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The Evaluated Nuclear Structure Data File

ENSDF

Its Philosophy, Content and Uses

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The Evaluated Nuclear Structure Data File (ENSDF) Its Philosophy, Content, and Uses*

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Abstract

The Evaluated Nuclear Structure Data File (ENSDF) is maintained by the National Nuclear Data Center (NNDC) on behalf of international Nuclear Structure and Decay Data Network sponsored by the International Atomic Energy Agency, Vienna. For $A \geq 44$ the file is used to produce the *Nuclear Data Sheets*. Data for $A = 5$ to 44 are extracted from the evaluations published in *Nuclear Physics*. The contents of ENSDF relevant to the ICRM are briefly described as is the philosophy and methodology of ENSDF evaluations. Also discussed are the services available at various nuclear data centers and the on-line services of the NNDC. Application codes developed for use with ENSDF are described with the program RADLST used as an example. The interaction of ENSDF evaluations with other evaluations is also discussed.

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1. Introduction

The Evaluated Nuclear Structure Data File (ENSDF)[1] is maintained by the National Nuclear Data Center (NNDC) on behalf of the international Nuclear Structure and Decay Data Network sponsored by the International Atomic Energy Agency, Vienna. The file contains nuclear structure and decay data for all known nuclides. For $A \geq 45$, ENSDF is used directly to produce *Nuclear Data Sheets*. Data for $5 \leq A \leq 44$ are extracted from references [2] to [7] appearing in *Nuclear Physics*. Data for $A = 1 - 4$ were provided by E.N. Shurshikov, *et al.*; future updates for $A = 3$ and 4 will be obtained from the evaluations appearing in *Nuclear Physics*[8].

2. Organization and Contents of ENSDF[1]

Briefly, ENSDF consists of "data sets" arranged by mass. For each mass there is a brief data set containing the abstract and other bibliographic information, a references data set containing all references cited in the evaluation,[2] and the data organized by isotope (^{A}Z).

For each ^{A}Z there is an adopted data set containing the recommended values for properties of the levels and gammas observed in that ^{A}Z and "experimental" data sets containing the "best" values obtained from the various types of experiments (*e.g.* β^- decay, α decay, thermal neutron capture, Coulomb excitation, particle reactions, *etc.*).[3] Of particular interest to this meeting are the $\approx$ 2800 decay data sets and the ground and metastable state half-lifes and branching ratios and the gamma-ray energies, branching ratios, multipolarities and mixing ratios, and conversion coefficients contained in the adopted data set.

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[1] A=4[9], A=11 and 12[2], and A=20-44[7] are currently under revision. See Table 1 for a summary of the revisions for $A \geq 45$. The current status of all mass chains is summarized in each issue of *Nuclear Data Sheets* and is available in some of the online systems; see section 4. on page 4.

[2] This data set is generated by the NNDC from the file submitted by the evaluators and the Nuclear Structure References file (NSR).

[3] For $A \leq 44$, usually only the adopted data set and decay data sets are included.

The decay data sets usually contain records giving the following information:

(a) Parent level energy, J^π, and $T_{1/2}$ and the Q-value for ground-state to ground-state decay.

(b) Branching ratio for the decay mode and normalization factors for converting the relative emission probablities for γ's and β's or ϵ's to absolute emission probablities. Intensities for α's are given as absolute emission probabilities for the decay mode.

(c) γ and $E0$ transition energies, intensities, characters (multipolarity and mixing ratio) of the transition, and the total and partial internal conversion coefficients.[4]

(d) β transition energies,[5] intensity,[6] $\log ft$'s, and average β energies. For $\epsilon + \beta^+$ decay, the intensities for positron emission and electron capture and the electron capture fractions are given.[7]

(e) α transition energies, intensities, and hindrance factors.

(f) Level energies,[8] J^π's,[9] and $T_{1/2}$'s.[10]

Radiation energies are in the laboratory system while level energies are in the center of mass. Data for other radiations such as the delayed *neutrons* observed in $\beta^- n$ decay include the energy, *intensity* (normalized as for α's), energy of the intermediate level, angular momentum transfer, and width (Γ) of the transition.

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[4]Conversion coefficients are usually calculated from theory using the energy and character from the adopted data set.

[5]If measured and on the same order of precision as the value deduced from the Q-value and level energy.

[6]Usually calculated from intensity balancing for the level.

[7]Usually calculated from $I_{\epsilon+\beta^+}$ and the theoretical ϵ/β^+ ratios given in reference [10].

[8]Usually obtained from a least-squares fit to the γ energies.

[9]Usually from the adopted data set.

[10]If measured as part of the experiment or relevant for applications.

Data for the annihilation radiation, X rays, and Auger and conversion electrons are not contained in the file but are calculated by the application programs using the properties listed above.[11] Details on other types of data sets and information included in ENSDF may be found in references [1] and [11].

3. Philosophy of ENSDF Evaluation

The philosophy of evaluation for ENSDF and *Nuclear Data Sheets* is to present the best data available from each type of experiment and the best information available for each isotope in a concise and well-documented manner. The procedures followed in the evaluations are detailed in reference [11]. The emphasis in ENSDF is on the nuclear structure and decay properties obtained from the experimental evidence or well-founded systematics and theory. This emphasis and conservative approach results in an excellent general purpose file useful for either the basic or applied scientist. However, for any specific application additional work may be required. For example, a reactor decay heat calculation may require the use of β-strength functions or measured $\overline{E_\beta}$ and $\overline{E_\gamma}$ to better estimate the decay heat from nuclei where the discrete data incomplete.

The propagation of uncertainties in an ENSDF evaluation is difficult due to the large amount of data, the correlations between quantities, and the lack of information provided by the authors.[12] The problems are further compounded by the need for the correct propagation of large standard uncertainties (standard propagation based on a first-order Taylor expansion may not be valid), asymmetric uncertainties, limits, and ranges. As these problems are addressed, new procedures are being developed, existing codes upgraded, and new codes developed. We have not

[11]See section 5. on page 5.

[12]For some quantities such as lifetimes the approach may be relatively straight forward and many evaluators follow a procedure similar to that outlined by Christmas, *et al.*[12]. The major difference may be in the interpretation of the weighted or unweighted mean of two or three measurements using the same method and no separation of random and systematic uncertainties.

reached the sophistication of the evaluations in the Evaluated Nuclear Data File (ENDF)[13, 14] and thus do not have variance-covariance matrices in ENSDF.

4. Services and On-line Retrieval Systems

Centers providing a wide range of services are listed in Table 2. Other centers such as the Isotopes Project, Lawrence Berkeley[15], or the Nuclear Data Project, Oak Ridge, supply a more limited range of services or gateways to the centers listed in Table 2. Each center typically maintains several data bases from which data are extracted to satisfy requests from the community; the results of these retrievals may be provided in the form of listings, plots, on magnetic media such as tapes or diskettes, or by electronic mail. The services are similar to, but more extensive than, the on-line services described below.

In the past few years the use of on-line retrieval systems has increased dramatically (retrievals from the NNDC system averaged 135 per month in 1986 and 728, in 1988). The system[13] developed at the NNDC[16] allows users to access several data bases including NSR (Nuclear Structure References), ENSDF, and NUDAT (Nuclear Data; selected data derived from ENSDF and other sources) with the results either displayed on a terminal or saved as computer files for later transmission to the users' computers.[14]

The most basic of the data bases listed above is the bibliographic data base, NSR.[15] NSR indexes publications in low and intermediate energy nuclear physics from 1910 to present and is complete for references from 1969. Each entry in this file, which is updated weekly, contains bibliographic information (Author, title, reference, *etc.*), a keyword abstract briefly describing what was measured or deduced in the paper, subjects, and selectors. Retrievals from this file may be made on the basis of subject (*e.g.* β decay), nuclide, reaction, target, or author. Publication

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[13]This system has also been provided to the NEA Data Bank.

[14]There are also three data bases available for nuclear reaction data: CINDA, CSISRS, and CINDA.

[15]NSR is used directly to produce the Recent References issues of *Nuclear Data Sheets.*

date, type of reference, and entry date into the file may also be specified. There is also the capability of constructing boolean operations to obtain more complex retrieval criteria.

Retrievals from ENSDF may be by mass, atomic number, isotope, or dataset identification;[16] one may also query the status of any mass. The data may be retrieved as an ENSDF file, in tabular form, or in the form of simple level schemes which may be plotted on POSTSCRIPT- or TEKTRONIX 4014-compatible devices.

NUDAT consists of a subset of information derived from ENSDF: adopted level and gamma properties and radiations observed in decay (including X rays, annihilation radiation, and Auger and conversion electrons) and their doses, an updated set of the information contained in *Nuclear Wallet Cards*[17], and thermal neutron cross sections and resonance integrals[18, 19]. Retrieval criteria depend to some extent on the type of information desired. For radiations from decay one may specify mass or atomic number, $T_{1/2}$, energy, and absolute intensity (either a single value, ranges, or limits) and type of radiation. Output is in a fixed tabular format. NUDAT is implemented in DATATRIEVE[17] and a user familiar with DATATRIEVE may design his own retrieval criteria.

5. Application Codes

Several systems have been designed for using data from ENSDF for applications.[18] One such system is the program RADLST[20] which will be briefly described as an example. RADLST and other similar programs are very useful in providing the information required for nuclear medicine, reactor decay heat calculations, and geophysics.

RADLST uses, as primary input, decay data sets in the ENSDF format and, as secondary inputs, atomic data such as electron binding energies and fluorescence yields and atomic masses.

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[16]Under development is an extension of this system which will allow additional retrieval criteria.

[17]A database management system of Digital Equipment Corporation

[18]See reference [20] for a summary of some of these systems.

From these data various outputs are generated containing the energies, intensities, and dose rates for the nuclear radiations: $\beta^{\pm}$'s, γ's, conversion electrons, electron-positron pairs from internal pair formation, and α's. For electron capture and internal conversion, the energies, intensities, and dose rates of the associated atomic radiations (X rays and Auger electrons) are also calculated and presented. As an option, the $\beta^{\pm}$ spectra and the internal bremsstrahlung spectra associated with $\beta^{\pm}$'s and electron capture may be calculated.

Output from the program includes a summary report file indicating problems encountered and assumptions made, a listing (sample given in Table 3) of the radiations and their energies, intensities, and doses, a file which is used to produce part of the NUDAT data base described on page 5, and a file in the ENDF-6 format[21]. This format was chosen since it is one of the most widely used for applied nuclear data and has an extensive set of software installed for its use.

6. Interaction with Horizontal Evaluations

The results of horizontal[19] evaluations are judiciously incorporated by the evaluators into ENSDF as the masses are revised.[20] This saves the ENSDF evaluator time, avoids the proliferation of slightly different values for the same quantity, and may provide useful expertise. I presume that the people involved in horizontal evaluations also make use of ENSDF or the related publications, at least as a starting point.

An unresolved problem in ENSDF is how to factor results from new horizontal evaluations into mass chains not under revision. This problem arises from the possibility of introducing inconsistencies within ENSDF. For example, a change in a Q-value or $T_{1/2}$ would effect the $\log ft$'s

[19]A horizontal evaluation is considered to be one which evaluates a given property or set of properties over a range of masses (*e.g.* the atomic masses of Wapstra *et al.*[22]).

[20]As an example, in the recent evaluation of $A = 57$[23] eight horizontal evaluations or reviews were used in evaluating the decay properties of ^{57}Co, properties relevant to Mossbauer spectroscopy, and the adopted properties of ^{57}Fe.

which may then affect the adopted spins and parities. A change in a gamma calibration energy or intensity would affect numerous other values.

7. Future Plans

The most immediate plan in the next few years is to include a complete set of information for $3 \leq A \leq 20$ in ENSDF. Longer term plans include:

(a) include a complete set of information for $21 \leq A \leq 44$ in ENSDF,

(b) continued improvements in the on-line retrieval systems including extended retrieval capabilities and better plots and tables, and

(c) databases or new output formats designed for specific applications.

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Masses	Center
50 58[a] 62[a] 63 66 69[a] 137[a] 139[b] 142[a] 146[a] 147[a] 148[a] 152[a]	National Nuclear Data Center. Brookhaven National Laboratory. Upton, NY 11973, U.S.A.
52[a] 53 195[b] 196 198[a]	Institute of Atomic Energy. P.O. Box 275 (41), Beijing, People's Republic of China
64 100[a]	Tandem Accelerator Laboratory. McMaster University, Hamilton, Ontario L8S 4K1, Canada
75[a] 77[a] 78 80	Nuclear Data Project. Kuwait Institute for Scientific Research, P.O. Box 24885, Kuwait, Kuwait
85[a] 87 89[a] 91	Fachinformationszentrum Energie, Physik, Mathematik GmbH. Kernforschungszentrum, D-7514 Eggenstein-Leopoldshafen 2, Federal Republic of Germany
90	Institute of Physics. University of Lund, Sölvegatan 14, S-223 62 Lund, Sweden
102 112[a]	Laboratorium voor Kernfysica. Proeftuinstraat 86, B-9000 Gent, Belgium
104 107 108 111 113[a] 114[a] 116[a]	Centre d'Etudes Nucleaires. DRF-CPN, Cedex No. 85, F-38041 Grenoble Cedex, France
119 121 177	Nuclear Data Center. Tokai Research Establishment, JAERI, Tokai-Mura, Naka-Gun, Ibaraki-Ken 319-11, Japan
130[a] 131 132	Data Center. Leningrad Nuclear Physics Inst., Gatchina, Leningrad Region 188350, U.S.S.R.
153[a] 160 161[a] 162 206	Idaho National Engineering Laboratory. E.G. and G. Idaho, Inc., P.O. Box 1625, Idaho Falls, ID 83415, U.S.A.
164 240[a] 242[a]	Center for Nuclear Structure and Reaction Data of the U.S.S.R. State Committee on the Utilization of Atomic Energy U.S.S.R., 46 Ulitsa Kurchatova, Moscow, D-182, U.S.S.R.
167[a] 175 184[a] 185[a] 187 188[a] 189[a] 193	Isotopes Project. Lawrence Berkeley Laboratory, Berkeley, CA 94720, U.S.A.
209 211 215 217 219 211 223 227 229[a] 233[a] 236 246 $\xrightarrow{even}$ 266[b] 247 249 $\xrightarrow{odd}$ 263[a]	Nuclear Data Project. Oak Ridge National Laboratory, Oak Ridge, TN 37831, U.S.A.

[a]Submitted for publication.

[b]Accepted for publication.

Table 1: Mass Chains for $A \geq 45$ Currently Under Revision (April 30, 1989)

Center	Service Area
Banque de Donnes de l'AEN, NEA Data Bank B.P. 9, F-91190 Gif-sur-Yvette, France	OECD countries except for USA and Canada
Fachinformationszentrum Energie, Physik, Mathematik GmbH Kernforschungszentrum, D-7514 Eggenstein-Leopoldshafen 2, Federal Republic of Germany	Federal Republic of Germany
IAEA Nuclear Data Section P.O. Box 100, A-1400 Vienna, Austria	Other countries not listed in this table
National Nuclear Data Center Brookhaven National Laboratory, Upton, NY, 11973, USA	USA and Canada

Table 2: ENSDF Distribution Centers

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57CO EC DECAY (271.80 D 5)        I(MIN)=0.0010%
        SEE 70RA51 FOR SUMMARY OF CONVERSION-ELECTRON
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Radiation Type	Energy (keV)		Intensity (%)		(G-Rad uCi-h)
AUGER-L	0.6700		251.1	20	0.0036
AUGER-K	5.620		106.5	16	0.0127
CE- K - 2	114.9494	10	1.84	15	0.0045
CE- L - 2	121.2153	5	0.193	20	0.0005
CE-MNO- 2	121.9685	10	0.032	5	0
CE- K - 3	129.3623	11	1.26	15	0.0035
X-RAY L	0.7000		0.783	6	0
X-RAY KA2	6.39084	3	16.8	5	0.0023
X-RAY KA1	6.40384	3	33.1	9	0.0045
X-RAY KB	7.060		6.68	21	0.0010
G 1	14.41300	15	9.68	25	0.0030
G 2	122.0614	3	85.9	12	0.223
G 3	136.4743	5	10.33	10	0.0300
G 5	339.69	21	0.0025	4	0
G 6	352.33	21	0.001932		0
G 8	570.09	20	0.0137	9	0.0002
G 9	692.41	7	0.162	5	0.0024
G 10	706.54	22	0.0048	6	0

Table 3: Sample Listing from the Program RADLST