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Report to the DOE Nuclear Data Committee

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REPORT TO THE DOE NUCLEAR DATA COMMITTEE

Compiled and edited by:

J. C. Lundy
F. G. Perey

NOTICE This document contains information of a preliminary nature.
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ABSTRACT

This report was prepared for the DOE Nuclear Data Committee and covers work performed at ORNL since April 1980 in areas of nuclear data of relevance to the U.S. applied nuclear energy program. The report was mostly generated through a review of abstracts of work completed to the point of being subjected to some form of publication in the open literature, formal ORNL reports, ORNL technical memoranda, progress reports, or presentation at technical conferences. As much as possible the complete abstract of the original publication has been reproduced with only minor editing. In a few cases progress reports were written specifically for this publication. The editors have selected the material to be included in this report on the basis of perceived interests of DOE Nuclear Data Committee members.

A. CROSS SECTION MEASUREMENTS

    1. Capture Cross Sections

        a. Current (2/81) Fission Product and other Capture Cross Section Measurements (R. L. Macklin)

Samples of ^{99}Tc, ^{109}Ag (and ^{107}Ag) have been requested to fulfill data needs. We hope to obtain and measure ^{131}Xe and ^{136}Xe as we have already successfully taken data for ^{86}Kr. Outside the fission product mass range we have a sample of ^{22}Ne and have measured ^{182,183,184,186}W samples (courtesy of D. Drake, LANL) up to ~2 MeV.

        b. Stable Isotope Capture Cross Sections from ORELA (R. L. Macklin and R. R. Winters*)

A computer coding error in data processed prior to December 1979 led to percentage errors in several published cross sections. Palladium isotope data were severely changed (up to ~40%), thorium, sulfur, holmium and ^{186}osmium in the 10-15% range and others were unaffected or in the 2-7% range. Corrected data for the most severe cases have been reprocessed to average microscopic capture cross sections and to resonance parameters.

        c. Neutron Capture Cross Section in ^{64}Zn** (J. B. Garg,[†] V. K. Tikku,[†] J. Halperin, and R. Macklin)

Total neutron capture cross section measurements of the separated isotope $^{64}_{30}$Zn have been made in the energy interval of 2.5-900 keV. These were made using time-of-flight techniques and a total energy γ-ray detector system with a nominal resolution of about 0.12 ns/m. Resonance energies and capture areas were determined for 191 resonances up to 131 keV. Values of the radiation widths and neutron widths for many resonances have been determined making use of the results available from transmission measurements. From these results mean values of $\langle\Gamma_\gamma\rangle$ = (726± 60) meV for s-wave and $\langle\Gamma_\gamma\rangle$ = (272±30) meV for p-wave resonances have been determined. A value for the p-wave strength function S_1 = (0.75±0.08) × 10^{-4} $eV^{-1/2}$ was obtained for neutron energy up to 130 keV. Bayes' theorem for conditional probability was used to identify d-wave levels and from these resonances a lower limiting value for d-wave strength function S_2 = (0.78±0.12) × 10^{-4} $eV^{-1/2}$ was obtained. The values for the p-wave mean level spacing for all resonances observed up to 130 keV and after elimination of d-wave resonances, were found to be (0.68±0.04) and (1.10±0.07) keV, respectively. An analysis of the linear correlation coefficient (ρ) between Γ_n^0 and Γ_γ gave a value of (0.47±0.08) at a confidence level of 99.7%.

d. ^{186,187,188}Os(n,γ) Cross Sections and Galactic Nucleosynthesis*
(R. R. Winters, R. L. Macklin, and J. Halperin)

The ^{186,187,188}Os(n,γ) cross sections were measured over the incident neutron energy range 2.6-800 keV. Optimized statistical model fits to the average cross sections were made employing estimates of the ^{186}Os, ^{187}Os, and ^{188}Os p-wave strength func: .ons 0.29 × 10^{-4}, 0.45 × 10^{-4}, and 0.33 × 10^{-4}, respectively, d-wave strength functions 1.3 × 10^{-4}, 4.0 × 10^{-4}, and 1.5 × 10^{-4}, respectively, and gamma ray strength functions $(\bar{\Gamma}_\gamma/D_0)$ 26.8 × 10^{-4}, 176 × 10^{-4}, and 20.8 × 10^{-4}, respectively. A lower bound for the ^{187}Os neutron inelastic cross section is estimated as 0.25(20) b at 30 keV. The Maxwellian-averaged capture cross sections are presented as a function of temperature. The ratio of 30 keV Maxwellian-averaged cross sections $<\sigma_\gamma(186)>/<\sigma_\gamma(187)>$ = 0.504(17) is reported and the lack of agreement with earlier measurements of this ratio is discussed. The use of this cross section ratio in estimating, via the ^{187}Re-^{187}Os beta decay, the duration of galactic nucleosynthesis is discussed. The cross section ratio from this work yields an estimate of 10.4(25) × 10^9 yr for the duration of galactic nucleosynthesis, a result higher than but still consistent with the estimate 7(2) × 10^9 yr derived from U/Th decay.

e. Thorium Resonance Neutron Capture (2.6-10 keV) (R. L. Macklin)

Individual resonance parameters are fitted to thorium neutron capture data up to 10 keV. The ENDF/B-V parameters (given up to 4 keV) do not describe the data well. An average radiation width Γ_γ = 25.5 ± 1.2 meV is derived together with fitted strength functions $10^4 S_1$ = (1.47 ± 0.07) $eV^{-1/2}$, $10^4 S_2$ = (1.13 ± 0.06) $eV^{-1/2}$ and $10^4 \Gamma_\gamma/D_{\ell=0}$ = 14.6 ± 0.4.

2. Total Cross Sections

a. ORELA Measurements to Meet Fusion Energy Neutron Cross Section Data Needs** (D. C. Larson)

Major neutron cross section measurements that have been made at the Oak Ridge Electron Linear Accelerator (ORELA) and are useful to the fusion energy program will be reviewed. Cross sections for production of gamma rays with energies 0.3 < E_γ < 10.5 MeV have been measured as a function of neutron energy over the range 0.1 < E_n < 20.0 MeV for Li, C, N, O, F, Na, Mg, Al, Si, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Nb, Mo, Ag, Sn, Ta, W, Au, Pb and Th. Neutron emission cross sections have been measured for ^{7}Li, Al, Ti, Cu and Nb for 1 < E_n < 20 MeV. Results of recent neutron total cross section measurements from 2-80 MeV for eleven materials of interest (C, O, Al, Si, Ca, Cr, Fe, Ni, Cu, Au and Pb) to the FMIT project will be presented. Finally, future directions of the ORELA program will be outlined.

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*Phys. Rev. C 21, 563 (1980).

**Abstract of paper presented at the Symposium on Neutron Cross Sections from 10-50 MeV, BNL, May 12-14, 1980; Proc. BNL-NCS-51245, Vol. I, p. 277 (1980).

b. <u>Precise Measurement and Analysis of Neutron Transmission</u>
<u>through ^{232}Th*</u>   (D. K. Olsen, R. W. Ingle, and J. L. Portney**)

Three sets of transmission time spectra through up to eight
samples of ^{232}Th have been measured for neutron energies from 6.0 meV to
0.1 MeV using a flight-time technique over 22- and 40-m path lengths, the
ORELA pulsed neutron source, and a 1-mm thick lithium glass detector. The
resulting total cross section from 0.1 to 20.0 eV seems to be smaller than
that contained in the ENDF/B-V evaluation. Least-squares analysis of the
transmissions from 9 to 440 eV using a multilevel Breit-Wigner formalism
results in neutron widths consistent with those previously reported. An
average radiation width of 25.2 meV is obtained for 19 low-energy s-wave
resonances. Higher resolution measurements are planned for next year.

c. <u>^{240}Pu Total Cross Section</u>   (L. W. Weston and R. R. Spencer)

Preparation has begun for measurements of the transmission of
^{240}Pu up to a few eV, concentrating on the large resonance at 1 eV.

3. <u>Scattering and Reactions</u>

a. <u>^{56}Fe Inelastic Scattering</u>   (J. K. Dickens and D. C. Larson)

Measurements are being prepared to observe the excitation
function of the cross section for inelastic scattering to the first 2^{+}
level of ^{56}Fe (846 keV) over a broad region of neutron energies.

b. <u>^{187}Os(n,n') Cross Section</u>   (Winters, Käppeler,[+] Beer,[+] Berman,[‡]
<u>Hershberger,[¶] McEllistrem,[¶] Macklin, and Hill)</u>

The very difficult measurement of the cross section for
inelastic neutron scattering to the 9.8 keV state has been pursued first
at Van de Graaff accelerators. In the Karlsruhe measurement an upper
limit of 0.4 barns was found at 30 keV. Collaborative measurements at the
University of Kentucky are getting under way (30 keV and 65 keV). Some
planning has been done for a possible 34 keV measurement at ORELA using an
anisotropic Fe-Al filter.

c. <u>^{238}U Inelastic Neutron Scattering at 82 keV[§]</u>   (Winters, Hill,
<u>Macklin, Harvey, Olsen, and Morgan[◊])</u>

Using a thick iron filter to produce an 82 keV group of nearly
monoenergetic pulsed neutrons from the Oak Ridge Electron Linear Accelera-
tor white neutron source, the differential and integrated neutron inelastic
scattering cross sections from the first excited state of ^{238}U have been

measured. We find that the angular distribution is forward-peaked and we obtain estimates of the Legendre coefficients P_0, P_1, and P_2. The measured integrated inelastic cross section is 381 ± 21 mb, in good agreement with the ENDF/B-V evaluation and with other statistical and optical model calculations.

4. Actinides

    a. Actinide Neutron Cross Sections Program (Dabbs, Johnson, Weston, Todd, Williams, Harvey, Carter, Dickens, Raman, Bemis, Halperin, Macklin, and Hill)

Fission - Conversions of measured data to cross sections for $^{241}Am(n,f)$, $\overline{^{242m}Am(n,f)}$, and $^{249}Cf(n,f)$ have been brought near to completion. Useful new techniques for handling complex background analyses were developed in the course of these conversions. A first measurement at RPI Pb Spectrometer on $^{248}Cf(n,f)$ was completed; continuation measurements on lighter even isotopes of Cm await sample preparations now in progress at LLL. A precise value of $\bar{\nu}_p$ for ^{242}Cm was published.[1]

Capture - A paper entitled "Neutron Capture Cross Section of Neptunium-237" has passed the review process and is ready for publication. The measurement covers the neutron energy region from 0.01 eV to 200 keV. Both resolved and unresolved resonance parameters were derived. These data in conjunction with previously reported total cross sections yield a 2200 m/s cross section which is 6.4% higher than that in ENDF/B-V.

Total - Measurements of the total cross section for ^{231}Pa were carried out over the range 0.01 eV-10 keV on two sample thicknesses at the 18 m and 80 m flight paths of ORELA. Liquid nitrogen cooling was used. The data were analyzed; a total of 137 resonances were characterized, and the s-wave strength function below 70 eV was determined. A paper has been submitted for publication.

Integral Experiments - The measurement program for analyzing 12 in-core and 2 in-blanket actinide samples irradiated for 4 years in EBR-II has been completed. For samples located near the core center, ORIGEN calculations show good agreement with experiment. A final report is in preparation. Encapsulation of 21 actinides (between ^{230}Th at the low mass end and ^{248}Cm at the high) for extended irradiations at the Dounreay PFR has also been completed.

Calculation and Analysis - During FY'81, the remaining irradiated EBR-2 samples were calculated and results compared with the experimentally determined compositions. For most samples agreement was quite good; however, for the ^{238}U and Th samples, which were located near the axial blankets of EBR-2, significant discrepancies were observed.

Although some results showed considerable improvement as a consequence of these studies, the calculated Pu concentration in the ^{238}U

[1]Nucl. Sci. Eng. 75, 56 (1980).

sample was still 20-30% lower than the measured value. A comprehensive final report on the EBR-2 actinide irradiation experiment is currently in preparation.

Concurrent with the above study was one that attempted to determine the effects of recent ORELA cross section measurements on the nuclear industry, as manifested by improvements in reactor calculations, fuel cycle costs, etc. The difference in the version IV and V results is an indication of the effect of recent cross section improvements. A report on this study has begun.

Fission-Product Yields - Measurements of thermal-neutron induced fission-product yields utilizing gamma-ray assay have been completed for ^{243}Cm. Data reduction is expected to be initiated soon and completed within a year. These measurements will yield the first fission-product yield data for ^{243}Cm. Data reduction to obtain fission-product yields for ^{229}Th(n,f) is in progress. Results of previous work on ^{245}Cm fission product yields were published[1] and on ^{249}Cf yields have been submitted for publication.

Actinide Newsletter - The fourth issue, edited by S. Raman, will appear in early 1981 and has 72 contributions from 24 laboratories in 11 countries. The IAEA Advisory Group on Transactinium Isotope Nuclear Data at its second meeting in Cadarache, France, in May 1979, made a strong recommendation for the continuation of the Actinide Newsletter and for persons working in this field all over the world to make contributions to it. The publication schedule is expected to be one issue per year in the future.

b. $\bar{\nu}_p$ of ^{233}U (R. Gwin)

The energy dependence of the average number of prompt neutrons emitted on fission $\bar{\nu}_p(E)$ has been measured relative to the $\bar{\nu}_p$ for ^{252}Cf. The results are higher than currently accepted values above the resonance region up to a few hundred keV. It is planned to measure simultaneously below 1 eV the ratio of $\bar{\nu}_p$ of ^{233}U, ^{235}U, and ^{239}Pu to the Cf standard.

c. ^{238}U Neutron Capture (de Saussure, Perez, Mukhopadhyay, and Yang)

Careful remeasurements of ^{238}U neutron capture up to ∿10 keV have been initiated, and are to be supplemented with self-indication measurements planned to enable deduction of self-shielded cross sections.

d. Yields of Short-Lived Fission Products Produced by Thermal-Neutron Fission of Plutonium-239* (J. K. Dickens, J. W. McConnell, and K. J. Northcutt)

The absolute yields of 28 fission products representing 23 different mass chains produced by thermal-neutron fission of ^{239}Pu and

[1]Phys. Rev. C 23, 331 (1981).
*Nucl. Sci. Eng. 77, 146 (1981).

having half-lives between 30 and 1100 s have been determined using Ge(Li)
spectroscopy methods. Spectra of 30 gamma rays emitted in the decay of
the fission products between 35 and 1950 s after a 5-s irradiation were
obtained. Gamma rays were assigned to the responsible fission products by
matching gamma-ray energies and half-lives. Fission-product yields were
then obtained from the data by first determining the appropriate gamma-ray
activity as of the end of the irradiation, correcting for detector effi-
ciency and gamma-ray branching ratio, and, finally, dividing by the number
of fissions created in the sample. The number of fissions was determined
by direct comparison of gamma rays emanating from fission products created
during a careful irradiation of a well-calibrated ^{239}Pu-loaded fission
chamber.

The resulting fission-product yields are compared with previous
measurements and with recommended yields given in two recent (and independ-
ent) evaluations. Uncertainties assigned to the present results range
between 6 and 45%, and are smaller than or comparable to uncertainties
assigned to previous experimental or evaluated yields for six mass chains.

e. Yields of Fission Products Produced by Thermal-Neutron Fission
of ^{245}Cm* (J. K. Dickens and J. W. McConnell)

Absolute yields have been determined for 105 gamma rays emitted
in the decay of 95 fission products representing 54 mass chains created
during thermal-neutron fission of ^{245}Cm. These results include 17 mass
chains for which no prior yield data exist. Using a Ge(Li) detector,
spectra were obtained of gamma rays between 30 sec and 0.3 yr after very
short irradiations of thermal neutrons on a 1 μg sample of ^{245}Cm. On the
basis of measured gamma-ray yields and known nuclear data, total chain
mass yields and relative uncertainties were obtained for 51 masses between
84 and 156. The absolute overall normalization uncertainty is <8%. The
measured A-chain cumulative yields make up 81% of the total light mass
(A $\leq$ 121) yield and 92% of the total heavy mass yield. The results are
compared with fission-product yields previously measured with generally
good agreement. The mass-yield data have been compared with those for
thermal-neutron fission of ^{239}Pu and for ^{252}Cf(s.f.); the influences of
the closed shells Z=50, N=82 are not as marked as for thermal-neutron
fission of ^{239}Pu but much more apparent than for ^{252}Cf(s.f.). Information
on the charge distribution along several isobaric mass chains was obtained
by determining fractional yields for 12 fission products. The charge
distribution width parameter, based upon data for the heavy masses, A=128
to 140, is independent of mass to within the uncertainties of the measure-
ments. Gamma-ray assignments were made for decay of short-lived fission
products for which absolute gamma-ray transition probabilities are either
not known or in doubt. Absolute gamma-ray transition probabilities were
determined as (51±8)% for the 374-keV gamma ray from decay of ^{110}Rh,
(35±7)% for the 1096-keV gamma ray from decay of ^{133}Sb, and (21.2±1.2)%
for the 255-keV gamma ray from decay of ^{142}Ba.

*Phys. Rev. C 23, 331 (1981).

f. Gamma Rays Following Alpha Decay of ^{245}Cm and t
    Structure of ^{241}Pu* (J. K. Dickens and J. W. M

Relative intensities for K x rays and gamma ray
from ^{245}Cm have been measured using several Ge photon detec
absolute intensity for the dominant 175-keV gamma ray in ^{24}
mined to be 9.5 photons per 100 ^{245}Cm alpha decays with an
±7%. Eleven gamma rays have been placed as transitions amc
^{241}Pu.

g. Yields of Fission Products Produced by Thermal-
    Fission of ^{249}Cf** (J. K. Dickens and J. W. Mc

Absolute yields have been determined for 107 ga
emitted in the decay of 97 fission products representing 54
created during thermal-neutron fission of ^{249}Cf. These res
mass chains for which no prior yield data exist. Using a C
spectra were obtained of gamma rays between 45 sec and 0.4
short irradiations of thermal neutrons on a 0.4 µg sample c
the basis of measured gamma-ray yields and known nuclear dt
mass yields and relative uncertainties were obtained for 5:
89 and 156. The absolute overall normalization uncertaint:
measured A-chain cumulative yields make up 77% of the tota
(A ≤ 123) yield and 79% of the total heavy mass yield.

The results are compared with fission-product
viously measured, with generally good agreement. Informat
charge distribution along several isobaric mass chains was
determining fractional yields for 11 fission products and
results with other measurements. The charge distribution
for the heavy masses, A = 128 to 140, is independent of mt
uncertainties of the measurements. For the light masses,
the charge distribution parameter is also independent of)
smaller than for the heavy masses. Total chain yields ar
ment with the current evaluation for ^{249}Cf.

h. ^{252}Cf Spontaneous Fission Neutron Spectrum (
    and D. K. Olsen)

A careful remeasurement of the ^{252}Cf spontant
neutron energy spectrum has been initiated. Recognized j
previous measurements and a conflict of many of the expe:
ments with a recent theoretical prediction have made thi:
The importance of accurate knowledge of the ^{252}Cf neutro
its use as a reference in a variety of measurements and
determinations of v, the average number of neutrons emit
for this isotope.

5. Experimental Techniques

a. Preliminary Study of Pseudorandom Binary Sequence Pulsing of ORELA* (N. M. Larson and D. K. Olsen)

It has been suggested that pseudorandom binary sequence (PRBS) pulsing might enhance the performance of the Oak Ridge Electron Linear Accelerator (ORELA) for neutron-induced, time-of-flight (TOF) cross-section measurements. In this technical memorandum, equations are developed for expected count rates, statistical variances, and backgrounds for a pulsing scheme in which a PRBS is superimposed on the periodic equal-intensity ORELA bursts. Introduction of the PRBS modification permits neutrons of different energies originating from different bursts to reach the detector simultaneously, and the signal corresponding to a unique flight time to be extracted mathematically. Relative advantages and disadvantages of measurements from conventional and PRBS pulsing modes are discussed in terms of counting statistics and backgrounds. Computer models of TOF spectra are generated for both pulsing modes, using as examples a 20-meter ^{233}U fission-chamber measurement and a 155-meter ^{238}U sample-in transmission measurement. Detailed comparisons of PRBS vs conventional results are presented. This study indicates that although PRBS pulsing could enhance ORELA performance for selected measurements, for general ORELA operation the disadvantages from PRBS pulsing probably outweigh the advantages.

b. User's Guide for SAMMY: A Computer Model for Multilevel R-Matrix Fits to Neutron Data Using Bayes' Equations** (N. M. Larson and F. G. Perey)

In this report we describe a method for determining the parameters of a model from experimental data based upon the utilization of Bayes' theorem. This method has several advantages over the least-squares method as it is commonly used; one important advantage is that the assumptions under which the parameter values have been determined are more clearly evident than in many results based upon least squares. Bayes' method has been used to develop a computer code which can be utilized to analyze neutron cross-section data by means of the R-matrix theory. The required formulae from the R-matrix theory are presented, and the computer implementation of both Bayes' equations and R-matrix theory is described. Results of our analysis of Ni^{60} transmission data from ORELA and of several artificial data sets, and a comparison of our results with those of an earlier multilevel R-matrix code, are also presented. Finally, details about the computer code and complete input/output information are given.

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*Abstract of ORNL/TM-6632, ENDF-290 (March 1980).
**Abstract of ORNL/TM-7485, ENDF-297 (November 1980).

c. Liquid Argon as an Electron/Photon Detector in the Energy Range
of 50 MeV to 2 GeV: A Monte Carlo Investigation* (Goodman,**
Denis,** Hall,** Karpovsky,** Wilson,** Gabriel, and Bishop)

Monte Carlo techniques have been used to study the character-
istics of a proposed electron/photon dete』tor based on the total absorption
of electromagnetic showers in liquid argon. The energy range studied was
50 MeV to 2 GeV. Results are presented on the energy and angular resolu-
tion predicted for the device, along with the detailed predictions of the
transverse and longitudinal shower distributions. Comparisons are made
with other photon detectors, and possible applications are discussed.

d. A Monte Carlo Simulation of an Actual Segmented Calorimeter: A
Study of Calorimeter Performance at High Energies† (Gabriel,
Bishop, Goodman,** Sessoms,** Eisenstein,‡ Wright,¶ and Kephart§)

The calculated responses including energy resolution, angular
resolution, and spatial energy deposition of a segmented iron and liquid-
argon calorimeter to incident pions in the energy range of 10- to 250-GeV
are presented. Experimental data for this calorimeter have been obtained
in the 10-to 40-GeV energy range and these results compare favorably with
the calculated data. The energy and angular resolutions including experi-
mental and calculated data can be summarized by the following expressions:

$$\sigma(E)/E = (5.07 + 33.4/\sqrt{E})\% ,$$

and

$$\sigma_\theta(E) = 15.7 + 458./E \quad (mrad) ,$$

respectively, where E is in GeV.

B. DATA ANALYSES

1. Theoretical Calculations

a. Calculation of the ^{23}Na(n,2n) Cross Section◇ (D. C. Larson)

The ^{23}Na(n,2n) reaction produces the radioactive product ^{22}Na,
which has a half-life of 2.61 years. For sodium-containing systems this
reaction can result in a radioactive contamination problem. Currently
available experimental cross sections for this reaction are in strong
conflict. Extensive multi-step Hauser-Feshbach calculations have been
done for neutron-induced reactions on sodium and will be presented. These
consistent calculations reproduce data for the (n,n'), (n,pγ), (n,αγ)
reactions, a neutron emission measurement and a gamma-ray production

*Abstract of ORNL/TM-7556 (December 1980).
**Harvard University.
†Abstract of ORNL/TM-7123 (January 1981).
‡University of Illinois, Urbana.
¶Enrico Fermi Institute,.University of Chicago.
§Fermi National Accelerator Laboratory.
◇Abstract of paper presented at ANS Meeting, Minneapolis, October 9-11, 1980.

measurement. The resulting cross sections for the (n,2n) reaction are found to be in good agreement with one of the experimental data sets.[1]

      b.   <u>Development and Applications of Multi-Step Hauser-Feshbach/Pre-Equilibrium Model Theory</u>*   (C. Y. Fu)

      A recently developed model that combines compound and precompound reactions with conservation of angular momentum is discussed. This model allows a consistent description of intermediate excitations from which tertiary reaction cross sections can be calculated for transitions to the continuum as well as to the discrete residual levels with known spins and parities. Predicted neutron, proton, and alpha-particle production cross sections and emission spectra from 14-MeV neutron-induced reactions are compared favorably with angle-integrated experimental data for 12 nuclides. The model is further developed to include angular distributions of outgoing particles. The random phase approximation used for the compound stage is partially removed for the precompound stages, allowing off-diagonal terms of the collision matrix to produce both odd and even terms in the Legendre polynomial expansion for the angular distribution. Calculated double differential cross sections for the 14.6-MeV ^{23}Na(n,n'x) reaction are compared with experimental data.

      c.   <u>Evaluation of Photon Production Data from Neutron-Induced Reactions</u>**   (C. Y. Fu)

      The evaluation methods and procedures used for generating the photon production data in the current Evaluated Nuclear Data File (ENDF/B, Version V) are reviewed. There are 42 materials in the General Purpose File of ENDF/B-V that contain data for prompt photon production. Almost all evaluations had substantial experimental data bases, but less than half of them employed any of the available evaluation methods. Only a few used theoretical techniques that are sophisticated enough to ensure internal consistency with other particle production data. Comments are made on four evaluation methods: the empirical formalism of Howerton *et al.*, the Troubetzkoy model, the multi-particle Hauser-Feshbach/Precompound model, and the Yost method. Critiques are also made on three procedures used for conserving photon energies in neutron capture reactions. The presence of photon production data in the file is necessary for studying energy balance, since photon production generally accounts for a dominant portion of the reaction energy output. Problems found in energy balance checks are discussed.

[1]H. Liskien and A. Paulsen, Nucl. Phys. <u>63</u>, 393 (1965).
 *Proc. BNL-NCS-51245, Vol. 2, p. 675 (July 1980).
**Presented at Workshop on Evaluation Methods and Procedures, BNL, Sept. 1980.

d. **Neutron Production by Medium-Energy ($\gtrsim$1.5 GeV) Protons in Thick Uranium Targets*** (R. G. Alsmiller, Jr., T. A. Gabriel, J. Barish, and F. S. Alsmiller)

A model, that includes fission, for predicting particle production spectra from medium-energy nucleon and pion collisions with uranium nuclei has been incorporated into the nucleon-meson transport code HETC. A variety of calculated results obtained with this revised code for protons incident on uranium targets have been obtained and are compared with experimental data and with the calculations of other investigators. For incident proton energies $\gtrsim$1 GeV the calculated results are in good agreement with several, but not all, of the available experiments.

e. **A Phenomenological Model for Particle Production from the Collision of Nucleons at Medium Energies with Fissile Elements**** (F. S. Alsmiller, R. G. Alsmiller, Jr., T. A. Gabriel, R. A. Lillie, and J. Barish)

A phenomenological model for particle production from the collision of nucleons at medium energies ($\lesssim$3 GeV) with fissile elements is presented. Calculated neutron multiplicities are compared with experimental data and agreement is found to be within the statistical errors expected from the Monte Carlo nature of the calculations.

f. **Thermal Neutron Flux Generation by High-Energy Protons in Thick Uranium Targets†** (R. G. Alsmiller, Jr., T. A. Gabriel, J. Barish, and F. S. Alsmiller)

For several applications, e.g., in designing facilities to produce an intense source of low-energy neutrons by using medium-energy protons and for studies of the feasibility of converting fertile-to-fissile material using medium-energy protons, it is necessary to carry out calculations of the transport of medium- and low-energy nucleons and pions through fissionable material. The high-energy transport code HETC[1] has often been used to carry out such transport calculations, but because this code did not take into account high-energy fission, the results were very approximate. Recently, a fission channel has been added to the intranuclear-cascade-evaporation model of nuclear reactions and this revised cross-section model has now been incorporated into the transport code, HETC, so that medium-energy nucleon and pion transport calculations in fissionable material may be carried out.

To test the validity of the revised code, calculations have been carried out and compared with the experimental data of Fraser *et al.*[2] At the proton energies of 540 and 960 MeV the calculated and experimental results are in very good agreement, but for incident protons of 1470 MeV the calculated results are larger than the experimental data. Comparisons similar to these with a variety of other experimental data will also be presented.

*Abstract of ORNL/TM-7527 (January 1981).
**Proc. ANS 35, 475 (1980).
†Proc. ANS 35, 477 (1980).
[1]T. W. Armstrong and K. C. Chandler, ORNL-4744 (1972).
[2]J. S. Fraser *et al.*, Phys. Canada 21, 17 (1965).

g. Calculated Differential π^+ Production Spectra at Large Angles from 28 GeV Protons on a Thick Iridium Target and Comparisons with Experimental Data* (R. G. Alsmiller, Jr., T. A. Gabriel, and B. L. Bishop)

Calculated results of the low-energy (<100 MeV) π^+ production spectra from 28 GeV protons incident on a thick iridium target are presented and compared with experimental data. Experimental results are available at angles of 66°, 90°, and 133° with respect to the incident proton beam and comparisons with calculations are given at each of these angles. The calculated and experimental results are in moderately good agreement (factor of 2 to 4) over the energy range considered. Calculated results of the neutron, proton, π^+ and π^- energy spectra, averaged over the angular interval 45° to 75°, are also presented for energies $\leq$500 MeV.

2. ENDF/B Related Evaluations

a. Logical Inference and Evaluation** (F. G. Perey)

Most methodologies of evaluation currently used are based upon the theory of statistical inference. It is generally perceived that this theory is not capable of dealing satisfactorily with what are called systematic errors. Theories of logical inference should be capable of treating all of the information available, including that not involving frequency data. A theory of logical inference as an extension of deductive logic via the concept of plausibility and the application of group theory is presented. Some conclusions, based upon the application of this theory to evaluation of data, are also given.

b. An Evaluation of Cross Sections for Neutron-Induced Reactions in Sodium† (D. C. Larson)

An evaluation of the neutron-induced cross sections of ^{23}Na has been done for the energy range from 10^{-5} eV to 20 MeV. All significant cross sections are given, including differential cross sections for production of gamma rays. The recommended values are based on experimental data where available and use results of a consistent model code analysis of available data to predict cross sections where there are no experimental data. This report describes the evaluation that was submitted to the Cross Section Evaluation Working Group (CSEWG) for consideration as a part of the Evaluated Nuclear Data File, Version V, and subsequently issued as MAT 1311.

c. Evaluation of Resonance Parameters for Neutron Interaction with Iron Isotopes for Energies up to 400 keV‡ (C. M. Perey and F. G. Perey)

This report documents the evaluation of the resolved resonance parameters of iron isotopes 54, 56 and 57 in the neutron energy region

*Abstract of ORNL/TM-7647 (January 1981).
**Presented at Workshop on Evaluation Methods and Procedures, BNL, Sept. 1980.
†Abstract of ORNL-5662, ENDF-299 (September 1980).
‡Abstract of ORNL/TM-6405, ENDF-298 (September 1980).

below 400 keV. Estimates of the uncertainties in the resonance parameters and correlation between the partial widths Γ_n and Γ_γ are given when significant. Some details about the procedures used to evaluate the resonance parameters, their uncertainties and correlations are reported. This evaluation was performed for the general purpose file of the Evaluated Nuclear Data File (ENDF/B-V MAT 1326).

d. Estimation of the Uncertainties in the ENDF/B-V ^{235}U Fission Spectrum* (R. E. Maerker, J. H. Marable, and J. J. Wagschal)

The uncertainty of the fission spectrum is necessary for calculating uncertainties of reactor performance parameters, for the adjustment of cross sections, and for applications using the dosimetry unfolding technique. However, the ENDF/B-V evaluation of χ^{25} does not include any uncertainties.

Assuming a Watt formulation for χ^{25}, the uncertainty in χ^{25} will be determined by the standard deviations in the Watt parameters a and b and by the correlation in the uncertainties of a and b.

From estimates[1] of the standard deviations in a and b and estimates[2] of the standard deviation of $\bar{E}$, the average energy, the covariance between a and b can be deduced and the uncertainties in the spectrum calculated. Typical standard deviations are 3% below 0.5 MeV and 10% at 10 MeV.

e. Evaluation of Neutron Cross Sections for Fissile and Fertile Nuclides in the keV Range** (L. W. Weston)

Procedures for evaluation of radiative capture, elastic and inelastic processes, and fission in the keV region of neutron energies are described. The use of theoretical tools along with the available ENDF utility codes allows the evaluator to extend and expand upon the experimental data which are often sparse or discrepant. A few problems with the utility codes are noted and suggestions made for improvement and extension. Some ENDF/B-V cross sections for important nuclei are plotted in detail and show significant need for improvement in the shape of the individual partial cross sections to be consistent with theoretical predictions within the constraints of the experimental data. In particular, uranium and plutonium isotopic evaluations, which are of critical importance to fast reactors, deserve careful attention using improved methodology.

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*Proc. ANS 35, 555 (1980).
[1]P. I. Johansson and B. Holmqvist, Nucl. Sci. Eng. 62, 695 (1977).
[2]J. L. Lucius and J. H. Marable, Trans. Am. Nucl. Soc. 32, 731 (1979).
**Presented at Workshop on Evaluation Methods and Procedures, BNL, Sept. 1980.

f. GLUCS: A Generalized Least-Squares Program for Updating Cross
Section Evaluations with Correlated Data Sets*
(D. M. Hetrick and C. Y. Fu)

The PDP-10 FORTRAN IV computer programs INPUT.F4, GLUCS.F4,
and OUTPUT.F4, which employ Bayes' theorem (or generalized least-squares)
for simultaneous evaluation of reaction cross sections, are described.
Evaluations of cross sections and covariances are used as input for incor-
porating correlated data sets, particularly ratios. These data are read
from Evaluated Nuclear Data File (ENDF/B-V) formatted files. Measured
data sets, including ratios and absolute and relative cross section data,
are read and combined with the input evaluations via the least-squares
technique. The resulting output evaluations have not only updated cross
sections and covariances, but also cross-reaction covariances. These
output data are written into ENDF/B-V format.

3. Validation of ENDF/B Evaluations Through Integral Measurements

a. ORNL Fusion Reactor Shielding Integral Experiments**
(Santoro, Alsmiller, Barnes, and Chapman)

Integral experiments that measure the neutron and gamma-ray
energy spectra resulting from the attenuation of ∿14 MeV T(d,n) ^{4}He reac-
tion neutrons in laminated slabs of stainless steel type 304, borated
polyethylene, and a tungsten alloy (Hevimet) and from neutrons streaming
through a 30-cm-diameter iron duct (L/D = 3) imbedded in a concrete shield
have been performed at ORNL. The facility, the NE-213 liquid scintillator
detector system, and the experimental techniques used to obtain the mea-
sured data are described. The two-dimensional discrete ordinates radiation
transport codes, calculational models, and nuclear data used in the
analysis of the experiments are reviewed. The measured and calculated
neutron energy spectra (>850 keV) obtained for the attenuation experiments
are in excellent agreement (∿10%) for shield compositions and thicknesses
up to 412 g/cm^2 thick. The calculated gamma-ray spectra (>750 keV) agree
with the measured data to within 15% for the slabs containing stainless
steel and borated polyethylene and within a factor of 5 when Hevimet is
included in the shield composition. The calculated neutron spectra
obtained for the streaming experiments are in good agreement (∿10-15%)
with the measured data for the on-axis detector position. For the off-
axis detector locations, the calculations overestimate the measurements by
as much as a factor of 5 depending on detector location. Current evidence
suggests that the angular distributions for elastic and inelastic neutron
scattering are not properly represented in the discrete ordinates analysis
and more accurate methods are required. The calculated and measured
gamma-ray spectra agree within ∿30%.

*Abstract of ORNL/TM-7341, ENDF-303 (October 1980).
**Invited paper at ANS Topical Meeting, King of Prussia, PA, October 1980.

b. The Adjustment of Cross Sections Based on Integral Experiments in Fast Benchmark Assemblies* (J. H. Marable)

The adjustment of multigroup cross sections using fast benchmark integral experiments is reviewed. The question of whether such adjustments lead to actual improvements in differential data or only to the determination of parameters in an artificial mathematical model is discussed. Data bases required for adjustment are also discussed, and the concept of calculated-response correctors (calculational biases) based on modeling and calculational approximations is presented. Linear and nonlinear adjustments are illustrated graphically. The need for careful examination of both input and output data, application of the χ^2-test, and confrontation with evaluators and experimentalists for feedback is emphasized. Applications based on ENDF/B-IV and ENDF/B-V are discussed. It is pointed out that in addition to being a practical tool for creating libraries incorporating integral experiment information, and in addition to the possibility of leading to improved nuclear data, least squares adjustment is required for the understanding of the complex of differential nuclear data, integral data, reactor modeling, cross section processing, analysis and calculational methods.

c. Calculation of Neutron and Gamma Ray Energy Spectra for Fusion Reactor Shield Design: Comparison with Experiment** (Santoro, Alsmiller, Barnes, and Chapman)

Integral experiments that measure the transport of $\sim$14 MeV D-T neutrons through laminated slabs of proposed fusion reactor shield materials have been carried out at ORNL. Measured and calculated neutron and gamma ray energy spectra are compared as a function of the thickness and composition of stainless steel type 304, borated polyethylene, and Hevimet (a tungsten alloy), and as a function of detector position behind these materials. The measured data were obtained using a NE-213 liquid scintillator using pulse-shape discrimination methods to resolve neutron and gamma ray pulse height data and spectral unfolding methods to convert these data to energy spectra. The calculated data were obtained using two-dimensional discrete ordinates radiation transport methods in a complex calculational network that takes into account the energy-angle dependence of the D-T neutrons and the nonphysical anomalies of the S_n method. The transport calculations incorporate ENDF/B-IV cross section data from the VITAMIN C data library. The measured and calculated neutron energy spectra are in good agreement behind slab configurations of stainless steel type 304 and borated polyethylene ($\sim$10% for all neutron energies above 850 keV). When 5 cm of Hevimet is added to a 45-cm-thick SS-304 plus borated polyethylene slab assembly, the agreement is less favorable. The agreement among the measured and calculated gamma ray spectra for energies above 750 keV ranges from $\sim$25% to a factor of $\sim$5 depending on the slab composition.

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*Presented at Workshop on Evaluation Methods and Procedures, BNL, Sept. 1980.
**Abstract of ORNL/TM-7360 (August 1980).

C. NUCLEAR DATA PROJECT ACTIVITIES - 1980 (S. J. Ball,* Y. A. Ellis,
W. B. Ewbank, B. Harmatz, F. W. Hurley,* M. J. Martin,** M. R. McGinnis,*
J. T. Miller,* S. Ramavataram,** C. D. Savin,* and M. R. Schmorak)

1. Data Evaluation

        As part of the international network, for nuclear structure data
evaluation, the Nuclear Data Project has continuing responsibility for
mass chains in the region A > 195. Revised nuclear data sheets for 11
mas: hains were prepared during 1980. In addition to its evaluation
res] ibility, NDP is committed to maintaining uniform, high standards
for ENSDF (and consequently for Nuclear Data Sheets) by providing a
thorough review of the first few mass chains prepared by each new evalu-
ator. The Nuclear Data Project provided a thorough review for 11 such
mass chains during 1980. NDP staff members have also organized training
seminars for new data evaluators in order to introduce them to NDP evalu-
ation techniques, analysis programs, and conventions used in ENSDF and
Nuclear Data Sheets.

2. Evaluated Nuclear Structure Data File

        The Evaluated Nuclear Structure Data File (ENSDF), developed and
implemented by the NDP, contains a documented summary of the current
status of nuclear measurements. The ENSDF now contains 7792 distinct sets
of evaluated nuclear information. This includes:

    1965 sets of adopted level properties (41,000 nuclear levels)
    2139 decay schemes
    3688 nuclear reaction data collections.

        All decay scheme information in ENSDF is now at least as complete
as the most recent Nuclear Data Sheets. Normalization information is
included wherever available, and details of electron capture and internal
conversion have been added systematically, so that complete tables of
atomic and nuclear radiations can be assembled for more than 1600 decay
schemes.

        The ENSDF computer format has been adopted as an international
standard for the systematic storage and exchange of nuclear structure
data. At six-month intervals NDP has prepared complete copies of ENSDF
on magnetic tape for distribution through an international network of
data centers.

3. Nuclear Structure References

        Nuclear Data Project's Nuclear Structure References (NSR) file con-
tains about 70,000 entries. Approximately 5000 indexed new research works
are added each year. About half of the additions are journal publications;
the other half consists of reports, conference abstracts, preprints, etc.
Each month an SDI (selective dissemination of information) service is

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*Technical support staff.
**Part-time assignment to Nuclear Data Project.

provided from new entries to the NSR file. An index to the new literature is published three times per year as "Recent References," which includes both isotope and reaction indexes for both journal and nonjournal literature.

The NSR file is being used as an international standard for the systematic exchange of indexed reference information. Copies of the complete indexed file have been distributed to the international network of data evaluation centers.

4. Publications

The Nuclear Data Project is the editorial and publications office for the journal Nuclear Data Sheets. The NDP prepares camera-ready copy which is sent to Academic Press for publication and distribution. Manuscripts are now being received from several data evaluation centers other than NDP. Thirty percent of the new evaluations published during 1979 were prepared by non-NDP evaluators.