INTRODUCTION

The National Nuclear Data Center (NNDC) provides coordination for and serves as the secretariat to the Cross Section Evaluation Working Group (CSWEG). CSEWG is responsible for the oversight of the ENDF/B Evaluated Nuclear Data File. All data are checked and reviewed by CSEWG, and the file is maintained at the NNDC. For a description of the ENDF/B-VI file, see the ENDF-102 Data Formats and Procedures for the Evaluated Nuclear Data File ENDF-6 [1]

The purpose of this addendum to the ENDF/B-VI Summary Documentation[2] is to provide documentation of Releases 1, 2, 3, and 4 for the ENDF/B-VI and ENDF/HE-VI evaluated nuclear data libraries. These releases contain many new and revised evaluations for the neutron, photo-atomic interaction, radioactive decay data, spontaneous fission product yield, neutron-induced fission product yield, thermal neutron scattering, proton, deuteron, and triton sublibraries.

The summaries have been extracted mainly from the ENDF/B-VI File 1 comments (MT=451), which have been checked, edited, and may also include supplementary information. Some summaries have been provided by the evaluators in electronic format, while others are extracted from reports on the evaluations. All references have been checked[3] and corrected, or updated where appropriate.

A list of the laboratories which have contributed evaluations used in ENDF/B-VI is given on the following page.

Appendix A contains a history of all materials issued in ENDF/B-VI. Appendix B contains a listing of the present content of the ENDF/B-VI library.

Release 1	distributed in September, 1991
Release 2	distributed in June, 1993
Release 3	distributed in May, 1995
Release 4	distributed December, 1996

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[1] CSEWG, *ENDF-102 Formats and Procedures for the Evaluated Nuclear Data File ENDF-6*, **BNL-NCS-44945** (1995), edited by V. McLane, C. L. Dunford, and P. F. Rose, National Nuclear Data Center, Brookhaven National Laboratory.

[2] *ENDF-201, ENDF/B-VI Summary Documentation*, **BNL-NCS-17541** (1991), Edited by P. F. Rose, National Nuclear Data Center, Brookhaven National Laboratory.

[3] If possible, *e.g.*, private communications could not be checked and some references were not available.

List of Laboratories

Following is the list of laboratories who have contributed to the evaluations cited in this document.

AI Atomics International (now Rockwell Int., Energy Systems) Canoga Park, CA
ANC Aerojet Nuclear Corp. (see INEL)
ANL Argonne National Laboratory, Argonne, IL
AWRE Atomic Weapons Research Laboratory, Aldermaston, U.K.
BAPL Bettis Atomic Power Laboratory, Pittsburg, PA
BAW Babcock and Wilcox, Lynchburg, VA
BNL Brookhaven National Laboratory, Upton, NY
BNW Batelle Northwest (now Pacific Northwest National Laboratories) Richland, WA
BRC Centre d'Etudes Nucleaires, Bruyere-le-Chatel, FRANCE
CNDC Chinese Nuclear Data Center, Institute of Atomic Energy, Beijing, CHINA
GA General Atomic (see GGA)
GGA Gulf General Atomic, San Diego, CA
HEDL Hanford Engineering Development Laboratory, Richland, WA
INEL Idaho Nuclear Engineering Laboratory, Idaho Falls, ID
JAERI Japan Atomic Energy Research Institute, Tokai, JAPAN
JNDC Japanese Nuclear Data Committee, JAPAN
KAPL Knolls Atomic Power Laboratory, Schenectady, NY
LANL Los Alamos National Laboratory, Los Alamos, NM
LLNL Lawrence Livermore National Laboratory, Livermore, CA
MAPI Mitsubishi Atomic Power Industries, Minato, JAPAN
ORNL Oak Ridge National Laboratory, Oak Ridge, TN
PTB Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY
RCN Energy Research Foundation, Petten, THE NETHERLANDS
SAI Scientific Applications Inc., La Jolla, CA
SRL Savannah River Laboratory, Aiken, GA
UI University of Illinois, Urbana-Champaign, IL

Part I

Incident Neutron Sublibrary (NSUB=10)

The documentation is organized by material. Each page contains a header giving the material and release number(s).

Evaluation: **^{1}H Incident Neutron Library, Release 1 (MAT 125)**
Energy Range: 10^{-5} eV to 100 MeV
Files (MF): 1, 2, 3, 4, 12, 14
Evaluators: G. M. Hale, D. C. Dodder, E. R. Siciliano, W. B. Wilson (LANL)

ENDF/B-VI MOD 2 REVISION 1 (G. Hale, LANL, July 1991)
The following comments on the standards covariances were added.

STANDARDS COVARIANCES

Phase 1 reviewers of the ENDF/B-VI standards cross sections have expressed the concern that the uncertainties resulting from the combination of R-matrix and simultaneous evaluations might have led to uncertainties that are too small. As a result, the Standards Subcommittee produced (at the May, 1990, CSEWG meeting) a set of expanded covariance estimates for the standard cross section reactions. These uncertainties are estimates such that if a modern day experiment were performed on a given standard cross section using the best techniques, approximately 2/3 of the results should fall within these expanded uncertainties. The expanded uncertainties for the n+^{1}H total cross section are, for the energy range 0.01 eV to 20 MeV, 0.2%.

ENDF/B-VI MOD 1 NEW EVALUATION (G. Hale, D. Dodder, E. Siciliano, W. Wilson, LANL, October 1989)

See ENDF-201 Summary Documentation, 4th Edition (1991), page 7, for documentation of the ENDF/B-VI MOD 1 evaluation.

Evaluation: **^{2}H Incident Neutron Library, Release 3, 4 (MAT 128)**
Files (MF): 1, 2, 3, 4, 6, 8, 9, 12, 14
Energy Range: 10^{-5} eV to 100 MeV
Evaluators: P. G. Young, L. Stewart,, A. Horsley(LANL)

ENDF/B-VI MOD 3, REVISION 2 (P.G. Young, LANL, November 1996)
A missing subsection was added to File 6, MT=16.

ENDF/B-VI MOD 2, REVISION 1 (P.G. Young, LANL, August 1994)
This evaluation is a revision of the ENDF/B-V evaluation by Stewart and Horsley [1]. The evaluation was extended to 100 MeV based on experimental total, elastic, and (n,2n) cross section measurements and elastic scattering angular distribution measurements. Additionally, the total cross section and the elastic cross section were revised between 3 and 8 MeV on the basis of newer data, and similarly the (n,2n) cross section was revised above 10 MeV.

REFERENCE

1. L. Stewart, A. Horsley, **LA-3271** (1968) Los Alamos National Laboratory

ENDF/B-VI MOD 0 (R. MacFarlane, LANL, December 1989)
ENDF/B-V MAT 1302 was converted to ENDF-6 format. For documentation of the ENDF/B-V evaluation, see ENDF-201 Summary Documentation, 4th Edition (1991), page 13.

Evaluation: **^{3}He Incident Neutron Library, Release 1 (MAT 225)**
Energy Range: 10^{-5} eV to 20 MeV
Files (MF): 1, 2, 3, 4
Evaluators: G. Hale, D. Dodder, P. Young (LANL)

ENDF/B-VI MOD 2 REVISION 1 (G. Hale, LANL, July 1991)
The following comments on the standards covariances were added.

STANDARDS COVARIANCES
Phase 1 reviewers of the ENDF/B-VI standards cross sections have expressed the concern that the uncertainties resulting from the combination of R-matrix and simultaneous evaluations might have led to uncertainties that are too small. As a result, the Standards Subcommittee produced (at the May, 1990, CSEWG meeting) a set of expanded covariance estimates for the standard cross section reactions. These uncertainties are estimates such that if a modern day experiment were performed on a given standard cross section using the best techniques, approximately 2/3 of the results should fall within these expanded uncertainties. The expanded uncertainties for the ^{3}He(n,p) cross section are as follows:

Energy Range (keV)	Estimated Uncertainty %
10^{-08} - 0.1	0.3
0.1 - 1.0	0.7
1.0 - 10.	2.0
10. - 50.	5.0

ENDF/B-VI MOD 1 NEW EVALUATION (G. Hale, D. Dodder, P. Young, LANL, May 1990)
See ENDF-201 Summary Documentation, 4th Edition (1991), page 15, for documentation of the ENDF/B-VI evaluation.

Evaluation: **^{6}Li Incident Neutron Library, Release 1 (MAT 325)**
Energy Range: 10^{-5} eV to 20 MeV
Files (MF): 1, 2, 3, 4, 5, 12, 14
Evaluators: G. Hale, P. Young
Laboratory: LANL

ENDF/B-VI MOD 2 REVISION 1 (G. Hale, LANL, July 1991)

The following changes were made:

1. The comments, below, on the standards covariances were added.
2. File 3, MT=53: LF flag and Q-value corrected.

STANDARDS COVARIANCES

Phase 1 reviewers of the ENDF/B-VI standards cross sections have expressed the concern that the uncertainties resulting from the combination of R-matrix and simultaneous evaluations might have led to uncertainties that are too small. As a result, the Standards Subcommittee produced (at the May, 1990, CSEWG meeting) a set of expanded covariance estimates for the standard cross section reactions. These uncertainties are estimates such that if a modern day experiment were performed on a given standard cross section using the best techniques, approximately 2/3 of the results should fall within these expanded uncertainties. The expanded uncertainties for the ^{6}Li(n,t) cross section are given in the following table and are compared to values from the combined output of the standards covariance analysis:

Energy Range (keV)	Estimated Uncertainty %	Combined Analysis %
0.1 - 1.0	0.5	
1.0 - 10.	0.7	0.14
10. - 50.	0.9	
50. - 90.	1.1	0.25
90. - 150.	1.5	
150. - 450.	2.0	0.29
450. - 650.	5.0	
650. - 800.	2.0	0.36
800. - 1000.	5.0	

ENDF/B-VI MOD 1 NEW EVALUATION (G. Hale, P. Young, LANL, April 1989)

See ENDF-201 Summary Documentation, 4th Edition (1991), page 18, for documentation of the ENDF/B-VI evaluation.

Evaluation: **^{10}B Incident Neutron Library, Release 1 (MAT 525)**
Energy Range: 10^{-5} eV to 20 MeV
Files (MF): 1, 2, 3, 4, 12, 13, 14
Evaluators: G. Hale, P. Young (LANL)

ENDF/B-VI MOD 2 REVISION 1 (G. Hale, LANL, July 1991)

The following changes were made:

1. The comments below on the standards covariances were added.
2. File 3, MT=55,57,62,64,65,68,70,71,73,74,76-81,83,84: LF flag and Q-value corrected.

STANDARDS COVARIANCES

Phase 1 reviewers of the ENDF/B-VI standards cross sections have expressed the concern that the uncertainties resulting from the combination of R-matrix and simultaneous evaluations might have led to uncertainties that are too small. As a result, the Standards Subcommittee produced (at the May, 1990, CSEWG meeting) a set of expanded covariance estimates for the standard cross section reactions. These uncertainties are estimates such that if a modern day experiment were performed on a given standard cross section using the best techniques, approximately 2/3 of the results should fall within these expanded uncertainties. The expanded uncertainties for the $^{10}B(n,\alpha_0)$ and $^{10}B(n,\alpha_1)$ cross sections are given in the following tables and are compared to values from the combined output of the standards covariance analysis:

Energy Range (keV)	Estimated Uncertainty %	Combined Analysis %
$^{10}B(n,\alpha_0)$ Cross Section		
10^{-08} - 0.1	0.5	0.21
0.1 - 5.0	1.5	
5.0 - 30	3.0	0.38
30 - 90	5.0	
90 - 150	10.0	0.86
150 - 200	12.0	
200 - 250	15.0	0.79
$^{10}B(n,\alpha_1)$ Cross Section		
10^{-08} - 0.1	0.2	0.16
0.1 - 5.0	0.4	
5.0 - 30	0.6	0.20
30 - 90	1.0	
90 - 150	1.5	0.48
150 - 200	2.0	
200 - 250	2.5	0.62

ENDF/B-VI MOD 1 NEW EVALUATION (G. Hale, P. Young, LANL, November 1989)

See ENDF-201 Summary Documentation, 4th Edition (1991), page 48, for documentation of the ENDF/B-VI evaluation.

Evaluation:	**^{nat}C Incident Neutron Library, Release 1 (MAT 600)**
Energy Range:	10^{-5} eV to 32 MeV
Files (MF):	1, 2, 3, 4, 5, 12, 14, 33
Evaluators:	C. Y. Fu, E. J. Axton, F. G. Perey (ORNL)

ENDF/B-VI MOD 2 REVISION 1 (C. Y. Fu, ORNL, July 1991)

The following changes were made for Revision 1 of ENDF/B-VI:

1. The comments below on the standards covariances were added.
2. References were updated, see below.

STANDARDS COVARIANCES

Following concerns expressed at the Standards Subcommittee meeting, May, 1990, about the seemingly small standards uncertainties, the Standards Subcommittee has provided expanded uncertainties. These uncertainties are estimates such that if a modern day experiment were performed today on a given standard using the best techniques, those results would fall within these expanded uncertainties (2/3 of the time). They take into account data inconsistencies and concerns about R-matrix parameters. Note that it is not assumed that the uncertainties are totally correlated within the energy ranges given. It is recommended that these expanded uncertainties be put in File 1 and in the documentation for the standards.

C(n,n) total elastic scattering cross section

Energy (keV)	Uncertainty (%)
1 - 500	0.46
500 - 1500	0.53
1500 - 1800	0.60

REFERENCES

Ax88 E. J. Axton, An Evaluation of Kerma in Carbon and the Carbon Cross Sections, NBS, to be published (1988)

Fu90 C. Y. Fu, ***Nucl. Sci. Eng.*** **106**, 494 (1990)

ENDF/B-VI MOD 1 NEW EVALUATION (C. Y. Fu, E. Axton, F. Perey, ORNL, August 1989)

See ENDF-201 Summary Documentation, 4th Edition (1991), page 78, for documentation of the ENDF/B-VI evaluation.

Evaluation: **^{14}N Incident Neutron Library, Release 2, 3 (MAT 725)**
Energy Range: 10^{-5} eV to 40 MeV
Files: 1, 2, 3, 4, 6, 12, 13, 14, 15
Evaluators: P. G. Young, G. Hale, M. Chadwick (LANL)

ENDF/B-VI MOD 3 REVISION 2 (P. Young, LANL, August 1994)

The elastic and inelastic cross sections (MT=63-90) at incident neutron energies above 13.5 MeV given in Revision 2 of ENDF/B-VI were corrected. This correction was made to improve agreement with elastic scattering measurements up to 25 MeV. The elastic neutron angular distributions above 20 MeV were also improved over the earlier data distributed in Release 2, based upon fits to experimental data.

ENDF/B-VI MOD 2 REVISION 1 (P. G. Young, LANL, September 1992)

The modified version of the ENDF/B-VI evaluation created for the Defense Nuclear Agency is extended in energy to 40 MeV. This extension was accomplished using experimental data and the September 1992 version of the GNASH code [1], which was updated for higher energy calculations. More details will be given in a later progress report.

The ENDF/B-VI evaluation was modified for DNA use to include results from Hale's R-Matrix analysis that include Harvey's new total cross section measurement [2]. These results are interim until the new ORNL scattering data can be incorporated. The ORNL preliminary scattering results confirm the parity of the first resonance as being positive, as used in the R-Matrix analysis.

REFERENCES

1. P. G. Young, E. D. Arthur, and M. B. Chadwick, **LA-12343-MS** (1992) Los Alamos National Laboratory
2. J. A. Harvey, et al., **Nuclear Data for Science and Technology**, Proceedings Conference, Jülich, 1991 (Springer-Verlag, 1992) p. 729

ENDF/B-VI MOD 1 NEW EVALUATION (P. Young, G. Hale, M. Chadwick, LANL, May 1990)

See ENDF-201 Summary Documentation, 4th Edition (1991), page 82, for documentation of the ENDF/B-VI evaluation.

Evaluation: **^{23}Na Incident Neutron Library, Release 1 (MAT 1125)**
Energy Range: 10^{-5} eV to 40 MeV
Files: 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 32, 33
Evaluators: D. C. Larson (ORNL)

ENDF/B-VI MOD 2 REVISION 1 (NNDC, July 1991)

The number of energy ranges in File 32, MT = 151 was corrected to be 1.

ENDF/B-VI MOD 0 (NNDC, January 1990)

ENDF/B-V MAT 1125 was converted to ENDF-6 format by NNDC.

ENDF/B-V NEW EVALUATION (D. C. Larson, ORNL, December 1977)

RESONANCE PARAMETERS (File 2)

Resonance region is 600 eV to 500 keV. The thermal neutron capture cross section is in agreement with the experimental results of 526.9±4.5 mb [Ry71], as well as earlier results summarized in [Ry71]. Using resonance parameters Γ_n=376 eV and Γ_γ=0.353 eV for the large 2.81 keV resonance gives the correct thermal capture value using a Breit-Wigner shape, and this form is used to calculate the capture cross section from 1.0×10^{-5} to 600 eV. The capture width Γ_γ=0.353 eV is consistent with a recent result by Wilson, et al. [Wi77] where they find $0.24<\Gamma_\gamma<0.4$ eV with a 90% confidence level, and with a recent preliminary result of Macklin [Ma76] where he found Γ^γ=0.385±0.04 eV. The Γ_n and E_{res} values are taken from Seltzer and Firk [Se74]. From 600 eV to 500 keV, the capture cross section is generated from resonance areas reported by Musgrove, et al. [Mu77], and neutron widths and spins obtained from a multilevel analysis of the transmission data of Larson and Hill [La76].

Thermal neutron capture cross section = 528 mb.

SMOOTH CROSS SECTION (File 3)

Elastic cross section calculated as total - nonelastic.

Nonelastic calculated as sum (n,n′) + (n,2n) + (n,γ) + (n,p) + (n,α).

Inelastic calculated as the sum of the inelastic to discrete levels (MT=51-68), plus the continuum (MT=91).

Capture cross section, as discussed above, the shape from 10^{-5} eV to 600 eV was taken from a single-level Breit-Wigner form; from 600 eV to 500 keV, File 3 gives no contribution. From 500 keV to 20 MeV, the capture file is the same as the ENDF/B-IV file by Pitterle & Paik [Pi72].

(n,p) taken from ENDF/B-IV modified above 8 MeV based on 2 step Hauser-Feshbach calculations.

(n,α) taken from ENDF/B-IV.

ANGULAR DISTRIBUTIONS (File 4)

Elastic taken mainly from [Ki76], ENDF-IV and Optical Model calculations.

All other angular distributions are assumed isotropic.

SECONDARY NEUTRON ENERGY DISTRIBUTIONS (file 5)

(n,2n) taken from ENDF-IV.

For the continuum (MT=91), temperatures were adjusted to fit neutron production data of Hermsdorf [He75].

RADIOACTIVITY (File 8)

Data from ENDF/B-V (Reich), and Endt and VanderLeun.

PHOTON PRODUCTION (Files 12, 13, 14, 15)

MF=12 Capture data taken from ENDF-IV.

MF=13 Nonelastic: (n,xγ) data taken from Larson and Morgan [La77].

MF=14 All angular distributions are assumed isotropic.

MF=15 Nonelastic: (n,xγ) data are taken from Larson and Morgan.

COVARIANCES (Files 32, 33)

MF=32 Uncertainty files for the resonance parameters below 32 keV are estimated from the literature for the 2.81 keV resonance, and an area analysis for the 7.6 keV resonance. Results from the multilevel analysis, capture areas, and area analysis form the basis for the remainder of the resonance parameter uncertainties. The uncertainties in the resonance parameters are most useful in self-shielding work.

MF=33 Uncertainty files for the capture cross section are estimated from the literature, and the spread of the various data sets.

REFERENCES

He75 H. Hermsdorf, et al., **ZFK-277** (1975) Zentralinst. Kernforschung, Rossendorf bei Dresden, Germany

Ki76 W. E. Kinney and F. G. Perey, private communication

La76 D. C. Larson, J. A. Harvey, and J. W. Hill, **ORNL-TM-5614** (1976) Oak Ridge National Laboratory

La77 D. C. Larson and G. L. Morgan, to be published

Ma76 R. L. Macklin, private communication (1976)

Mu77 A. R. del Musgrove, B. J. Allen, R. L. Macklin, **Neutron Physics and Nuclear Data**, Int. Conference, Harwell, 25-29 Sept. 1978 (O. E. C. D., 1978) p. 426

Pi72 T. A. Pitterle and N. C.Paik, **WARD 3045T4B-2**, Appendix A (1972) Westinghouse Advanced Reactor Division

Ry71 T. B. Ryves, **Chemical Data, Measurements & Applications**, Conference, Canterbury, 1991 (Inst. of Civil Engineers, U. K., 1991) p. 139

Se74 J. Seltzer and F. W. K. Firk, ***Nucl. Sci. Eng.*** **53**, 415 (1974)

Wi77 W. M. Wilson, H. E. Jackson, and G. E. Thomas, ***Nucl. Sci. Eng.*** **63**, 55 (1977)

Evaluation: **^{27}Al Incident Neutron Library, Release 3, 4 (MAT 1325)**
Energy Range: 10^{-5} eV to 40 MeV
Files: 1, 2, 3, 4, 6, 8, 9, 12, 14, 15
Evaluators: P. G. Young (LANL)

ENDF/B-VI MOD 2 REVISION 1 (P. G. Young (LANL), V. McLane (NNDC) August 1996)

File 1: The thermal cross section were added to MT=451.

File 3: The interpolation code on the first 3 points of MT=1 and the first 10 points on MT=102 was changed to 5.

ENDF/B-VI MOD 1 NEW EVALUATION (P. G. Young, LANL)

GENERAL COMMENTS

This evaluation is based on a theoretical analysis that utilizes Hauser-Feshbach statistical theory, with corrections for preequilibrium and stripping processes. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions. Some data from ENDF/B-VI (MOD=0), are retained, in particular, the neutron total cross section below 20 MeV and the radiative capture cross section and photon multiplicities below about 100 keV.

Cross sections and spectra for individual reactions are included for reactions that exceed a cross section of approximately 1 mb at any energy. Multiplicities and emission energy spectra are given for gamma rays, particles, and recoil nuclei emitted in each reaction. Energy-angle-correlated spectra are given for all outgoing particles.

2200 m/sec Cross Sections
Total = 1.58 barns
Elastic = 1.348 barns
Capture = 0.232 barns

Capture resonance integral = 0.13377 barns

HAUSER-FESHBACH STATISTICAL THEORY CALCULATIONS

The GNASH code [Yo92] was used for all Hauser-Feshbach statistical theory calculations. Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach [Ka77,Ka85]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk [Ig75] and pairing and shell parameters from the Cook [Co67] analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model [Ko90]. Calculations were performed for all significant reactions producing neutrons, protons, deuterons, tritons, α particles, and γ rays for incident neutrons between 10^{-11} and 40 MeV. At the highest energies, approximately 30 compound nuclei had to be included, leading to ~180 reaction paths. The angular distribution systematics by Kalbach [Ka88] were used to describe the angular distributions for all continuum particles.

OPTICAL MODEL POTENTIALS

For incident and exiting neutrons, the phenomenological optical potential by Petler, et al. [Pe85], based on a microscopic optical model analysis of experimental data, was utilized at all energies. A modified version of Perey's potential [Pe63] was used to calculate transmission coefficients for protons below 44 MeV, switching to the Madland potential [Ma88] at higher energies. The potential by Perey and Perey [Pe63] was utilized to calculate deuteron transmission coefficients for deuterons at all energies. Similarly, a triton potential by Becchetti and Greenlees [Be71] and an alpha potential determined by Arthur and Young [Ar80] for n + ^{56}Fe reactions were used at all energies for those particles.

DIRECT REACTIONS

Energy-dependent cross sections of inelastic neutrons from ^{27}Al(n,n′) direct reactions were calculated using the DWUCK code [Ku70], normalized to values of the angle-integrated cross sections in ENDF/B-VI at 14 MeV.

ENDF/B-V CARRYOVERS

The following reactions/data were carried over unchanged from ENDF/B-V:

MF=2, MT=151: Resonance Parameters: effective scattering radius = 0.32752×10^{-12} cm. (Resonance parameters not given.)

CALCULATIONAL RESULTS

The MF=3 cross sections and MF=6 energy/angle distributions based completely on calculations are:

MT = 11, (n,2nd)
MT = 16, (n,2n)
MT = 17, (n,3n)
MT = 22, (n,nα)
MT = 24, (n,2nα)
MT = 28, (n,np)
MT = 29, (n,n2α)
MT = 32, (n,nd)
MT = 33, (n,nt)
MT = 41, (n,2np)
MT = 42, (n,3np)
MT = 44, (n,n2p)
MT = 45, (n,npα)
MT = 64-89, (n,n′) Discrete Levels
MT = 91, (n,n′) Continuum
MT = 103, (n,p) (MF=6 only)
MT = 104, (n,d)
MT = 105, (n,t)
MT = 107, (n,α) (MF=6 only)
MT = 108, (n,2α)
MT = 111, (n,2p)
MT = 112, (n,pα)
MT = 115, (n,pd)
MT = 116, (n,pt)
MT = 117, (n,dα)
MT = 649, (n,p) Continuum
MT = 650-669, (n,d) Discrete Levels
MT = 699, (n,d) Continuum
MT = 700-710, (n,t) Discrete Levels
MT = 749, (n,t) Continuum
MT = 849, (n,α) Continuum

Kalbach systematics [Ka88] are used to specify all continuum particle angular distributions. All continuum photon angular distributions are assumed isotropic.

Additionally, the radioactive nuclei formation data in MF = 8 and 9 were obtained directly from the GNASH calculations.

OTHER REACTIONS

The following reactions are based on combinations of experimental data and theoretical calculations or other techniques:

SMOOTH CROSS SECTIONS (File 3)

Total Cross Section: Below 20 MeV, carried over from ENDF/B-V. At higher energies based on data of Perey [Pe72] and optical model calculation.

Elastic Cross Section: Obtained by subtracting sum of nonelastic cross sections from the total. Mainly results from the optical model calculations above 14 MeV. At lower energies the nonelastic cross sections are a combination of experimental data (ENDF/B-V evaluations) and the theoretical calculations.

Inelastic Cross Section: Summation of MT=51-91.

Inelastic Cross Section to Discrete States: Combination of experimental data below 14 MeV, (especially the (n,n′) data of Kinney and Perey [Ki70], the (n,xγ) data of Orphan and Hoot [Or71] and Dickens, et al. [Di71,Di73]), and calculated excitation functions, with a rough match to the ENDF/B-V evaluation near 14 MeV.

(n,γ) Cross Section: Below 1 keV, ENDF/B-V was adopted. At higher energies, calculations from GNASH code used, including a semidirect model.

(n,p) and (n,α) Cross Section: Taken directly from the International Reactor Dosimetry File IRDF-90 of the IAEA, obtained by Wagner, et al. (IRK) [Wa90]. At higher energies, calculated excitation function were used, normalized to the IRK data at 20 MeV.

ANGULAR DISTRIBUTIONS (File 4)

Elastic Angular Distributions: ENDF/B-V adopted below 6 MeV. At higher energy optical model calculations used (see above). Tabulated distributions given in the center-of-mass system.

ENERGY-ANGLE DISTRIBUTIONS (File 6)

Inelastic Level Neutron & Photon Distributions: For MT=51-62, neutron angular distributions are combination of experimental data and calculated shapes below 14 MeV and are represented by Legendre expansions in the center-of-mass system. At higher energies, calculated shapes are used. For MT=63-89, calculated angular distributions are used at all energies. Photon multiplicities based on experimental branching ratios and GNASH calculations. Photon angular distributions assumed isotropic.

PHOTON PRODUCTION (Files 12, 15)

Radiative Capture Photon Multiplicities: Below 1 keV, ENDF/B-V adopted. At higher energies, based on GNASH calculations.

Radiative Capture Photon Energy Distributions: Below 1 keV, ENDF/B-V adopted. At higher energies, based on GNASH calculations.

REFERENCES

Ar80 E. D. Arthur and P. G. Young, **BNL-NCS-51245**, Vol. II, p. 731 (1980) Brookhaven National Laboratory

Be92 O. Bersillon, **Computation and Analysis of Nuclear Data Relevant to Nuclear Energy and Safety**, ICTP Workshop, 10 February-13 March, 1992, Trieste, Italy, to be published, World Scientific Press

Be71 F. D. Becchetti, Jr., and G. W. Greenlees, **Polarization Phenomena in Nuclear Reactions**, Proc. Symposium, Madison, WI, 1971 (The University of Wisconsin Press, 1971) p.682

Co67 J. L. Cook, H. Ferguson, and A. R. del Musgrove, ***Aust.J.Phys.*** **20**, 477 (1967)

Di71 J. K. Dickens **ORNL-TM-3284** (1971) Oak Ridge National Laboratory

Di73 J. K. Dickens, T. A. Love, and G. L. Morgan, **ORNL-TM-4232** (1973) Oak Ridge National Laboratory

Ig75 A. V. Ignatyuk, G. N. Smirenkin, and A. S. Tishin, ***Sov. J. Nucl. Phys.*** **21**, 255 (1975); translated from ***Yad. Fiz.*** **21**,485 (1975).

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Evaluation: **^{45}Sc Incident Neutron Sublibrary, Release 2 (MAT 2125)**
Energy Range: 10^{-5} eV to 20 MeV
Files: 1, 2, 3, 4, 5, 12, 13, 14, 15
Evaluators: A. B. Smith (ANL), R. J. Howerton (LLNL)

ENDF/B-VI MOD 1 NEW EVALUATION (A. B. Smith (ANL), R. J. Howerton (LLNL), July 1992)

This evaluation provides a reasonable basic scandium evaluated data file; no equivalent file was previously available. The available experimental data is far from definitive, thus, considerable reliance had to be placed on calculational extrapolation. See Smith, et al. [1] for detailed information.

RESONANCE PARAMETERS (File 2)

Resonance parameters taken from Mughabghab, et al. [2]; no adjustments were made to these parameters.

SMOOTH CROSS SECTIONS (File 3)

The total and elastic scattering cross section evaluation relies primarily upon the model calculations of Smith and Guenther [3], slightly adjusted to improve agreement with the measured values of Barnard, et al. [4].

The capture cross section evaluation uses the results calculated using ABAREX [5], slightly adjusted at ≈ 100 keV to match the resonance region.

(n,p) cross sections modified as per P. Young and D. Muir (LANL). Thermal value may be large.

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Evaluation: **Chromium Isotopes Incident Neutron Sublibrary, Release 1**
MAT 2425 (^{50}Cr), 2431 (^{52}Cr), 2434 (^{53}Cr), 2437 (^{54}Cr)
Energy Range: 10^{-5} eV to 20 MeV
Files: 1, 2, 3, 4, 6, 12, 14, 15, 33
Evaluators: D. M. Hetrick, D. C. Larson, N. M. Larson, C. Y. Fu (ORNL)

ENDF/B-VI MOD 2 REVISION 1

The elastic transformation matrix was removed.

The secondary particle distributions for File 6, ^{50}Cr MT=51-56, ^{53}Cr MT=51-62, and ^{54}Cr MT=51-54, were corrected to center-of-mass coordinates (from laboratory coordinates).

ENDF/B-VI MOD 1 NEW EVALUATION

See ENDF-201 Summary Documentation, 4th Edition (1991), page 131, for documentation of the ENDF/B-VI evaluation.

Evaluation: **Iron Isotopes Incident Neutron Sublibrary, Release 1**
MAT 2625 (^{54}Fe), 2631 (^{56}Fe), 2634 (^{57}Fe), 2637 (^{58}Fe)
Energy Range: 10^{-5} eV to 20 MeV
Files: 1, 2, 3, 4, 6, 12, 14, 15, 33
Evaluators: D. M. Hetrick, C. Y. Fu, N. M. Larson (ORNL)

ENDF/B-VI MOD 2 REVISION 1 (D. Hetrick, C. Fu, N. Larson, ORNL, July 1991)

The elastic transformation matrix was removed.

The secondary particle distributions for File 6, for ^{57}Fe MT=51-55 and ^{58}Fe MT=51-52, were corrected to center-of-mass coordinates (from laboratory coordinates).

ENDF/B-VI MOD1 NEW EVALUATION (D. Hetrick, C. Fu, N. Larson, ORNL, November 1989)

See ENDF-201 Summary Documentation, 4th Edition (1991), page 149, for documentation of the ENDF/B-VI evaluation.

Evaluation: **^{59}Co Incident Neutron Sublibrary, Release 2 (MAT 2725)**
Energy Range: 10^{-5} eV to 20 MeV
Files: 1, 2, 3, 4, 5, 12, 13, 14, 15, 33
Evaluators: A. B. Smith, ET AL. (ANL), G. DeSaussure, et al. (ORNL), R. Howerton (LLNL), M.Sugimoto (JAERI)

ENDF/B-VI MOD 2 REVISION 1 (G. de Saussure, N. M. Larson, J. A. Harvey, N. W. Hill, ORNL, June 1992)

Resonance parameters reevaluated by analyzing six ORELA transmission measurements (described in [1]) using a Reich-Moore approximation and the resonance analysis code SAMMY. See reference [1] for complete documentation.

REFERENCES

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ENDF/B-VI MOD1 NEW EVALUATION (A.Smith, D.Smith, P. Guenther, J. Meadows, R. Lawson (ANL), R. Howerton (LLNL), M. Sugimoto (JAERI), July 1989)

See ENDF-201 Summary Documentation, 4th Edition (1991), page 174, for documentation of the ENDF/B-VI evaluation.

Evaluation: **Nickel Isotopes Incident Neutron Sublibrary, Release 1**
MAT 2825 (^{58}Ni), 2831 (^{60}Ni), 2834 (^{61}Ni), 2837 (^{62}Ni), 2843 (^{64}Ni)
Energy Range: 10^{-5} eV to 20 MeV
Files: 1, 2, 3, 4, 6, 12, 14, 15, 33
Evaluators: D. C. Larson, C. M. Perey, D. M. Hetrick, C. Y. Fu (ORNL)

ENDF/B-VI MOD 2 REVISION 1 (D. C. Larson, C. M. Perey, D. M. Hetrick, C. Y. Fu, ORNL, July 1991)

<u>^{58}Ni</u> Capture widths corrected for 58.7 and 439.52 keV resonances. The elastic transformation matrix was removed.

<u>^{60}Ni</u> The resonance region from 10 eV to 450 keV has been changed, based on SAMMY analysis by F. G. Perey [1] of the ^{60}Ni ORELA data up to 100 keV of Harvey, et al. (described in [1]). This work reproduces the thermal cross sections and includes the small resonances inadvertently left out in the original file. No Background cross sections are required in File 3 in the resonance region. The elastic transformation matrix was removed.

REFERENCES

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<u>^{61}Ni</u> The secondary particle distributions for File 6 MT=51-58 were corrected to center-of-mass, not laboratory coordinates. The elastic transformation matrix was removed.

<u>^{62}Ni</u> The secondary particle distributions for File 6 MT=51-54 were corrected to center-of-mass, not laboratory coordinates. The elastic transformation matrix was removed.

<u>^{64}Ni</u> The secondary particle distributions for File 6 MT=51-52 were corrected to center-of-mass, not laboratory coordinates. The elastic transformation matrix was removed.

ENDF/B-VI MOD 1 NEW EVALUATION (D. C. Larson, C. M. Perey, D. M. Hetrick, C. Y. Fu, ORNL, October 1989)

See ENDF-201 Summary Documentation, 4th Edition (1991), page 181, for documentation of the ENDF/B-VI evaluation.

Evaluation:	**^{63,65}Cu Incident Neutron Sublibrary, Release 2**
	MAT 2925 (^{63}Cu) , 2931 (^{65}Cu)
Energy Range:	10^{-5} eV to 20 MeV
Files:	1, 2, 3, 4, 6, 12, 14, 15, 33
Evaluators:	D. M. Hetrick, C. Y. Fu, D. C. Larson (ORNL)

ENDF/B-VI MOD 3 REVISION 2 (D. M. Hetrick, C. Y. Fu, D. C. Larson, ORNL, July 1992)

^{63}Cu The following changes were made:

1) Corrections to MF=6, MT=65 at 17.0 MeV to prevent negative values in the angular distribution.
2) Corrections to MF=33, MT=102

^{65}Cu Corrections to MF=6, MT=63 at 17.5 MeV to prevent negative values in the angular distribution.

ENDF/B-VI MOD 1 NEW EVALUATION (D. M. Hetrick, C. Y. Fu, D. C. Larson, ORNL, November 1989)

This work employed several nuclear model codes including the Optical-Model code GENOA [1], the Distorted-Wave Born Approximation (DWBA) program DWUCK [2], and the Hauser-Feshbach code TNG [3,4]. The TNG code provides energy and angular distributions of particles emitted in the compound and pre-compound reactions, ensures consistency among all reactions, and maintains energy balance.

See ENDF-201 Summary Documentation, 4th Edition (1991), page 198, and Hetrick, et al. [5] for complete documentation of the ENDF/B-VI evaluation.

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4. K. Shibata and C. Y. Fu, **ORNL/TM-10093** (1986) Oak Ridge National Laboratory
5. D. M. Hetrick, C. Y. Fu, and D. C. Larson, **ORNL/TM-9083 [ENDF-337]** (1984) Oak Ridge National Laboratory

Evaluation: **^{73}Ge Incident Neutron Sublibrary, Release 2 (MAT 3234)**
Energy Range: 10^{-5} eV to 20 MeV
Files: 1, 2, 3, 4, 5
Evaluators: R. E. Schenter and F. Schmittroth (HEDL)

ENDF/B-VI MOD 2 REVISION 1 (NNDC, February 1993)
Q-value for MT=53 corrected from 98.6 keV to 68.75 keV.

ENDF/B-VI MOD 0 (NNDC, February 1993)
ENDF/B-V MAT 9051 translated to ENDF/B-VI format.

ENDF/B-V NEW EVALUATION (R. E. Schenter, F. Schmittroth, HEDL, April 1974)
Evaluated for ENDF/B-IV, MAT 49. Translated to ENDF/B-V format by NNDC, July, 1980.

RESONANCE PARAMETERS (File 2)
Resonance parameters taken from Mughabghab, et al. [3].

2200 m/sec capture cross section (barns)	
(from resonance parameters)	= 6.066
(from 1/v component)	= 8.934
Total	= 15.000

Computed capture resonance integral= 69.915

SMOOTH CROSS SECTIONS (File 3)
Total cross sections, above the resonance region, calculated using Moldauer Potential [4], elastic cross section from $\sigma_{total} - \sigma_{n,\gamma} - \sigma_{inl}$.
Inelastic cross sections calculated using COMNUC-3 [5].
Neutron capture evaluated using methods (NCAP code) in Refs.[1,2] for energies above the resonance region. A 1/v component was added in the resonance region to give the 2200 m/sec cross section of Mughabghab [3].

ANGULAR DISTRIBUTIONS (File 4)
The elastic angular distribution were assumed to be isotropic.

SECONDARY NEUTRON ENERGY DISTRIBUTIONS (File 5)
For MT= 91 the evaporation spectrum (LF=9) parameters obtained using NCAP code [2].

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3. S. F. Mughabghab and D. I. Garber, **BNL 325** ,3rd Ed., Vol.1 (1973) Brookhaven National Laboratory
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Evaluation: **^{89}Y Incident Neutron Sublibrary, Release 4 (MAT 3925)**
Energy Range: 10^{-5} eV to 20 MeV
Files: 1, 2, 3, 4, 5, 12, 13, 14, 15, 33
Evaluators: A. B. Smith, D. L. Smith, P. Rousset, R. D. Lawson (ANL), R. J. Howerton (LLNL)

ENDF/B-VI MOD 2 REVISION 1 (V. McLane, NNDC, October 1996)

Changes included:

File 1: Update of comments; thermal values added.

File 5, MT=91: Last energy range modified to fix problem of outgoing neutron having an energy greater than incoming neutron.

ENDF/B-VI MOD 0 (NNDC, January 1990)

Converted from ENDF/B-V MAT 9202 to ENDF-6 format. The ENDF/B-V evaluation is fully documented in reference [1]. .

2200n/sec cross sections (barns)	
Total	= 8.992
Elastic	= 7.707
Capture	= 1.285

Capture resonance integral = l0.917

REFERENCE

1. A.B. Smith, D.L. Smith, P. Rousset, R.D. Lawson, and R. J. Howerton, **ANL/NDM-94** (1986) Argonne National Laboratory

Evaluation: **^{nat}Zr Incident Neutron Sublibrary, Release 1 (MAT 4000)**
Energy Range: 10^{-5} eV to 20 MeV
Files: 1, 2, 3, 4, 5
Evaluators: M. Drake, D. Sargis, T. Maung (SAI); P. Rose (BNL)

ENDF/B-VI MOD 2 REVISION 1 (NNDC, August 1991)

An error in the parameter U for the continuum inelastic energy distribution (MF=5,MT=91) has been corrected.

ENDF/B-VI MOD 0 (NNDC, January 1990)

ENDF/B-V MAT 4000 converted to ENDF-6 format by NNDC.

ENDF/B-V EVALUATION

For complete summary of ENDF/B-V evaluation. See Summary Documentation, 3rd Edition, Supplement 1 (1985), and Drake, et al. [33].

RESONANCE REGION (Re-evaluated by P.F. Rose, BNL for revision 2)

Resolved resonance parameters were taken from the output of BNLNDF [34] which is based on the recommended values given Mughabghab, et al. [1]. The upper boundary of the resonance region = 90 keV.

2200 m/sec capture cross sections and resonance parameters

Material	MAT #	$\sigma_{n,\gamma}$ (barns)	I_{res} (barns)
^{90}Zr	1385	0.011	0.179
^{91}Zr	1386	1.188	4.913
^{92}Zr	1387	0.221	0.655
^{94}Zr	1388	0.049	0.311
^{96}Zr	1389	0.023	5.629
^{nat}Zr	1340	0.186	0.965

Unresolved parameters given for ^{91}Zr only.

SMOOTH CROSS SECTIONS (File 3)

The total cross section was smoothly joined to the resonance region cross sections for the individual isotopes. Between 90 keV and 500 keV, the data of Seth [3] were used. Between 500 keV and 2 MeV, the evaluated data were based on the measurements of Green and Mitchell [4], and Stooksberry and Anderson [5]. Above 2 MeV, the measurements of Green and Mitchell [4], Foster and Glasgow [6], Carlson and Barschall [7], and Peterson, et al. [8] were used.

The (n,2n) cross section was based on estimates for the separated isotopes. Except for ^{90}Zr, the results from a statistical model were used. The (n,2n) cross section for ^{90}Zr was based on measurements by Prestwood and Bayhurst [9], Nethaway [10], and several measurements near 14 MeV.

The <u>(n,α) cross section</u> was based on estimates for the separated isotopes. The energy dependent measurements by Bayhurst and Prestwood [11], statistical model calculations, and several measurements at 14 MeV were used.

The <u>(n,p) cross section</u> for ^{90}Zr was based on measurements by Carroll and Stooksberry [12] and Bayhurst and Prestwood [11]; for ^{91}Zr, on measurements by Carroll and Stooksberry [12], Reed [13], and Levkovskii [14]; for ^{92}Zr and ^{94}Zr, on measurements by Carroll and Stooksberry (12), Reed (13), Bramlitt and Fink [15], Lu, et al. [16] Levkovskii [14], Prasad and Sarkar [16], and Paul and Clarke [17].

For the <u>(n,γ) cross section</u> the data recommended by Benzi (18) were used.

For <u>inelastic scattering</u>, 19 level excitation cross sections and a continuum cross section have been given. The cross sections were based on a previous evaluation by KAPL and the experimental data of Tessler, et al [19], Day [20], McDaniel, et al. [21], Brandenberger and Glasgow, Smith and Whalen [22], Lind and Day [23], Tessler and Glickstein [24], Guenther, et al. [22], and Glazkov [25].

The <u>elastic scattering cross section</u> was taken, basically, as the difference between the total cross section and the non-elastic cross section. The experimental data used includes Engelbrecht and Smith [26], Hans and Snowdon [27], Kent, et al. [28], Walt and Beyster [29], Walt and Barschall [30], Gilboy and Towle [31], and Clark and Cross [32].

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