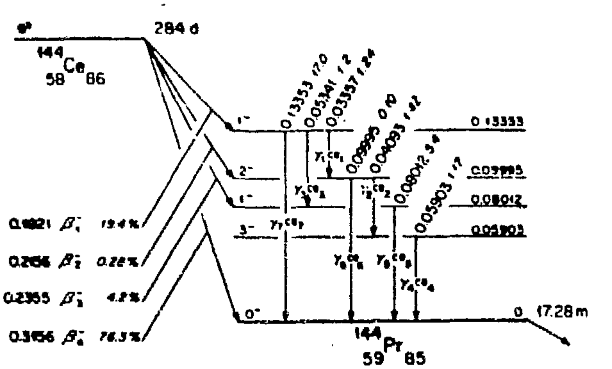


Fig. 1. Decay scheme of $^{144}$Ce.

structure research. However, it should be emphasized that the level properties, where known, should be available to the compiler of a file of decay data for specialized applications. Such information may be necessary for the determination of radiation properties which have not been directly measured or for the estimation of errors.

The half-life is a level property of great importance, since it determines the fractional number of atoms of a given isotope which decay per unit time. As such, a knowledge of its value is required in any quantitative measurement of the radiations emitted by a radioisotope to determine the number of atoms present in a given sample. It is also needed in making decay corrections to data acquired at different times from a radioactive sample. The atomic masses of the parent and daughter ground states are of interest in some applications of decay data (e.g., decay heat) by virtue of the fact that the energy equivalent of their difference is the total energy available (Q value) for the decay process ($\beta^-$ in Fig. 1).

The radiations emitted as the radioactive nucleus decays exhibit an energy and intensity pattern which is unique to, and characteristic of, that nucleus. For $\beta^-$ (and $\beta^+$) decay, the individual transitions possess a continuous distribution of energies, ranging from zero up to a maximum value (the "endpoint" energy) which is the total energy available to that transition. This fact, and the experimental difficulties associated with $\beta$-ray spectroscopy, make the $\beta$ radiation of little use as a tool for nuclide identification. However, a knowledge of the $\beta$ energy distribution is important in a number of applications, e.g., decay heat and absorbed-dose estimates in biomedical studies. In $\alpha$ decay, on the other hand, the spectrum of emitted particles consists of discrete lines and is a useful tool in nuclide identification. One application of such information lies in the area of nuclear fuel safeguards, where the identification and quantitative assay of actinide isotopes associated with the nuclear fuel cycle is recognized as a critical problem.

The daughter nucleus formed in the decay of the radioactive parent is generally left in one of a number of excited states. These states generally decay via $\gamma$-ray emission (or the competing process of internal-conversion electron emission) to lower-lying states of the same nucleus. As is the case for the radiations emitted directly in the decay of a radioactive nucleus, the spectrum (i.e., energies and relative intensities) of $\gamma$ radiation is uniquely characteristic of a given nuclide. This fact, and the relative ease with which $\gamma$-ray spectra can be measured using modern techniques, make the knowledge of the $\gamma$-ray spectrum one of the most powerful tools presently available for radioactive-nuclide identification. Of major importance in the applications of radioactivity are the branching ratios (the number of $\gamma$ rays emitted per 100 decays) of the various $\gamma$ rays. These data, together with the nuclide half-life, are essential quantities in all applications where the quantitative assay of radioactivity is required. Since both qualitative and quantitative radionuclide assay utilizing $\gamma$-ray spectroscopy are widely employed in many applications involving radioactivity, $\gamma$-ray data constitute a particularly important category of decay data.

The spectrum of internal-conversion electrons associated with a particular $\gamma$-ray transition is rather complicated and more difficult to determine experimentally than is the $\gamma$-ray spectrum. However, if the multipolarity of the $\gamma$-ray transition is known, this spectrum can be calculated with good accuracy in almost all cases using the theoretical internal-conversion coefficients.[6] Following the ejection of a conversion electron, x radiation and a rather complicated spectrum of low-energy secondary (Auger) electrons are emitted. A knowledge of these quantities is important in such applications as internal radiation-dose estimation, where not only the total released energy but also the form in which it appears is required. Where the contributions of these processes to the complete energy characterization are not measured (and this represents the majority of such cases), they can be calculated theoretically with sufficient realism to be adequate for most applications.

Under certain conditions, particle emission can take place from excited states of the daughter nucleus. A particularly important special case of such "delayed-particle" emission is delayed-neutron emission. As a result of the development of improved neutron counters[7] and the availability of isotope-separated samples for "on-line" study, delayed-neutron energy spectra, measured with good resolution, of a number of fission-product nuclides have recently begun to appear in the literature.[8]

In Table I, we list some of the quantities more commonly measured in radioactive-decay studies and indicate their relevance in several broad areas of application.

## Nuclear Data for Summation Calculations of Decay Heat

The summation calculation of the fission-product decay-heat source term represents one important application of decay data. Because of its relevance to the subsequent discussion, we now present a brief description of this calculational procedure. More complete discussions are given in, e.g., Refs. 9-11 as well as in the following papers.[12,13] The summation approach to the decay-heat calculation involves first predicting the fission-product inventory of a reactor core at a given time. This involves an assumption of a power operating history for the reactor as well as a knowledge of the direct fission yields, capture cross sections and half-lives of the individual fission products and nuclides produced by neutron capture. From this inventory, the energy release per fission as a function of time can be calculated for all times following shutdown by summing the contributions of the individual nuclides. To do this requires, for each isotopic species present, values of the half-life, the average $\beta$ energy per decay, $\langle E_\beta \rangle$ and the average $\gamma$ energy emitted per decay, $\langle E_\gamma \rangle$.

TABLE I

Several categories of decay data and areas of their application

| Measured Quantity | End Use<br>Decay Heat | <br>Nuclide Identification | <br>Quantitative Nuclide Assay | <br>Biomedical and Tracer | <br>Basic Nuclear Physics |
|---|---|---|---|---|---|
| Half-life | X | X | X | X | X |
| γ-ray energy | X | X | X | X | X |
| γ-ray relative intensity | | X | X | X | X |
| γ-ray branching ratio | X | | X | X | |
| x-ray intensity | X | | | X | |
| electron energy | X | | | X | X |
| electron relative intensity | | | | X | X |
| electron absolute intensity | X | | | | |
| β-ray energy | X | | | X | X |
| β-ray relative intensity | | | | X | X |
| β-ray branching ratio | X | | | | |
| α-particle energy | X | X | X | X | X |
| α-particle relative intensity | | X | | X | X |
| α-particle branching ratio | X | | X | X | |
| Q-value | X | | | | X |
| level energy | | | | | X |
| level spin and parity | | | | | X |

Nuclide-Decay Data for ENDF/B: An Example of a User-Oriented Special-Purpose Data File

In recognition of the pressing need for radioactive-nuclide decay data in a variety of reactor-related applications, a decision was made about two years ago to expand the scope of the Evaluated Nuclear Data File (ENDF/B) to include such information. The impetus for this was provided by the need for a reliable and common data base to be used in summation calculations of the decay-heat source term in power reactors. Our involvement in this expansion of ENDF/B has been twofold: (1) to establish the categories of decay data to be included in ENDF/B and to set up a framework within which they could be prepared; and (2) to evaluate the experimental data and prepare a file of such data for a number of nuclides. There were primarily fission products of priority interest for the decay-heat problem.

The Experimental Decay-Data File for ENDF/B

As seen above, a decay-data file adequate for the needs of the decay-heat problem could be set up with a quite modest data content (i.e., $T_{1/2}$, $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$) and a relatively simple format. However, in view of the importance of decay data for many reactor-related problems, it was felt that a file of decay data for ENDF/B should have sufficient content to adequately address the needs of several types of users. Thus it was decided at the outset to set up a data file of much broader scope than what would be required for the decay-heat problem alone. Since the content and format established for this file has been discussed in detail elsewhere[14], only a brief treatment of them is given here.

A sample case, the decay data for $^{144}$Ce is illustrated in Table II. It should be pointed out that, in ENDF/B, these data are given in File 1, MT=457 under the standard ENDF/B conventions (e.g., energies in eV, half-lives in sec, etc.). Consequently, their appearance there differs somewhat from that of Table II, where they are given in the "people-readable" card-image format in which we prepare them. A computer program[15] (FIPP) has been written to carry out the translation to the ENDF/B format.

As indicated in Table II, each data set is headed by the Z and A value of the parent. In the following column an integer "isomer flag" is given. A zero indicates that the nuclide is in its ground state, a 1 indicates that the data are for the decay of the first excited isomeric state, a 2 indicates the decay of the second excited isomeric state, etc. (Isomers are arbitrarily restricted to nuclear states with half-lives ≥ 0.1 sec.) Following this first card is a group of cards giving any desired comments, such as the references for the data and how they have been treated.

The rest of the set is composed of data cards. The first contains the half-life together with its uncertainty and units, the number of decay modes of this nuclide and the number of "energy spectra" to be listed. This is followed by one card for each decay mode giving the following information: the type of radiation emitted in the decay of the parent state (e.g., a 1 indicates $\beta^-$ emission); which final-nucleus isomeric state is fed (a 0 indicates population of the ground-state, a 1 indicates population of the first excited isomeric state, etc.); and the Q value and its uncertainty; and the branching ratio (in percent) for this decay mode and its uncertainty. With the feeding of the daughter-nucleus ground and isomeric states treated in this way, the series of daughter nuclides produced from a given parent isotope can be kept track of. Also, it should be noted that the decay data related to the daughter-nucleus isomeric state are not contained under the parent. They are given under a file entry for the isomeric state. In the present example, the 59-keV state in $^{144}$Pr (see Fig. 1) is isomeric ($T_{1/2}$ = 7.2 min). Consequently, the 59-keV

Table II. Decay data for $^{144}$Ce prepared in our laboratory-file format (prior to translation tc the ENDF/B format).

| Z A IS | | Number of Comment Cards |
|---|---|---|
| 581440 | CE | 8 |

Documentation and Comments

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PREPARED FOR FILE:   7/74                                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- M.J. MARTIN AND P.H. BLICHERT-TOFT, NUCLEAR
                    DATA TABLES A 8, NOS.1-2, (1970).
                    J.L. FASCHING, W.B. WALTERS AND C.D. CORYELL,
                    PHYS. REV. C 1, 1126 (1970).
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| Half-Life | Δ | Units | Number of Decay Modes | No. of Spectra |
|---|---|---|---|---|
| 284.4 | 0.2 | 0 | 2 | 2 |

| Decay Mode | Final State | Q | ΔQ | Branching |
|---|---|---|---|---|
| 1 | 0 | 315.5 | 1.5 | 98.8 |
| 1 | 1 | 256.3 | 1.5 | 1.2 |

| ⟨E-Beta⟩ | Δ | ⟨E-Gamma⟩ | Δ |
|---|---|---|---|
| 82.96 | | 28.07 | |

| Normalization | Δ | Number of Transitions | Radiation Type |
|---|---|---|---|
| 1.0 | | 4 | 1 |

| E | ΔE | I | ΔI |
|---|---|---|---|
| 182.1 | 1.5 | 19.4 | 0.7 |
| 215.6 | 1.5 | 0.28 | 0.1 |
| 235.5 | 1.5 | 4.2 | 0.3 |
| 315.6 | 1.5 | 76.3 | 0.7 |

| Normalization | Δ | Number of Transitions | Radiation Type |
|---|---|---|---|
| 1.0 | | 6 | 0 |

| E | ΔE | I | ΔI | ICC | ΔICC |
|---|---|---|---|---|---|
| 33.57 | 0.03 | 0.22 | 0.02 | 4.6 | 0.7 |
| 40.93 | 0.03 | 0.39 | 0.03 | 2.6 | 0.4 |
| 53.41 | 0.05 | 0.14 | 0.02 | 7.7 | 1.6 |
| 80.12 | 0.03 | 1.54 | 0.15 | 2.52 | 0.27 |
| 99.95 | 0.05 | 0.038 | 0.004 | 1.6 | 0.3 |
| 133.53 | 0.03 | 10.8 | 0.5 | 0.58 | 0.04 |

γ ray observed in the $^{144}$Ce γ-ray spectrum is listed not in the $^{144}$Ce data set but rather in the data set for $^{144m}$Pr (identified as 591441).

Following the decay-mode cards is a card giving the average energy per decay for the different radiation types. Entered, sequentially, are the average β energy $\langle E_\beta \rangle$, its uncertainty, $\langle E_\gamma \rangle$, its uncertainty, $\langle E_\alpha \rangle$ and its uncertainty.

Next in the data set come the listings of the various radiation spectra. In the example there are two such spectra: $\beta^-$, denoted by the radiation-type 1, and γ, denoted by the radiation type 0. For each spectrum listed, two card types are present. The first is a single card which gives: a normalization factor, which provides a conversion from relative intensities to absolute intensities for the listed intensity data; its uncertainty; the number of transition energies; and a number denoting the type of radiation. The spectral data follow, with one card for each transition. These latter cards give: transition energy (keV) and its uncertainty; and the (relative) intensity and its uncertainty. For γ radiation, the fifth and sixth fields include the total internal-conversion coefficient and its uncertainty. The separation of relative and absolute intensities in this manner is done for the following reason. For γ radiation, it is the relative values that are customarily obtained from spectral measurements. The conversion of these to absolute intensities (i.e., photons per 100 disintegrations) is usually made from considerations of the specific decay scheme involved or from a separate measurement, this involving its own uncertainty. It is thus possible to treat the two measurement errors separately; and, if the basis for the absolute-intensity data should subsequently change, this can be taken into account simply by a single change in the normalization. For example, in the $^{144}$Ce decay scheme shown in Fig. 1 the absolute γ-ray intensities are based upon a value of ∿ 76% for the ground-state β branch. Should this value eventually be found to be incorrect, these absolute intensities will have to be changed. The relative intensities, however, would remain unaffected.

In addition to $\beta^-$ decay given in the example shown in Table II, the file is set up to include the following decay modes: electron capture and/or $\beta^+$; isomeric transition; α particle; delayed neutron; and spontaneous fission.

Status of Decay Data on ENDF/B-IV. The status of the nuclide-decay data on ENDF/B-IV, as of March 1974, and the relation of the various aspects of the data-preparation process are illustrated in Fig. 2.

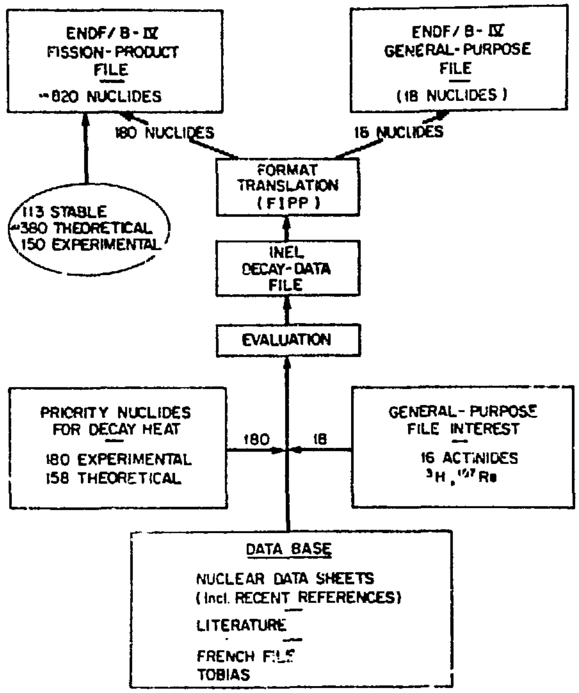


Fig. 2. Relation of the decay-data compilation effort to the present status of decay data on ENDF/B-IV.

The ENDF/B-IV Fission-Product File contains entries for ∿ 820 nuclides, in mass chains ranging from A=72 through A=167. These are believed to constitute a sufficient data base for decay-heat calculations for decay times ≳ 1 sec. Of these, 113 are stable ($T_{1/2}$ > $10^{10}$ y). Of the remaining ∿ 710, the present experimental data are sufficiently complete to permit $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values to be extracted for only ∿ 330 nuclides. For the remaining ∿ 380, most all of which are short-lived, the $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values (and in some cases the half-lives as well) must be inferred from theoretical considerations[12] in order that their contribution to the decay heat can be taken into account.

In the Version-IV Fission-Product File data sets similar to that shown in Table II above have been prepared for 180 nuclides.[12] These are the ones of primary importance in the decay-heat problem for which decay-data exist. This data-compilation effort was helped considerably by the availability of other compilations of Fission-Product decay data[16,17], particularly that of the French groups. The entries for the remaining ~ 150 experimentally studied fission products as well as for the ~ 380 "theoretical" cases (this number includes the 158 "priority" nuclides shown in Fig. 2) are restricted to only the quantities needed for the decay-heat calculations; their $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values are derived from theoretical considerations.[12]

Data on 18 additional isotopes, mainly actinides, were also prepared as illustrated in Table II. These are included in the Version-IV General-Purpose File of ENDF/B.

Future Work. At the present time, the format and data content of the file are being expanded to include spin and parity values for the nuclides and to allow a more detailed treatment of x-ray and discrete-electron energy spectra. Also included will be a more unified and consistent approach to the incorporation of delayed-particle emission, of which delayed-neutron energy spectra are an important component.

In addition, decay data are being prepared for the remaining ~ 150 "experimental" fission-product nuclides and for nuclides important in other applied areas. Examples of such areas include: fast-reactor dosimetry and reaction-rate determinations; decay heating from structural, control and fuel materials in fast-reactor systems; activation products important for determination of integral capture cross sections of fission-product nuclides; and environmental monitoring of effluents from nuclear-power facilities and determination of radioactivity source terms for safety analyses.

## Specialized Data Files

The data content of the file described above, while much larger than required for the decay-heat problem, is nonetheless much more restricted than those of such broadly based data compilations as the Table of Isotopes[18] or the Nuclear Data Sheets[19]. This file treats only a specialized subset of the broader category of "decay data", a subset oriented toward certain areas of application. It thus represents a specialized data compilation. It also possesses another characteristic important for such a compilation, namely the data it contains are reduced to and presented in a form convenient for their intended use.

The need for specialized compilations of nuclear data has long been recognized. Numerous examples of such compilations in nuclear physics are contained in the journal Nuclear Data Tables.[20] Compilations of $\gamma$ rays ordered by energy, nuclide and half-life are quite useful in applications involving $\gamma$-ray spectral analysis and isotopic identification; and a number of such tables exist.[21,22] In the fields of nuclear medicine and health physics, the decay-data requirements for internal-dose estimates have led to the so-called MIRD documents as well as other compilations[5,23] providing such information. As the uses of radioactivity expand and the volume of data accumulates, it appears that the need for specialized data compilations (such as the present one) will increase.

## Comments on the Current Status of Decay Data

In view of the effort which has been expended over the years in decay-scheme studies, it is natural to ask whether or not more such studies are in fact needed and whether the present base of decay data is adequate. This question cannot be considered meaningfully without a careful consideration of the uses for which the data are needed. We briefly treat two facets of the problem of the adequacy of the current base of decay data, namely the lack of certain information and the precision of already existing data.

### Lack of Data

One obvious example of a gap in the present decay data is provided by nuclides for which few if any decay data exist. The bulk of such cases are the neutron-rich and neutron-deficient nuclides far off the line of stability. This lack of data is quite evident in the ENDF/B-IV decay-data file. As noted above, data on over half of the fission-product nuclides in this data file were sufficiently lacking that theoretical estimates rather than experimental data had to be used for their $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values. And, in some cases, even the half-lives were not available. Generally these nuclides are the shorter-lived fission products, whose major contribution to the decay-heat source term occurs at short times.

In this connection, it appears that rather specialized basic nuclear-physics measurements may have a direct application to this problem and provide $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values for some of these nuclei. Measurements of the $\beta$-strength functions of $\gtrsim$ 90 fission-product nuclides with half-lives in the range from ~ 1 to ~ 200 sec have been carried out at the OSIRIS facility in Sweden[24,25]. These measurements provide information about the average $\beta$ feeding per unit energy in the decay of these nuclides and hence provide a means of extracting $E_\beta$ values. From the relation

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

where $\langle E_\nu \rangle$ is the average (anti)neutrino energy per decay and is closely related to $\langle E_\beta \rangle$ it should be possible to obtain realistic values for $\langle E_\gamma \rangle$. Although somewhat over half of the nuclides investigated in these studies are already included in our data file, 43 of them represent cases for which only theoretical estimates of the $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ values are presently available. Although these $\beta$-strength-function studies provide no detailed information about the discrete components of either the $\beta$- or the $\gamma$-ray spectrum and hence may not be relevant to many applications, they do appear to provide data specifically required by the decay-heat problem. This situation is also an illustration of the frequent need for compilers of files to consider data outside the specific file content in order to obtain values for certain of the file data.

Less obvious, but no less important, are cases where an otherwise large body of data on a given nuclide cannot be used because of a lack of certain information. A frequently occurring example of such data is provided by the $\gamma$ -ray branching ratios. In the preparation of decay data for inclusion in the ENDF/B file, it was necessary to exclude data on roughly ten nuclides for which extensive spectral data were reported and for which rather detailed decay schemes had been proposed. This was done because no $\gamma$-ray branching ratio data were measured and hence no values for $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ could be obtained.

The Question of Precision. In the use of decay data in specific areas, an important consideration is the precision of the data required in a given application. This question cannot be treated in general but must be evaluated for each specific case. Since nuclide half-life and $\gamma$-ray branching ratio data are required in all applications involving quantitative assay of radioactivity using γ-ray spectroscopy, these two types of decay data warrant special attention. The range of reactor-related problems in which such assay is used is quite large, including, e.g., dosimetry, nondestructive assay, activation-analysis techniques for integral cross-section determinations[26], effluent monitoring, nuclear fuel safeguards and radioactive waste management.

The precision of the present half-life data appears adequate for most applications related to quantitative radionuclide assay. However, in the area of nuclear fuel safeguards and accountability, assay for actinide elements is frequently carried out using calorimetric measurements or absolute α counting. The interpretation of these data to provide nuclide assay with the necessary precision requires highly accurate half-life values (~ 0.1%) in some cases. These requirements may in some instances lie beyond the capabilities of the present data. A specific instance of a lack of adequate precision in γ-ray branching-ratio data is given in a paper contributed to this conference.[27] In the determination of absolute reaction rates in "standard" neutron spectra with high precision (the ILRR program), absolute γ-ray counting of activation products in various irradiated foils was carried out. There it was found[27] that, while absolute γ-ray branching-ratio data existed for all the reaction products of interest, in a few cases the data did not possess the required precision of ±2½%.

The reasons why the absolute γ-ray branching ratio data are of such uneven quality are not difficult to understand. To make such measurements with high precision is generally a difficult and time-consuming task, requiring special instrumentation and techniques. Furthermore, a knowledge of these values frequently contributes very little to the basic-physics information which is obtained from the study of a decay scheme. As a result, few basic-physics investigations attempt to measure these quantities, a situation which is sometimes abetted by a lack of realization by the experimenter of the real value of such data to the applied user. Because of this unfortunate situation, it appears most appropriate to mount an effort to measure such data in a systematic fashion. This could be done as one aspect of a broadly scoped program of radioactive-nuclide metrology.

## Conclusion

The field of radioactive-nuclide data is one with particular relevance for both basic nuclear physics and for other research as well. At present, it is characterized by a large and steadily increasing base of data. Effective use of this data base is being made by individuals and groups active in nuclear physics and related activities such as radiochemistry, who by and large are also its producers. However, improvements in its utilization by workers in other basic and applied scientific disciplines need to be made. Because of the expansion of the scope of ENDF/B to include decay data, it appears that this evaluated subset of these data will become available to an important group of users. The wide acceptance and use of ENDF/B as a source of nuclear data by the nuclear-power industry and its associated reactor research and development activities makes ENDF/B the logical mechanism for providing a commonly available base of evaluated decay data. The data content presented above was chosen with the eventuality in mind that all segments of the nuclear program, including the regulatory (e.g., effluent monitoring and reporting) and fuel-safeguards functions, as well as the CTR programs, would have access to a common base of evaluated, relevant decay data. Because of the international role of ENDF/B, this addition to its scope has had impact in international nuclear-data activities as well. It is most encouraging to observe the increasing international awareness of the importance of decay data, as evidenced by the results of the recent IAEA Fission Product Nuclear Data Panel Meeting[28], and to note the generally favorable reception of the ENDF/B decay-data content and format internationally.

In order to make more effective utilization of decay data in other areas, attention must be given to increasing the interaction between the users, producers and compilers of such data. It should be pointed out that a similar problem existed within the field of neutron cross-section data; and to solve it a fairly close, formal relation was set up between these three segments of the data effort. We can envision a similar pattern operating effectively within other areas of "nuclear data" as well. An example of one possible mechanism for accomplishing this is shown in Fig. 3.

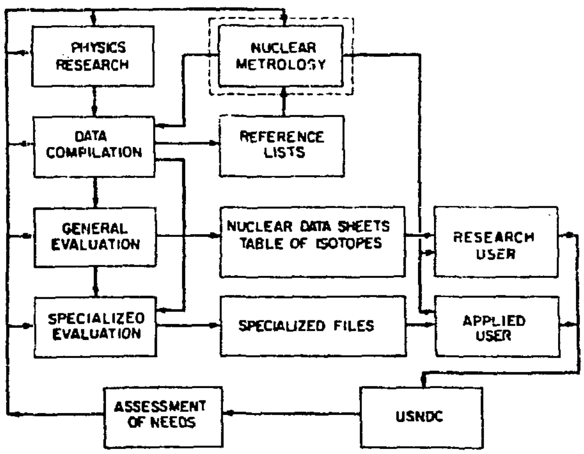


Fig. 3. One possible mechanism for coordinating the functions of measurement, compilation and application in the area of radioactive-nuclide decay data.

An especially important feature of such an interaction is the identification of "needs" and deficiencies in the data base. This identification will lead to improvements in this base and, in some instances, may lead to the production of specialized data evaluations intended for use in particular applied areas. The file of decay data set up for ENDF/B represents one example of such a specialized evaluation. Coordination of this effort is also important; and the U.S. Nuclear Data Committee, with the expanded scope of its interests, seems particularly suited for such a function. This would also provide a natural mechanism for establishing and maintaining communication between the U.S. efforts and international efforts in this field. One result of the Bologna meeting[28] was an articulation of the awareness of the importance of decay data, as one aspect of the broad category of "nuclear data", and of the need for international cooperation in this area.

An important component in the decay-data activities outlined in Fig. 3 is the radioactive-nuclide metrology function. The orientation of this function would be the development of experimental techniques for the measurement with high precision of basic radioactive-decay parameters such as, e.g., γ-ray branching ratios. As such, it would most effectively be carried out within the context of basic nuclear-measurement laboratories. One of its emphases would be the generation of specific high-precision decay data in support of the nuclear-data effort.

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