**An Integrated System for Production
of Neutronics and Photonics Computational Constants**

Volume 15, Part C

**THE LLL EVALUATED NUCLEAR DATA LIBRARY (ENDL):
TRANSLATION OF ENDL NEUTRON-INDUCED
INTERACTION DATA INTO THE ENDF/B FORMAT**

MASTER

R. J. Howerton

April 1, 1976

Prepared for U.S. Energy Research & Development
Administration under contract No. W-7405-Eng-48

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research & Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."

Printed in the United States of America
Available from

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road

Springfield, Virginia 22151

Price: Printed Copy \$ __*, Microfiche \$2.25

<u>*Pages</u>	<u>NTIS Selling Price</u>
1-50	\$4.00
51-150	\$5.45
151-325	\$7.60
326-500	\$10.60
501-1000	\$13.60

LAWRENCE LIVERMORE LABORATORY
University of California Livermore California 94550

UCRL-50400 Volume 15 Part C

**THE LLL EVALUATED NUCLEAR DATA LIBRARY (ENDL):
TRANSLATION OF ENDL NEUTRON-INDUCED
INTERACTION DATA INTO THE ENDF/B FORMAT**

R. J. Howerton

MS. date: April 1, 1976

Foreword

The UCRL-50400 series describes an integrated and computer-oriented system for the production and application of neutronics and photonics calculational constants.

The system must supply reliable up-to-date data, select specific types of data on request, provide output in a variety of forms -- ultimately in the form of input to other computer codes -- and function rapidly and efficiently. The system has now been developed to a point where these goals are being realized.

The UCRL-50400 series, *An Integrated System for the Production of Neutronics and Photonics Calculational Constants*, comprises the following volumes:

- Vol. 1, *Photon Cross-Section, Calculational and Input Data for Neutronics*, March 1974.
- Vol. 2, *Bibliography of the Experimental Data of Neutron-Induced Interactions*, March 1974.
- Vol. 3, *An Index of the Experimental Data of Neutron-Induced Interactions*, March 1974.
- Vol. 4, *Evaluated Nuclear Cross-Section Library*, April 1971.
- Vol. 5, *SLIDE: A Nuclear Data-Processing Computer Program for Producing Calculational*

Constants, September 1975.

- Vol. 6, *Photon Cross-Section Data for 122 Vol.*, October 1975.
- Vol. 7, *Experimental Data for Major Neutron-Induced Interactions*, April 1974.
- Vol. 8, *Experimental Data for Supplemental Neutron-Induced Interactions*, October 1974.
- Vol. 9, *Decay Data of Nuclear Reactions Induced by Neutrons, Photons, Protons, Deutons, and Alpha Particles*, September 1970.
- Vol. 10, *Tabulated Experimental Data for Neutron-Induced Interactions*, May 1974.
- Vol. 11, *Experimental Data, Indices and Techniques of Obtaining a Selected Set of Neutron Resonance Parameters*, May 1972.
- Vol. 12, *An Atlas of Resolved Neutron Resonance Parameters* July 1972.
- Vol. 13, *An Atlas of Unresolved Neutron Resonance Parameters*, September 1972.
- Vol. 14, *WARTON: A Coupled Neutron-Photon Monte Carlo Transport Code*, September 1975.
- Vol. 15, *The ILL Evaluated*

*Nuclear Data Library (ENDL):
Evaluation Techniques, Re-
action Index, and Descriptions
of Individual Evaluations,
September 1975.*

- *Vol. 16, Tabular and Graphical
Presentation of 175 Neutron
Group Constants Derived from
the LLNL Evaluated Neutron Data
Library (ENDL), April 1976.*

THE LLL EVALUATED NUCLEAR DATA LIBRARY (ENDL): TRANSLATION OF ENDL NEUTRON-INDUCED INTERACTION DATA INTO THE ENDF/B FORMAT

Abstract

The LLL evaluated nuclear data library (ENDL) has been translated into the evaluated neutron data file/version B (ENDF/B) format. This translation is for the convenience of those who wish to use ENDL data but

who are more familiar with ENDF/B formats and procedures. Only that portion of ENDL dealing with neutron-induced interactions (including photon production from neutron-induced reactions) has been translated.

Introduction

ENDL has existed in one form or another since 1958. During that time, we have frequently changed the form, format, and content of the library in response to changing laboratory needs. The changes have been easy to make because we have had access to newer and more powerful computational facilities and because we supply the data needs of only one laboratory - LLL. Descriptions of the current ENDL system, the associated formats,¹ and the processing code² are available in the UCRL-56400 series of reports.

During the past eighteen years, requests for the ENDL data have come from other ERDA laboratories, DoD laboratories, U.S. Government agencies and contractors, and universities. To comply with both the letter and

the spirit of the law, the ENDL data have been made readily available, but often in a form that is unfamiliar to the requestor (and therefore inconvenient to use). While the ENDF/B system^{3,4} does not provide for some of the data representations used in ENDL, it is a relatively stable system, has been well publicized, is generally well-known, and will accommodate almost all of the data forms for neutron-induced reactions, including photon production, used in ENDL. However, the ENDF/B system allows for some data representations that are not currently used in the ENDL system.

To accommodate outside requestors we have translated the ENDL library into the ENDF/B format. Previous

versions of the translated library were available in 1973 and 1975.^{5,6} The version of April 1, 1976 (ENDL 76) is now available from:

- The Radiation Shielding Information Center (RSIC), Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, Tennessee 37830.
- The National Neutron Cross

Section Center, Brookhaven National Laboratory, Upton, New York 11973.

- The Nuclear Data Section of the International Atomic Energy Agency, P. O. Box 590, A-1011, Vienna, Austria.
- Centre de Compilation de Données Neutronique B.P. 9, 91190, Gif-sur-Yvette, France.

Responsibility of the Physical Data Group

The primary responsibility of the LLL Physical Data Group is to supply the best available calculational constants for the Laboratory's needs. To this end, the group maintains

- A library of experimental neutron-induced reaction data⁷⁻¹⁵ (ECSIL).
- A processing code² that manipulates the ENDL data into

the forms required for the laboratory's various neutronics, photonics, and linked neutronics-photonics codes.

- Advanced Monte-Carlo neutronics, photonics, and linked neutronics-photonics computer programs¹⁶
- A file of evaluated integral neutron experiments for data-testing purposes.

ENDL Evaluations

Historically, the original ENDL data were all produced at LLL and were, in that sense, a private collection. However, during the past 5 years excellent evaluations that were done elsewhere have become available, especially for the light isotopes and for neutron energies less

than about 1 keV. Many of these data have been incorporated into ENDL, usually with some modifications, especially for neutron energies greater than about 5 MeV. The bulk of the ENDL data have been produced at LLL, but whenever a new evaluation from another source has become

Table 1. Magnetic tapes that contain the LLL ENDL-76 data translated into the ENDF/B format.

ZA	Material	MAT Number	ZA	Material	MAT Number
Tape Number 1 (15421 card image records)			Tape Number 3 (27221 card image records)		
1001	Neutron	7100	22000	Nat_Ti	7128
1001	Hydrogen	7101	23051	51_V	7129
1002	Deuteron	7102 ^a	24000	Nat_Cr	7130
1003	Triton	7103	25055	55_Mn	7131
2003	³ He	7104	26000	Nat_Fe	7132
2004	⁴ He	7105	27059	59_Co	7135
3006	⁶ Li	7106	28000	Nat_Ni	7136
3007	⁷ Li	7107	28058	58_Ni	7137
4007	⁷ Be	7108	29000	Nat_Cu	7138
4009	⁹ Be	7109	31000	Nat_Ga	7140
5010	¹⁰ B	7110	40000	Nat_Zr	7141
5011	¹¹ B	7111	Tape Number 4 (20588 card image records)		
6012	¹² C	7112			
7014	¹⁴ N	7113			
8016	¹⁶ O	7114	41093	93_Nb	7143
9019	¹⁹ F	7115	42000	Nat_Mo	7144
Tape Number 2 (15181 card image records)			47107	107_Ag	7145
11023	²³ Na	7116	47109	109_Ag	7146
12000	Nat_Mg	7117	48000	Nat_Cd	7147
13027	²⁷ Al	7119	50000	Nat_Sn	7150
14000	Nat_Si	7120	56138	Nat_Ba	7151
15031	³¹ P	7121	63000	Nat_Eu	7152
16032	³² S	7122	64000	Nat_Gd	7153
17000	Nat_Cl	7123	67165	165_Ho	7154
18000	Nat_Ar	7124			
19000	Nat_K	7125			
20000	Nat_Ca	7126			

^aThe energy-angle distribution of secondary neutrons from the n,2n reaction for D is represented by an energy-angle Legendre expansion in the ENDL system. No equivalent representation exists in the ENDF/B system. Consequently, the representation in the translated form is deficient.

Table 1. (Continued)

ZA	Material	MAT Number	ZA	Material	MAT Number
Tape Number 5 (19942 card image records)			Tape Number 8 (20563 card image records)		
73181	181 _{Ta}	7155	94242	242 _{Pu}	7180
74000	185 _{Nat_w}	7156	94243	243 _{Pu}	7181
75185	187 _{Re}	7158	95241	241 _{Am}	7182
75187	187 _{Re}	7159	95242	242 _{mAm}	7183
78000	197 _{Nat_{Pt}}	7160	95243	243 _{Am}	7184
79197	197 _{Au}	7161	96242	242 _{Cm}	7185
82000	238 _{Nat_{Pb}}	7162	96243	243 _{Cm}	7186
Table Number 6 (23605 card image records)			Tape Number 9 (18585 card image records)		
90231	231 _{Th}	7163	96244	244 _{Cm}	7187
90232	232 _{Th}	7164	96245	245 _{Cm}	7188
90233	233 _{Th}	7165	96246	246 _{Cm}	7189
92233	233 _U	7166	96247	247 _{Cm}	7190
92234	234 _U	7167	96248	248 _{Cm}	7191
72235	235 _U	7168	97249	249 _{Bk}	7192
72236	236 _U	7169	Tape Number 10 (12108 card image records)		
92237	237 _U	7170	98249	249 _{Cf}	7193
92238	238 _U	7171	98250	250 _{Cf}	7194
Tape Number 7 (16336 card image records)			98251	251 _{Cf}	7195
92239	239 _U	7172	98252	252 _{Cf}	7196
92240	240 _U	7173	99120	Crude fission product	7197
93237	237 _{Np}	7174			
94238	238 _{Pu}	7175			
94239	239 _{Pu}	7176			
95240	240 _{Pu}	7177			
94241	241 _{Pu}	7178			

available, it has been inspected, tested (if possible), and, if judged superior to existing ENDL data, adopted in part or in full. Current plans are to continue to adopt as much useful information as possible from evaluations made outside the Laboratory.

Table 1 lists ten magnetic tapes that contain the ENDL 76 data in the ENDF/B format. The table lists 88

materials for which complete evaluations are provided.* A pseudo-material labeled "Crude fission product" is included. This pseudo-material is complete in form, but it represents only a zero-order approximation to an average fission-product. The crude fission product material is not to be taken too seriously, but for some applications it has proved to be a convenient construct.

Translation Procedures from ENDL to ENDF/B

A computer code (LIDE) was written for the CDC 7600 to translate ENDL to the ENDF/B form. As mentioned above, there are some quantities and some representations in ENDL for which there are no equivalents in the ENDF/B system. As a result of this, local and total energy deposits were not translated, and the Legendre representations of energy-angle distributions, $\pi_L(E \rightarrow E')$, were truncated at the $L = 0$ term. The Legendre truncation affects only the secondary-neutron distribution from the $(n,2n)$ reaction of the deuteron.

We ran the translated evaluations through the CHECKER code.¹⁹ Other than the exceptions noted below, all materials complied with the standards of the code. The evaluations of ^{56}Ni , ^{93}Nb and ^{232}Th consisted of more than 4000 data points for the total cross section, as well as more than 5000 points for either the elastic or (n, γ) cross sections. In the case of ^{241}Am , two (n, γ) cross sections were evaluated: one for capture to the ground state of ^{242}Am and the other to the meta-stable state of that isotope.

*Many of the evaluations contained in ENDL have not been documented in any formal way. This has been a recognized deficiency in the library but this lack of documentation is currently being remedied.^{17,18}

[†]Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

References

1. R. J. Howerton, R. J. Doyas, T. C. Minnie's, and S. T. Perkins, *Evaluated Nuclear Cross Section Library*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 4 (1971).
2. R. J. Doyas, R. E. Dye, R. J. Howerton, and S. T. Perkins, *CLYDE, A Code for the Production of Calculational Constants from Nuclear Data*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 5, Rev. 1 (1975).
3. M. K. Drake, *Data Formats and Procedures for the ENDF Neutron Cross Section Library*, Brookhaven National Laboratory, Upton, New York, Rept. ENDF-102, Vol. 1 (1970). (Also referred to as BNL-50274.)
4. D. J. Dudziak, *ENDF Formats and Procedures for Photon Production and Interaction Data*, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, Rept. ENDF-102, Vol. 2 Rev. (1971). (Also referred to as LA-4549.) References 3 and 4 have been modified in content by actions of the Cross Section Evaluation Working Group (CSEWG) since they were written. Documentation of modifications are available from Dr. S. Pearlstein, National Neutron Cross Section Center, Brookhaven National Laboratory, Upton, New York 11973.
5. R. J. Howerton, *The Lawrence Livermore Laboratory Evaluated Nuclear Data Library (ENDL) Translated into the ENDF/B Format*, Lawrence Livermore Laboratory, Rept. UCID-16376 (1973).
6. R. J. Howerton, *The Lawrence Livermore Laboratory Evaluated Nuclear Data Library (ENDL) Translated into the ENDF/B Format*, Lawrence Livermore Laboratory, Rept. UCID-16727 (1975).
7. D. E. Cullen, K. L. Hill, R. J. Howerton, and S. T. Perkins, *ECSIL, A System for Storage, Retrieval, and Display of Experimental Neutron Data*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 1, Rev. 2 (1974).
8. S. T. Perkins, D. E. Cullen, R. C. Haight, R. J. Howerton, and M. H. MacGregor, *A Bibliography of the Experimental Data of Neutron-Induced Reactions*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 2, Rev. 1 (1974).
9. S. T. Perkins, D. E. Cullen, R. C. Haight, R. J. Howerton, and M. H. MacGregor, *An Index of the Experimental Data of Neutron-Induced Reactions*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 3, Rev. 1 (1974).

10. S. T. Perkins, and R. J. Howerton, *Tabulated Experimental Data for Neutron-Induced Reactions*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 10 (1971).
11. M. Gyulassy, R. J. Howerton, and S. T. Perkins, *Experimental Data, Indexes and Techniques of Obtaining a Selected Set of Neutron Resonance Parameters*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 11 (1972).
12. S. T. Perkins and M. Gyulassy, *An Atlas of Resolved Neutron Resonance Parameters*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 12 (1972).
13. M. Gyulassy and S. T. Perkins, *An Atlas of Unresolved Neutron Resonance Parameters*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 13 (1972).
14. D. E. Cullen, R. C. Haight, R. J. Howerton, M. H. MacGregor, and S. T. Perkins, *Graphical Experimental Data for Major Neutron-Induced Reactions*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 7, Parts A and B (1974).
15. D. E. Cullen, R. C. Haight, R. J. Howerton, M. H. MacGregor and S. T. Perkins, *Graphical Experimental Data for Supplemental Neutron-Induced Reactions*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 8 (1974).
16. E. F. Plechaty and J. R. Kimlinger, *TAPWAP: A Coupled Neutron-Photon Monte Carlo Code*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 14 (1975).
17. R. J. Howerton, D. E. Cullen, R. C. Haight, M. H. MacGregor, S. T. Perkins, and E. F. Plechaty, *The LLL Evaluated Nuclear Data Library (ENDL): Evaluation Techniques, Reaction Index, and Descriptions of Individual Evaluations*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 15, Part A (1975). (Part B in preparation).
18. E. F. Plechaty, D. E. Cullen, R. J. Howerton, and J. R. Kimlinger, *Tabular and Graphical Presentation of 175 Neutron Group Constants Derived from the LLL Evaluated Neutron Data Library (ENDL)*, Lawrence Livermore Laboratory, Rept. UCRL-50400, Vol. 16 (1976).
19. O. Ozer, *Description of the ENDF/B Processing Codes and Retrieval Subroutines*, Brookhaven National Laboratory, Rept. BNL-50300 (1971).