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UCRL-50400 Volume 15
Part D, Rev. 1

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

Volume 15 Part D, Rev. 1

THE LLL EVALUATED NUCLEAR DATA LIBRARY (ENDL): DESCRIPTIONS OF INDIVIDUAL EVALUATIONS FOR $Z = 0-98$

R. J. Howerton and M. H. MacGregor

May 17, 1978

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UCRL-50490 Volume 15 Part D, Rev. 1

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FOREWORD

The UCRL-50400 series described 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 Production of Neutronics and Photonics Calculational Constants*, comprises the following volumes:

- Vol. 1, Rev. 3, *ECSIL, A System for Storage, Retrieval and Display of Experimental Neutron Data*, September 1976.
- Vol. 2, Rev. 2, *Neutron-Induced Interactions: Bibliography of Experimental Data*, July 1976.
- Vol. 3, Rev. 2, *Neutron-Induced Interactions: Index of Experimental Data*, July 1976.
- Vol. 4, *Evaluated Nuclear Cross-Section Library*, April 1971.
- Vol. 5, Rev. 1, *CLYDE: A Code for the Production of Calculational Constants from Nuclear Data*, September 1975.
- Vol. 6, Rev. 1, *Tables and Graphs of Photon Interaction Cross Sections from 1.0 keV to 100 MeV Derived from the ENB Evaluated Nuclear Data Library*, October 1975.
- Vol. 7, Part A, Rev. 1, *Major Neutron-Induced Interactions ($Z \leq 55$): Graphical, Experimental Data*, July 1976.
- Vol. 7, Part B, Rev. 1, *Major Neutron-Induced Interactions ($Z > 55$): Graphical, Experimental Data*, July 1976.
- Vol. 8, Rev. 1, Part A, *Experimental Neutron-Induced Interactions ($Z \leq 55$): Graphical, Experimental Data*, July 1976.
- Vol. 8, Rev. 1, Part B, *Experimental Neutron-Induced Interactions ($Z > 55$): Graphical, Experimental Data*, July 1976.
- Vol. 9, *Thresholds of Nuclear Reactions Induced by Neutrons, Photons, Deuterons, Tritons, and Alpha Particles*, September 1970.
- Vol. 10, *Tabulated Experimental Data for Neutron-Induced Interactions*, July 1976.

- Vol. 11, *Experimental Data, Indexes 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, *TARTNP: A Coupled Neutron-Photon Monte Carlo Transport Code*, July 1976.
- Vol. 15, Part A, *The LLL Evaluated Nuclear Data Library (ENDL): Evaluation Techniques, Reaction Index, and Descriptions of Individual Evaluations*, September 1975.
- Vol. 15, Part B, *The LLL Evaluated Nuclear Data Library (ENDL): Graphs of Cross sections from the Library*, April 1976.
- Vol. 15, Part C, *The LLL Evaluated Nuclear Data Library (ENDL): Translation of ENDL Neutron-Induced Interaction Data into the ENDF/B Format*, April 1976.
- Vol. 15, Part D, Rev. 1, *The LLL Evaluated Nuclear Data Library (ENDL): Descriptions of Individual Evaluations*, May 1978.
- Vol. 16, *Tabular and Graphical Presentation of 175 Neutron Group Constants Derived from the LLL Evaluated Neutron Data Library (ENDL)*, April 1976.
- Vol. 17, Part A, *Program Linear (Version 77-1): Linearize Data in the Evaluated Nuclear Data File/Version B (ENDF/B) Format*. January 1977.
- Vol. 17, Part B, *Program SIGMA1 (Version 77-1): Doppler Broaden Evaluated Cross Sections in the Evaluated Nuclear Data File/Version B (ENDF/B) Format*. January 1977.
- Vol. 18, *ACTL-Evaluated Neutron Activation Cross Section Library (1977)*.
- Vol. 19, *Neutron Induced Angular and Energy Distributions: Graphical Experimental Data*, April 1977.
- Vol. 20, *Bonderenko Self-Shielded Cross Sections and Multi-Band Parameters Derived from the LLL Evaluated Nuclear-Data Library (ENDL)*, September 1978.

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THE LLL EVALUATED NUCLEAR DATA LIBRARY (ENDL): DESCRIPTIONS OF INDIVIDUAL EVALUATIONS FOR $Z = 0-98$

ABSTRACT

We have presented descriptions of evaluated nuclear data sets for 86 isotopes in the range $Z = 0-98$.

INTRODUCTION

In UCRL-50400, Volume 15, Part A, we describe techniques that are used to produce sets of evaluated nuclear data. Graphical displays of the evaluated data are given in Part B of Volume 15, and the translation of the LLL Evaluated Nuclear Data Library (ENDL) into the ENDF/B format is described in Part C. The present volume describes evaluation procedures that were used to produce sets of evaluated data for 86 individual elements or isotopes that cover the range from $Z = 0$ to $Z = 98$.

In the description of the evaluations that are contained here, frequent references are made to the following

volumes in this series:^{*} Vol. 2 for a listing of the experimental data sets; Vol. 3 for a listing of the available experimental data for each specific isotope; Vol. 7 for graphical displays of the major types of reactions; Vol. 8 for graphical displays of supplemental reactions; and Vol. 15, Part B, for graphical displays of the ENDL cross sections.

At the beginning of the discussion for each individual isotope, a computer-generated listing is given which summarizes the main properties of the data sets that are contained in the evaluation.

^{*}See the Foreword.

Neutron

GENERAL COMMENTS

The only neutron-neutron interaction that occurs below 20 MeV is elastic scattering. No direct experimental measurements are available for this process. However, indirect information about (n,n) scattering can be obtained from (n,D) scattering analyses, and also from the results of (p,p) and (n,p) phase shift analyses.

TOTAL CROSS SECTIONS

Since there are no inelastic events, the total cross section, σ_{nn} , is equal to the total elastic cross section. The total cross section can be obtained from effective range theory by means of the equation

$$\sigma_{nn}(k^2) = \frac{4\pi a^2}{k^2 a^2 + \left(1 - \frac{1}{2} r a k^2\right)^2},$$

where a is the scattering length, r is the effective range, and k^2 is the center-of-mass momentum squared (in units of fermi squared). In this equation $k^2 = 0.01205 E_{LAB}$. Analyses of (n,D) scattering experiments, in

which the effects of the spectator proton have been subtracted, give the values $a = -17$ fermi and $r = +2.84$ fermi for the scattering length and effective range, respectively.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

These have not been measured directly. However, they can be derived from the isotropic spin $I = 1$ nucleon-nucleon amplitudes, which, in turn, are determined from (p,p) and (p,n) phase shift analyses. The (n,n) angular distributions were calculated from the phase shifts of M. H. MacGregor, R. A. Arndt, and E. M. Wright, *Phys. Rev.* **182**, 1714 (1969). In calculating these (n,n) angular distributions, we used only the nuclear components of the amplitudes: no electromagnetic connections were applied. Calculations were performed at neutron energies of 0.001, 0.01, 0.1, 1, 5, 10, and 20 MeV. The calculated angular distributions were isotropic to within 0.06% below 1 MeV, and to within 1.1% below 5 MeV. At 20 MeV, the ratio $\sigma(0^\circ)/\sigma(90^\circ)$ was about 1.09.

Neutron

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	59	5/29/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	7	2/09/73	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	2	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	2	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1

Hydrogen-1

GENERAL COMMENTS

The evaluation for hydrogen is based on, but is not identical to, the evaluation for hydrogen reported by L. Stewart, R. J. LaBauve, and P. G. Young in LA-4574 (1970). Most of the data in LA-4574 were in turn synthesized from previous evaluations reported by J. C. Hopkins and G. Breit in *Nucl. Data* 9, 137 (1971), and by A. Horsley in *Nucl. Data* 2, 243 (1966). For convenience, the material contained in the three papers just cited will be summarized in the appropriate sections of the present report. Those wishing more detail should consult the original documents.

ELASTIC SCATTERING CROSS SECTIONS AND ANGULAR DISTRIBUTIONS

Hopkins and Breit reported phase shift analyses for the hydrogen scattering cross section from 0.1 to 30 MeV. The analyses were compared with values reported by M. H. MacGregor, R. A. Arndt, and R. M. Wright (MAW) in *Phys. Rev.* 182, 1714 (1969). Hopkins and Breit stated that "the differences between the cross sections or polarizations as calculated with the Yale (Hopkins and Breit) or LRL (MAW) phase shifts are less than the uncertainties associated with those quantities." This excellent agreement between two independent

determinations of the phase shifts (which give the cross sections and angular distributions) for neutron scattering off hydrogen settles the question of the values to be used. Hopkins provided Stewart *et al.* with the phase shift program and the phase shifts reported by Hopkins and Breit, so that scattering cross sections and angular distributions could be calculated for intermediate energies. The lowest energy recommended for running the phase shift program was 0.1 keV. The value obtained for the scattering cross section at this energy was 20.449 barns, which agreed with the thermal cross section of 20.442 ± 0.023 barns derived by Davis and Barschall (*Phys. Lett.* 27B, 636 [1968]). Thus the scattering cross section was assumed to be constant at a value of 20.449 barns for all neutron energies below 0.1 keV.

CROSS SECTION FOR THE (n, γ) REACTION

The Q-value for the n, γ reaction is 2.2247 MeV. The cross sections for radiative capture used by Stewart *et al.* were taken from the Nuclear Data publication of Horsley (see above). The Horsley data were also used in the present evaluation for neutron energies up to 0.11 MeV. At 0.11 MeV, the cross section falls to 0.1 mbarns, which is a negligible

Hydrogen-1

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	99	7/27/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	13	7/27/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	4	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	4	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	219	2/24/71	2.2247+ 0	1.0000-10	2.0000+ 1
N,G	G ANGULAR DIST.	4	11/01/72	2.2247+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	11/01/72	2.2247+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	11/01/72	2.2247+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	2.2247+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	2.2247+ 0	1.0000-10	2.0000+ 1

value for all practical purposes. Hence, a single n,γ value of 0.026 mbarns is entered into the calculation at 20 MeV, and linear interpolation is used between 0.11 and 20 MeV.

PHOTON PRODUCTION FROM THE (n,γ) REACTION

In the process of neutron capture by hydrogen, a single photon is pro-

duced, which has an energy equal to the Q-value of the reaction plus one-half the kinetic energy of the incident neutron in the laboratory system. The photon production for this process is represented in the evaluation by the product of unit multiplicity and an approximate delta function. The function represents the photon spectrum.

Deuteron-2

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for the deuteron are listed in UCRL-50400, Vol. 3. The ECSIL references to these data are contained in UCRL-50400, Vol. 3. The evaluated deuterium data are shown graphically in UCRL-50400, Vol. 15, Part B.

The deuterium evaluation is based largely on work done by L. Stewart and R. Howerton in 1964, with substantive revisions being incorporated in 1972. Subsequent to the earlier work of Stewart and Howerton, a collaborative effort between L. Stewart and A. Horsley resulted in the evaluation reported by A. Horsley in *Nucl. Data A4*, 321 (1968). The present ENDL evaluation does not differ substantially from the results reported in the Nuclear Data paper, with the exception of the energy and angular distributions of secondary neutrons from the $n,2n$ reaction: Stewart and Horsley used the assumption of equal probability in phase space, whereas we have assumed the validity of the cluster model, as described below.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections are shown graphically on pages 1-15 to 1-21 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular

experimental values are given on pages 1-22 and 1-23 of this reference.

ELASTIC SCATTERING CROSS SECTION

For incident neutron energies below 0.01 MeV, a constant value for the elastic cross section was assumed, with a value of 3.4 barns. This value was based on a single point (reported in ECSIL reference 51-2794), corresponding to an incident neutron energy of 0.0724 eV. Since the experimental value was reported as 3.4 ± 0.4 barns, considerable latitude was possible in selecting this low energy value. For energies above 0.1 MeV and below the threshold for the $n,2n$ reaction (3.35 MeV), the elastic scattering cross section was based on the experimental data reported in ECSIL references 53-795, 53-290, 55-120, 71-3163, 71-3166, 67-570, 71-3245, and 57-22, with the heaviest reliance placed on reference 71-3163. For energies above the $n,2n$ threshold, the elastic scattering cross section was derived by subtracting the $n,2n$ cross section from the total cross section. From 0.01 to 0.1 MeV, the elastic scattering cross section was assumed to make a smooth transition between the 3.4-barn constant low energy value and the experimental values at the higher energies.

Deuteron-2

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	40	11/03/72	0.0000+0	1.0000-10	2.0000+1	
N,ELASTIC	N ANGULAR DIST.	14	11/03/72	0.0000+0	5.0000-2	2.0000+1	
N,ELASTIC	N TOTAL ENERGY DEP.	24	11/12/74	0.0000+0	1.0000-10	2.0000+1	
N,ELASTIC	N LOCAL ENERGY DEP.	24	11/12/74	0.0000+0	1.0000-10	2.0000+1	
N,2N	CROSS SECTION	12	7/09/72	-2.2300+0	3.3500+0	2.0000+1	LEVEL = 2.2300+0 MEV
N,2N	N ANGULAR DIST.	2	7/09/72	-2.2300+0	3.3500+0	2.0000+1	LEVEL = 2.2300+0 MEV
N,2N	N ENERGY-ANGLE DIST.	10	10/25/72	-2.2300+0	3.3500+0	2.0000+1	LEVEL = 2.2300+0 MEV
N,2N	N TOTAL ENERGY DEP.	2	10/25/72	-2.2300+0	3.3400+0	2.0000+1	LEVEL = 2.2300+0 MEV
N,2N	N LOCAL ENERGY DEP.	2	10/25/72	-2.2300+0	3.3400+0	2.0000+1	LEVEL = 2.2300+0 MEV
N,G	CROSS SECTION	72	11/03/72	6.2500+0	1.0000-10	2.0000+1	
N,G	G ENERGY-ANGLE DIST.	2	11/01/72	6.2500+0	1.0000-10	2.0000+1	
N,G	G MULTIPLICITY	2	11/01/72	6.2500+0	1.0000-10	2.0000+1	
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.2500+0	1.0000-10	2.0000+1	
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.2500+0	1.0000-10	2.0000+1	

Graphical values of the experimental and evaluated elastic scattering cross sections are shown on pages 1-21 and 1-22 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on page 1-23 of this reference.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19.

The angular distribution for elastic scattering was assumed to be isotropic for incident energies less than or equal to 0.05 MeV. From 0.1 to 20 MeV, the elastic scattering angular distributions was based on measurements reported in ECSIL references 55-214, 53-290, 62-1606, 66-2586, 57-499, 51-285, 71-3245, 69-1602, 53-464, 55-471, 68-2582, 67-2880, and 65-3388. Since the highest energy covered by the above references was 14.8 MeV, the 20-MeV value was obtained by continuing the trend shown at lower energies, with proper attention paid to Wick's limit.

$n,2n$ CROSS SECTION

Measurements for the $n,2n$ cross section are reported in ECSIL Refs. 69-1307, 61-683, 58-7, and 66-2586. For energies less than 14 MeV, the $n,2n$ cross section is based on the experimental data. Above 14 MeV

there are no measurements, and the evaluated cross section is obtained by extrapolation, using nuclear systematics.

Experimental and evaluated $n,2n$ cross sections are shown graphically on pages 1-2 and 1-3 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular experimental values are given on page 1-4 of this reference.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

This reaction is assumed to proceed in accordance with the assumptions of the cluster model. In this model, a broad bound level is assumed at a negative energy of 0.04 MeV, with the first neutron in the $n,2n$ reaction scattering from the wing of the bound level. This first neutron is assumed to be isotropic in the center-of-mass system. The second neutron from the $n,2n$ reaction is represented, in accordance with the assumptions of the cluster model, by Legendre polynomial coefficients up through the third order. The coefficients supply the angular-energy correlations.

CROSS SECTION FOR THE (n,γ) REACTION

The Q-value for the n,γ reaction is 6.25 MeV. Measurements at 0.0253 eV are reported in ECSIL references 52-1624 and 68-1604, and a single measurement at 14.4 MeV is reported in ECSIL reference 61-687. Some

tabular values for the capture cross section are given on page 1-24 of UCRL-50400, Vol. 7, Part A, Rev. 1.

The evaluated cross section was obtained by extrapolating on a $1/v$ basis in both directions from the 0.0253 eV measurements: to a lower energy of 0.0001 eV; and to an upper energy of 10 eV. At 10 eV, the n,γ cross section has fallen to a value of 30 μ barns. In the evaluation, the capture cross section is held constant at that value up to an energy of 14.6 MeV, where it then falls off to a value of 20 μ barns at 20 MeV.

PHOTON PRODUCTION FROM THE (n,γ) REACTION

The only source of photons from neutron-induced reactions in the deuteron is the n,γ reaction. At all incident neutron energies, a single photon is produced, with an energy equal to the Q-value of the reaction plus two-thirds of the incident neutron energy in the laboratory system. Due to the very low cross section for the n,γ process, photon production for this isotope is negligible in most applications.

Triton-3

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for tritium are listed in UCRL-50400, Vol. 3; the evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. The ECS11 references to the experimental data are given in UCRL-50400, Vol. 2.

This evaluation is based on work done originally by L. Stewart and R. Howerton in 1964 at LLL, with most of the evaluation at that time done by Stewart. Subsequently, a modification of the original evaluation was published by L. Stewart in LA-3270 (1965), and a further modification was carried out by A. Horsley and L. Stewart, with the results published in Addendum-1 of LA-3270 (1966). The ENDL evaluation discussed here is not identical to any of the above-mentioned evaluations, but it does not differ significantly from the Horsley and Stewart data. Some of the data (in particular, angular distributions for elastic scattering) have been carried over directly from the 1964 evaluation; for most neutron energies, these data are identical (to several significant figures) to the data reported in LA-3270.

TOTAL CROSS SECTION

Graphical and tabular values for the tritium total cross section are given on pages 1-24 and 1-25 of UCRL-50400, Vol. 7, Part A, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

For this isotope, the elastic scattering cross section is almost the same as the total cross section for energies below the 8.36-MeV threshold of the $n,2n$ reaction. Measurements of the elastic scattering cross section are reported in ECS11 references 59-532, 57-491, 60-555, and 71-3245. A constant cross section with a value of 1.3 barns is assumed at all neutron energies below 0.1 MeV. For incident neutron energies above 0.1 MeV, the elastic scattering cross section is determined from experiments; although the measurements are sparse, there are enough of them to determine the cross section. Values for the elastic scattering cross section are shown graphically on page 1-25 of UCRL-50400, Vol. 7, Part A, Rev. 1, and some tabular values are given on page 1-26 of this reference.

Triton-3

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	36	7-07-72	0.0000+0	1.0000-10	2.0000+1
N,ELASTIC	N ANGULAR DIST.	12	11-03-72	0.0000+0	5.0000-2	2.0000+1
N,ELASTIC	N TOTAL ENERGY DEP.	25	11-12-74	0.0000+0	1.0000-10	2.0000+1
N,ELASTIC	N LOCAL ENERGY DEP.	25	11-12-74	0.0000+0	1.0000-10	2.0000+1
N,2N	CROSS SECTION	11	7-07-72	-6.2600+0	8.3600+0	2.0000+1
N,2N	N ANGULAR DIST.	5	7-07-72	-6.2600+0	8.3600+0	2.0000+1
N,2N	N ENERGY-ANGLE DIST	1	7-07-72	-6.2600+0	8.3600+0	2.0000+1
N,2N	N TOTAL ENERGY DEP.	4	11-12-74	-6.2600+0	8.3600+0	2.0000+1
N,2N	N LOCAL ENERGY DEP.	4	11-12-74	-6.2600+0	8.3600+0	2.0000+1

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental determinations of elastic angular distributions are reported in ECSIL references 58-555, 71-3245, 67-2744, 51-568, 67-2880, and 61-1911. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In addition to the direct measurements of elastic scattering of neutrons by the triton, there have been numerous measurements of the elastic scattering of protons by He^3 . The latter are helpful in deducing the elastic scattering of neutrons from the triton. Elastic scattering is assumed to be isotropic in the center-of-mass system for energies below 0.05 MeV. The lowest incident neutron energy at which angular distribution measurements have been made is 1 MeV. From 1 to 20 MeV the angular distributions are based on measurement, and are essentially identical to the values reported in LA-3270. In the energy region from 0.05 to 1 MeV, a single entry is made at an incident neutron energy of 0.5 MeV, using an estimated shape in view of the lack of measurements in this region.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is 8.34 MeV. The only measurement for this reaction is at 14 MeV,

but since the $n,2n$ reaction is the only nonelastic reaction for the triton, the measurements of the nonelastic cross section above 14 MeV (reported in ECSIL reference 71-3245) are useful in evaluating the $n,2n$ cross section at these energies. The nonelastic cross section is shown graphically on page 1-5 of UCRL-50400, Vol. 8, Rev. 1, Part A. The shape of the $n,2n$ excitation function was determined by nuclear systematics up to 14 MeV. Above 14 MeV, the evaluated cross section was based on experiment.

ENERGY AND ANGULAR DISTRIBUTIONS FOR THE $n,2n$ REACTION

Secondary neutrons from the $n,2n$ reaction are assumed to be distributed in angle and energy according to the assumption of equal probability in phase space.* This assumption implies an energy-angle correlation, but for the purposes of this evaluation it is assumed that the energy and angle distributions are uncorrelated.

OTHER REACTIONS

The neutron capture reaction for the triton is either nonexistent or

*G. E. Uhlenbeck, S. Goudsmit, "Statistical Energy Distributions for a Small Number of Particles," *Pieter Zeeman Verhandelingen*, 's - Gravenhage, The Netherlands (1935), pp. 201-211.

extremely small. One reported measurement is on the order of 6 μ barns, and that value is subject to question. Even if it is correct, a cross section of that magnitude is negligible. The (n,γ) reaction has therefore been neglected in this evaluation. Similarly, the $(n,3n)$ reaction is energetically possible, but it is of

such small magnitude and such experimental uncertainty that it was not included in this evaluation.

None of the reactions included in this evaluation are photon producing reactions; hence, it is assumed that photon production from neutron interactions with the triton is insignificant.

Helium-3

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^3_2\text{He}$ are listed in UCRL-50400, Vol. 3. The evaluated data for this isotope are shown graphically in UCRL-50400, Vol. 15, Part B. The ECSIL data references are described in UCRL-50400, Vol. 2. This evaluation is based on work done by L. Stewart and R. Howerton in 1964, with some modifications added by R. Howerton in 1972.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections are shown graphically on pages 1-40 and 1-41 of UCRL-50400, Vol. 7, Part A, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

The experimental measurements of He^3 elastic scattering, which are listed in ECSIL Refs. 61-578 and 60-555, span the incident neutron energy range from 0.95 to 17.5 MeV. While the number of measurements is quite small, the smoothness of the elastic cross section permits a reasonable determination of the cross section from the available measurements in this energy range. At energies below 0.95 MeV, the elastic cross section must be estimated. Since the (n,p) cross section is much larger than the elastic cross section

in this energy range, the elastic cross section cannot be deduced from the total cross section. For energies below 0.01 MeV, the cross section for elastic scattering is set equal to 1.0 barns. Between 0.01 MeV and 0.95 MeV (where the first measurement is reported) the cross section is obtained by interpolation. Some tabular values of the elastic scattering cross section are given on page 1-42 of UCRL-50400, Vol. 7, Part A, Rev. 1.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Angular distributions for elastic scattering at incident neutron energies ranging from 1 to 14.4 MeV are reported in ECSIL Refs. 58-555, 60-578, 66-1613, and 67-1614. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. For energies below 0.5 MeV, the neutrons from elastic scattering are assumed to be isotropic. From 1 to 14 MeV, the angular distributions are based on experimental data. At 20 MeV, the angular distribution is deduced from the scattering of protons by a tritium target.

n,p CROSS SECTION

The n,p cross section has a Q-value of 0.76 MeV. At low energies,

Helium-3

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	55	1/03/75	0.0000+0	1.0000-10	2.0000+1
N,ELASTIC	N ANGULAR DIST.	10	1/03/72	0.0000+0	5.0000-1	2.0000+1
N,ELASTIC	N TOTAL ENERGY DEP.	20	11/12/74	0.0000+0	1.0000-10	2.0000+1
N,ELASTIC	N LOCAL ENERGY DEP.	20	11/12/74	0.0000+0	1.0000-10	2.0000+1
N,P	CROSS SECTION	140	7/10/72	7.6000-1	1.0000-10	2.0000+1
N,P	TOTAL ENERGY DEP.	2	11/12/74	7.6000-1	1.0000-10	2.0000+1
N,P	LOCAL ENERGY DEP.	2	11/12/74	7.6000-1	1.0000-10	2.0000+1
N,D	CROSS SECTION	23	7/10/72	-3.2700+0	4.3500+0	2.0000+1
N,D	TOTAL ENERGY DEP.	2	11/12/74	-3.2700+0	4.3500+0	2.0000+1
N,D	LOCAL ENERGY DEP.	2	11/12/74	-3.2700+0	4.3500+0	2.0000+1
N,G	CROSS SECTION	2	11/01/72	2.0578+1	1.0000-10	2.0000+1
N,G	G ENERGY-ANGLE DIST.	2	11/01/72	2.0578+1	1.0000-10	2.0000+1
N,G	G MULTIPLICITY	2	11/01/72	2.0578+1	1.0000-10	2.0000+1
N,G	TOTAL ENERGY DEP.	2	11/21/76	2.0578+1	1.0000-10	2.0000+1
N,G	LOCAL ENERGY DEP.	2	11/21/76	2.0578+1	1.0000-10	2.0000+1

the n,p cross section can be deduced from total cross section measurements, since the only other two-neutron cross sections — elastic scattering and neutron capture — are extremely small in comparison to the several-thousand-barn cross section for the n,p reaction. Calculations and measurements of the n,p cross section from 9 keV to 14.4 MeV are reported in ECSIL Refs. 58-519, 55-752, 69-2752, 50-187, 59-1612, 60-578 and 67-1614. Values for the n,p cross section are shown graphically on pages 1-7 to 1-9 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-11. Many of these detailed-balance calculations are based on T(p,n) results. There are, however, some measurements in which the protons from the n,p reaction are detected directly, and these measurements agree reasonably well with the cross sections derived from detailed-balance calculations. From 14.4 to 30 MeV, the n,p cross section is obtained by extrapolation, with nuclear systematics used as a guide.

n,d CROSS SECTION

The n,d reaction has a Q-value of -3.27 MeV, with a threshold at 4.36 MeV. Measurements of this reaction in the energy range from 4.36 to 14.4 MeV are reported in ECSIL Refs. 62-984, 60-578, and

67-1614. Graphical and tabular displays of the n,d cross section are given on pages 1-10 and 1-11 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated cross sections are in good agreement with the data of Ref. 62-984. The data were obtained from detailed-balance calculations based on experimental data from the $d(D,n)He^3$ reaction. The 14-MeV (n,d) value that is deduced from the detailed-balance calculations is in good agreement with the direct measurement reported in Ref. 67-1614. This direct measurement is obtained by detecting secondary deuterons. From 14 to 20 MeV, the cross section is obtained by extrapolating the lower-energy cross sections, using nuclear systematics as a guide.

CROSS SECTION FOR THE (n, γ) REACTION

The Q-value for the n, γ reaction is 20.578 MeV. The only measurement for this reaction was made at 4 MeV (Ref. 63-839) and yielded a cross section value of 42 μ barns. Because of the extremely large n,p cross section at low energies, the assumption was made that the n, γ cross section was constant at a value of 42 μ barns over the entire energy range.

PHOTON PRODUCTION FROM THE (n, γ) REACTION

Within the incident neutron energy range, it is assumed that a

single photon is produced by neutron capture. The photon has an energy value of $20.578 \text{ MeV} + 3/4 E_n$, where E_n is the incident neutron laboratory energy in MeV.

OTHER REACTIONS

The total breakup reaction $(n, 2n2p)$, with a Q-value of 7.72 MeV,

is possible at energies greater than 10.3 MeV, but the single measurement of this reaction at 14 MeV indicates that the cross section is either negligible or zero. Since the measurement at 14 MeV is 3.7 MeV above the threshold for the reaction, the total breakup cross section is assumed to be negligible at all energies covered in the evaluation.

Helium-4

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^4_2\text{He}$ are listed in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. The ECSIL data references are described in UCRL-50400, Vol. 2.

R. J. Howerton did this evaluation in 1964, and, except for minor adjustments, it has not been changed since that time.

TOTAL CROSS SECTION

Graphical and tabular values of the total cross section are given on pages 1-34 to 1-39 of UCRL-50400, Vol. 7, Part A, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

Since elastic scattering is the only possible neutron interaction in the energy range below 20 MeV, the elastic scattering cross section is determined by total cross section measurements for all energies greater than approximately 10 eV. Below 10 eV, molecular binding effects become important and are thus reflected in the total cross section measurements. Since the ENDL library gives only the free atom cross sections, the elastic scattering at energies below 10 eV is deduced from the elastic cross section value in the

neighborhood of 10 eV; this cross section is assumed to be 0.73 barns for all energies below 10 eV. Above 10 eV, the cross section varies smoothly, in good agreement with the results of the experimental total cross section values. Measurements deriving the He^4 elastic scattering cross section are reported in ECSIL Refs. 53-777, 69-2998, 60-570, 72-3237, 59-532, 62-694, 53-274, 68-2372, and 71-3270. Values of the elastic scattering cross section are shown graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental measurements of the He^4 elastic scattering angular distributions are reported in ECSIL Refs. 52-462, 63-1615, 62-694, 53-466, 66-1617, 63-1616, 55-1610, 63-1618, 64-796, and 71-3271. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. These measured angular distributions, which start at an incident neutron energy of 0.4 MeV and continue past 20 MeV, cover most of the range of the evaluation. The He^4 neutron elastic scattering process is assumed to be isotropic at incident neutron energies below 0.02 MeV. At neutron energies above 0.4 MeV, the angular distributions are based on the experimental data.

Helium-4

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	31	7/09/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	30	1/03/72	0.0000+ 0	2.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	30	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	30	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1

Lithium-6

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^6_3\text{Li}$ are listed in UCRL-50400, Vol. 3. The evaluated data for this isotope are shown graphically in UCRL-50400, Vol. 15, Part B. The ECSIL data references are given in UCRL-50400, Vol. 2.

The Li^6 evaluation was done originally by R. J. Howerton in 1959, and there have been a number of subsequent modifications. The most recent modifications were added in 1977.

TOTAL CROSS SECTION

Graphical and tabular values for the total cross section are given on pages 1-48 to 1-50 and 1-52 of UCRL-50400, Vol. 7, Part A, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

The lowest neutron energy at which this cross section has been measured is 1 MeV. Measurements from 1 to 14.1 MeV are reported in ECSIL Refs. 67-1899, 63-841, 68-1632, 63-2335, 65-1627, and 64-1633. At all neutron energies below 0.075 MeV, the elastic scattering cross section was assumed to have a constant value of 0.7 barns. This value was obtained by differencing the measured total cross section and the measured n,t cross section in

the incident neutron energy range from 0.01 to 0.75 MeV. In that energy range there are measurements of both the total cross section and the n,t cross section and the difference of these cross sections is essentially constant. The assumption that the elastic scattering cross section remains constant at low energies is consistent with the general nuclear systematics of the light isotopes. Between 0.075 and 1 MeV, the energy dependence of the elastic scattering cross section was obtained, as at the lower energies, by differencing the total and n,t cross sections. From 1 to 14.1 MeV the elastic scattering cross section was determined directly from the experimental data, with a smooth variation assumed between the experimental points. From 14 to 20 MeV, the cross section was estimated on the basis of nuclear systematics. Graphical and tabular values of the elastic cross section are given on pages 1-51 and 1-52 of UCRL-50400, Vol. 7, Part A, Rev. 1.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of angular distributions for elastic scattering in the energy range from 0.049 to 14.1 MeV are reported in ECSIL references 60-571, 56-484, 67-1899, 63-841,

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06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	55	4/01/71	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	15	10/15/70	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	29	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	29	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,2N	CROSS SECTION	5	10/15/70	-5.6600+ 0	6.6100- 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	5	10/15/70	-5.6600+ 0	6.6100- 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	16	11/12/74	-5.6600+ 0	6.6100+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	14	11/12/74	-5.6600+ 0	6.6100+ 0	2.0000+ 1
N,N'D	CROSS SECTION	26	12/15/71	-1.4600+ 0	1.7048+ 0	2.0000+ 1
N,N'D	N ANGULAR DIST.	12	1/05/74	-1.4600+ 0	1.7048+ 0	2.0000+ 1
N,N'D	N ENERGY-ANGLE DIST.	12	3/13/73	-1.4600+ 0	1.7048+ 0	2.0000+ 1
N,N'D	N TOTAL ENERGY DEP.	6	11/12/74	-1.4600+ 0	1.7048+ 0	2.0000+ 1
N,N'D	N LOCAL ENERGY DEP.	6	11/12/74	-1.4600+ 0	1.7048+ 0	2.0000+ 1
N,N'D	CROSS SECTION	22	4/01/71	-1.4600+ 0	2.6000+ 0	2.0000+ 1
N,N'D	N ANGULAR DIST.	6	4/19/71	-1.4600+ 0	2.6000+ 0	2.0000+ 1
N,N'D	N TOTAL ENERGY DEP.	8	2/07/73	-1.4600+ 0	2.6000+ 0	2.0000+ 1
N,N'D	N LOCAL ENERGY DEP.	8	2/07/73	-1.4600+ 0	2.6000+ 0	2.0000+ 1
N,P	CROSS SECTION	14	4/01/71	-2.7300+ 0	3.1800+ 0	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	11/12/74	-2.7300+ 0	3.1800+ 0	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	11/12/74	-2.7300+ 0	3.1800+ 0	2.0000+ 1
N,T	CROSS SECTION	301	3/15/77	4.7900+ 0	1.0000-10	2.0000+ 1
N,T	TOTAL ENERGY DEP.	2	11/12/74	4.7900+ 0	1.0000-10	2.0000+ 1
N,T	LOCAL ENERGY DEP.	2	11/12/74	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	271	9/08/70	7.2600+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	11/01/72	7.2600+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	11/01/72	7.2600+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	7.2600+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	7.2600+ 0	1.0000-10	2.0000+ 1

LEVEL = 2.1800+ 0 MEV
LEVEL = 2.1800+ 0 MEV
LEVEL = 2.1800+ 0 MEV
LEVEL = 2.1800+ 0 MEV

68-1632, 62-1622, 65-1627, and 64-1633. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. The elastic scattering was assumed to be isotropic for energies less than or equal to 0.01 MeV, and to vary smoothly between 0.01 MeV and the first measured value at 0.049 MeV. In the incident neutron energy range from 0.05 to 14 MeV, the elastic scattering angular distributions were based on experimental data. For incident neutron energies greater than 14 MeV, the angular distribution was held constant at the 14-MeV values. The 20-MeV value thus obtained does not satisfy Wick's limit, but in the absence of experimental information, any evaluated angular distribution which is highly peaked forward is probably as good as any other.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 6.61 MeV. Measurements of the n,2n cross section from 10.2 to 14.1 MeV are reported in ECSIL Refs. 60-593, 61-2375, 63-2335, 69-2519, 58-594, 61-487. Each of these references is for a single data point, and all but one of the data points (60-593) are either at 14 or at 14.1 MeV. In the evaluation, the cross section was assumed to rise rather more slowly than is usual for n,2n

reactions so that it would be consistent with the measured values at 10.2 and 14 MeV. From 14 to 20 MeV, the cross section was assumed to continue the trend established at lower energies. Some tabular values for the n,2n cross section are given on page 1-23 of UCRL-50400, Vol. 8, Rev. 1, Part A.

n,2n ANGULAR AND ENERGY DISTRIBUTIONS

The secondary neutrons from the n,2n reaction were assumed to be isotropic in the laboratory system. Energy distribution tables of the secondaries are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n'd CROSS SECTION

The threshold for the n,n'd process is 1.72 MeV. Measurements of this cross section from 3.35 to 14.1 MeV are reported in ECSIL Refs. 63-841, 56-589, 68-1632, and 61-487. In the ENDL evaluation, this reaction has been broken into two parts: an excitation function for the 2.18-MeV level (which de-excites by particle breakup); and a continuum cross section for the remainder. The cross section for the excitation of the 2.18-MeV level is assumed to have a threshold at 2.6 MeV, and to rise in a sigmoid shape to match the first

measured value at 3.35 MeV. From 3.5 to 7.6 MeV, the evaluated cross section is consistent with the experimental values. From 7.5 to 14 MeV there are no measurements, and the cross section is assumed to follow the trend established at lower energies, passing through the measured point at 14 MeV. From 14 to 20 MeV, the cross section is assumed to continue the decline in magnitude established at the lower energies, reaching a value of 0.075 barns at 20 MeV. Some graphical values for the $n,n'd$ cross section are shown on pages 1-14 and 1-15 of UCRL-50400, Vol. 8, Rev. 1, Part A, and tabular values are given on page 1-23.

ENERGY AND ANGULAR DISTRIBUTIONS FOR THE $n,n'd$ REACTION

The angular distribution for the excitation of the 2.18-MeV level used in the evaluation was suggested by L. Hansen; the distribution is assumed to be isotropic in the center-of-mass system for energies less than or equal to 4 MeV. From 4 to 14 MeV, the secondary neutron angular distribution is anisotropic, with the anisotropy based on measurements between 3.35 and 14 MeV (see ECSIL Refs. 63-841, 68-1632, 62-1622, and 65-1627). For incident neutron energies greater than 14 MeV, the angular distribution was assumed constant at the 14-MeV value. The energy distribution of

the secondary neutrons produced by the excitation of the 2.18-MeV level is determined by angular distributions and reaction kinematics. For the continuum portion of the $n,n'd$ reaction, the data in Refs. 56-589 and 63-841 give an energy-angle correlation for the secondary neutrons, but the experimental uncertainties in these data are so large that this correlation can, for all practical purposes, be left out of the evaluation. Hence both the angular and energy distributions were derived from a three-body phase space calculation,* which yields results that are consistent with the experimental data.

n,p CROSS SECTION

The threshold for the n,p reaction is 3.18 MeV. Measurements of this reaction from 3.5 to 14.1 MeV are reported in ECSIL references 63-842, 65-1629, 53-86, 54-104, and 61-487. The evaluations for this cross section generally follow the measurements of Ref. 63-842. (Reference 65-1629 gives somewhat higher values than Ref. 63-842, but it does not show the

*G. E. Uhlenbeck, S. Goudsmit, "Statistical Energy Distributions for a Small Number of Particles," *Pieter Zeeman Verhandeligen*, 's - Gravenhage, The Netherlands (1935), pp. 201-211.

experimental errors; hence Ref. 63-842 was followed, rather than an average of the two references). Near 14 MeV the evaluated n,p cross section is about 3 mbarns higher than the measured cross section, but this difference is felt to be inconsequential. The extrapolation to 20 MeV was carried out in accordance with nuclear systematics. Graphical and tabular values of the n,p cross section are given on pages 1-16 and 1-24 of UCRL-50400, Vol. 8, Rev. 1, Part A.

n,t CROSS SECTION

The Q-value for the n,t reaction is 4.79 MeV. Measurements of the n,t cross section from 0.009 to 18.25 MeV are reported in ECSIL Refs. 59-525, 56-1628, 66-1631, 59-1626, 54-109, 52-1637, 60-586, 67-2691, 58-495, 61-487, 65-1634, 67-1020, 64-3333, 56-147, 49-506, 54-109, 59-741, 60-832, and 57-492. Because of its use as a standard, this cross section has received much attention from evaluators and experimenters. Below 0.02 MeV, the n,t cross section has an essentially $1/v$ dependence, which in this evaluation was matched to a value of 944.7 barns at 0.0253 eV. For incident neutron energies above 0.02 MeV, the cross section was determined by experiment, but with a continuing controversy over the location and magnitude of a resonance

in the general neighborhood of 0.25 MeV. In the present evaluation, the resonance was assumed to occur at 0.245 MeV and to have a value of 3.31 barns at the peak. These values agree with the measurements of some experimenters and disagree with the measurements of others. Above the 0.25 MeV resonance, the evaluation generally follows the experimental data up to 18.25 MeV, with an extrapolation to 20 MeV. Graphical values of the n,t cross section are shown on pages 1-17 to 1-20 of UCRL-50400, Vol. 8, Rev. 1, Part A, and some tabular values are given on page 1-24.

n, γ CROSS SECTION

The Q-value for the n, γ reaction is 7.26 MeV. The only measurements for this reaction were made at 0.025 eV (see ECSIL Refs. 61-2799 and 57-2800). A more recent measurement at that energy was made by E. Jurney of LASL. The very large n,t cross section at low energies makes it difficult to measure the capture cross section. For lack of other information, an assumed n, γ cross section value at 0.025 eV was extrapolated in both directions on a $1/v$ basis. The upward $1/v$ extrapolation stopped at 0.024 MeV, at which point the extrapolated cross section had a value of 46 μ barns. For energies greater than 0.024 MeV, the

cross section was assumed to fall linearly until it reached a value of 1 pbarn at 20 MeV. Including this cross section in the evaluation is largely *pro forma*, since it is more than four orders of magnitude less than the n,t cross section at the only measured point. The assumed n, γ cross section value at 0.025 eV was 45 mbarns, which is in good agreement with the subsequent unpublished value of 38.5 mbarns obtained by Jurney. In view of the relative magnitudes of the n,t and the n, γ cross sections, no change in the n, γ evaluation was made to accommodate the newer data.

PHOTON PRODUCTION FROM THE n, γ REACTION

Photon production from the n, γ reaction is represented in the ENDL system by an energy-dependent multiplicity combined with a normalized energy spectrum. In the Li⁶ evaluation, a constant multiplicity of 1.39 photons per capture was assumed for all incident neutron energies. This value is based on the thermal capture photon production measurement of Ref. 67-1898. From the same experiment, the primary gamma-ray energy was set equal to the sum of the Q-value of the reaction (7.26 MeV) plus an energy that is six-sevenths of the incident neutron kinetic energy. It was assumed that 39% of the n, γ photons cascaded through the 0.478-MeV level in Li⁷.

Lithium-7

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^7_3\text{Li}$ are summarized in UCRL-50400, Vol. 3. The ECSIL references to these data are given in UCRL-50400, Vol. 2. The evaluated data for this isotope are shown graphically in UCRL-50400, Vol. 15, Part B.

R. J. Howerton did the original evaluation in 1959. It has been frequently updated, with the most recent changes being added in January 1975.

TOTAL CROSS SECTION

Graphical representations of the total cross section data are shown on pages 1-52 to 1-54 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on pages 1-56 and 1-57.

ELASTIC SCATTERING CROSS SECTION

Measurements of the elastic scattering cross section at incident neutron energies from 1.1 to 4.8 MeV and at 14 MeV are reported in ECSIL Refs. 68-2592, 63-841, 68-1632, 63-2335, 66-1640, and 64-1633. For incident neutron energies less than 1.1 MeV, the elastic scattering cross section was determined from total cross section measurements, since the only other cross section process likely to occur is neutron capture,

and neutron capture for this isotope is a relatively small quantity even at very low neutron energies. In common with other light isotopes, the elastic scattering cross section for Li^7 is constant at neutron energies less than 0.01 MeV. The value of the elastic cross section in this low energy regime was assumed to be 1.1 barns; this value is based on the total cross section measurement of ECSIL Ref. 68-3005 at 0.01 MeV. The first nonelastic reaction for Li^7 is inelastic scattering, which has a threshold at 0.547 MeV; the second nonelastic reaction, $n,n'\alpha$, has a threshold at 2.826 MeV; and the $n,2n$ reaction has a threshold at 8.31 MeV. Each of these reactions is well-determined by experiment. As a result, the elastic scattering cross section can be readily obtained in regions where it has not been measured by subtracting the sum of the inelastic reactions from the total cross section. The total cross section has been measured with fine energy resolution over the entire energy range of interest. The total cross section measurements that were used for this evaluation are contained in Refs. 70-3153, 71-3181, and 67-750, as well as Ref. 68-3005 mentioned above. Since the elastic cross section has only been directly measured over limited energy

Lithium-7

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	53	7/09/72	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	16	1/03/72	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	31	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	31	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	11	7/09/72	0.0000+ 0	5.4700- 1	2.0000+ 1	LEVEL = 4.7740- 1 MEV
N,N'	N ANGULAR DIST.	3	7/09/72	0.0000+ 0	5.4700- 1	2.0000+ 1	LEVEL = 4.7740- 1 MEV
N,N'	G ENERGY-ANGLE DIST.	2	11/01/72	0.0000+ 0	5.4700- 1	2.0000+ 1	LEVEL = 4.7740- 1 MEV
N,N'	G MULTIPLICITY	2	11/01/72	0.0000+ 0	5.4700- 1	2.0000+ 1	LEVEL = 4.7740- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	11/12/74	0.0000+ 0	5.4700- 1	2.0000+ 1	LEVEL = 4.7740- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	11/12/74	0.0000+ 0	5.4700- 1	2.0000+ 1	LEVEL = 4.7740- 1 MEV
N,2N	CROSS SECTION	5	7/09/72	-7.2600+ 0	8.3100+ 0	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	6	7/09/72	-7.2600+ 0	8.3100+ 0	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	12	11/12/74	-7.2600+ 0	8.3100+ 0	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	11	11/12/74	-7.2600+ 0	8.3100+ 0	2.0000+ 1	
N,N'T	CROSS SECTION	14	7/09/72	-2.4700+ 0	2.8260+ 0	2.0000+ 1	
N,N'T	N ANGULAR DIST.	6	7/27/72	-2.4700+ 0	2.8260+ 0	2.0000+ 1	
N,N'T	N ENERGY-ANGLE DIST.	6	7/09/72	-2.4700+ 0	2.8260+ 0	2.0000+ 1	
N,N'T	N TOTAL ENERGY DEP.	3	11/12/74	-2.4700+ 0	2.8260+ 0	2.0000+ 1	
N,N'T	N LOCAL ENERGY DEP.	4	11/12/74	-2.4700+ 0	2.8260+ 0	2.0000+ 1	
N,G	CROSS SECTION	78	1/03/75	2.0300+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY-ANGLE DIST.	2	11/01/72	2.0300+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	11/01/72	2.0300+ 0	1.0000-10	2.0000+ 1	
N,G	N TOTAL ENERGY DEP.	2	11/21/76	2.0300+ 0	1.0000-10	2.0000+ 1	
N,G	N LOCAL ENERGY DEP.	2	11/21/76	2.0300+ 0	1.0000-10	2.0000+ 1	

ranges, these measurements have been used primarily as checks on the accuracy of the elastic cross sections that were obtained by subtracting the nonelastic cross section from the total cross section.

Evaluated cross sections for elastic scattering are shown graphically on page 1-55 of UCRL-50400, Vol. 7, Part A, Rev. 1, and some tabular values are given on page 1-56.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of elastic scattering angular distributions for incident neutron energies from 0.05 to 14 MeV are reported in ECSIL Refs. 60-571, 56-484, 63-841, 68-1632, and 62-1622. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. The elastic scattering angular distribution was assumed to be isotropic in the center-of-mass system for incident neutron energies less than or equal to 0.05 MeV. From 0.05 to 14 MeV, the angular distributions were determined from experiment, with interpolation used in the region between 7 and 14 MeV where there are no experiments. Above 14 MeV, the shapes of the angular distributions were determined from optical model calculations, using the optical model parameters of Becchetti and Greenless in *Phys. Rev.* 182, 1190 (1969). In this

region of the periodic table, optical model calculations usually are not accurate in terms of absolute magnitudes; but at these high energies, in the absence of measurements, optical model calculations are probably as good as any other for obtaining relative angular distributions.

INELASTIC SCATTERING CROSS SECTION

The only inelastic scattering for Li^7 is the excitation of the 0.4774-MeV level. Measurements of the cross section for this excitation have been reported in ECSIL Refs. 55-40, 68-2592, 63-828, 63-841, 68-1632, 65-1639, and 66-1640. These measurements span a range of incident neutron energies from 0.54 to 14 MeV, with a notable gap between 4 and 14 MeV. The interpolation over the gap and the extrapolation from 14 to 20 MeV were performed in accordance with nuclear systematics. Values of the inelastic scattering cross section are shown graphically on pages 1-25 to 1-27 of UCRL-50400, Vol. 8, Rev. 1, Part A, and some tabular values are given on pages 1-30 and 1-31.

ANGULAR DISTRIBUTION FROM INELASTIC SCATTERING

Measurements of the angular distribution for scattering from the 0.4774 level have been reported in ECSIL Refs. 63-841 and 68-1632. The measurements span the energy range

from 1.5 to 4.83 MeV. For energies below 5 MeV, the evaluation was based on the experimental measurements, and for the extrapolation from 5 to 20 MeV, the trend established below 5 MeV was continued.

PHOTON PRODUCTION FROM INELASTIC SCATTERING

A single photon is produced from inelastic scattering, with an energy of 0.477 MeV. It has been assumed that this photon is emitted isotropically, which is probably incorrect. However, the photon angular distribution has not been measured, and in view of the relatively small magnitude of the photon production cross section, no great uncertainties will be introduced by making this assumption.

n,n't CROSS SECTION

The threshold for the n,n't reaction is 2.82 MeV. Measurements of the n,n't cross section for incident neutron energies between 3.75 and 14.8 MeV are reported in ECSIL Refs. 68-838, 63-841, 58-1641, 68-1632, 56-589, 61-2386, and 61-487. For the region just above threshold, where there are no measurements, the n,n't cross section was estimated on the basis of nuclear systematics. At higher energies up to 5 MeV, the evaluation was based on the data of Ref. 68-838. Between 5 and 14 MeV,

the values selected for the evaluation generally followed the nuclear emulsion measurements of Rosen and Stewart, as reported in Ref. 56-589. For neutron energies above 14 MeV, the trend established at the lower energies was continued up to 20 MeV. Values of the n,n't cross section are shown graphically on pages 1-27 to 1-29 of UCRL-50400, Vol. 8, Rev. 1, Part A, and some tabular values are given on pages 1-31.

ANGULAR AND ENERGY DISTRIBUTIONS OF NEUTRONS FROM THE n,n't REACTION

The evaluated energy and angular distributions of the secondary neutrons from the n,n't reaction were based on the data reported in ECSIL Ref. 56-589. In that reference, the secondary neutrons are shown to be correlated by energy and angle, but subsequent neutronics calculations have indicated that the neglect of this correlation is permissible, especially in view of the large experimental uncertainties. For these reasons, the energy and angular distributions are treated as uncorrelated distributions in the evaluation, and these distributions were derived from a three-body phase space calculation.*

* G. E. Uhlenbeck, S. Goudsmit, "Statistical Energy Distributions for a Small Number of Particles," *Pieter Zeeman Verhandelingen*, 's - Gravenhage, The Netherlands (1935), pp. 201-211.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 8.29 MeV. Measurements of this cross section at 10.2 MeV and in the neighborhood of 14.1 MeV are reported in ECSIL Refs. 60-593, 61-2375, 69-2519, and 58-594. The reactions rise gradually from threshold to a value of 0.1 barns at 17 MeV, pass through the measured values at 14 MeV, and pass within the experimental error limits of the 10.2-MeV measurement. Some tabular values of the n,2n cross section are given on page 1-31 of UCRL-50400, Vol. 8, Rev. 1, Part A.

ENERGY AND ANGULAR DISTRIBUTIONS FROM THE n,2n REACTION

Neutrons from the n,2n reaction were assumed to be isotropic in the laboratory system. The energy distributions were obtained by calculating them from a temperature model, using nuclear temperatures described in UCRL-50400, Vol. 15, Part A, page 24.

CROSS SECTION FOR THE n, γ REACTION

The Q-value of the n, γ reaction is 2.03 MeV. Measurements of this reaction at 0.0253 eV are reported in ECSIL Refs. 59-354 and 47-2803, and from 0.037 to 1 MeV in Ref. 58-354.

A $1/v$ cross section extrapolation was carried out in both directions from the 0.0253 eV value, with the upper extrapolation terminating at 0.05 MeV at a cross section value of 10 μ barns. The cross section at 50 μ barns was assumed to be constant from 0.05 MeV to 20 MeV. Some graphical values of the capture cross section are shown on page 1-56 of UCRL-50400, Vol. 7, Part A, Rev. 1; tabular values are given on page 1-57.

PHOTON PRODUCTION FROM THE n, γ REACTION

The multiplicity of photons from the n, γ reaction was assumed to be 1.08 for all incident neutron energies. It was also assumed that the spectrum of photons is made up of three lines, the most energetic of which occurs 92% of the time and is equal to the sum of the Q-value of the reaction plus seven-eighths of the kinetic energy of the incident neutron in the laboratory system. The other 8% of the events were assumed to produce two photons as a result of cascading through the 0.98-MeV level in Li^8 . This assignment for the photon distribution is in agreement with thermal capture measurements of natural lithium (Ref. 70-2415).

Beryllium-7

GENERAL COMMENTS

R. J. Howerton did this evaluation in 1974. Because of the almost total lack of experimental data, the evaluation is based on nuclear systematics. The evaluated data for ${}^7_4\text{Be}$ are shown on pages 25-27 of UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

There are no measurements of either the elastic scattering cross section or the elastic scattering angular distribution for this isotope. The elastic scattering cross section was assumed to be essentially the same as that of Li^7 , except that the 11-barn resonance in Li^7 was assumed to be absent in Be^7 .

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

The angular distributions assumed for this isotope are the same as those used for Li^7 .

n,p CROSS SECTION

The Q-value for the n,p reaction is 1.65 MeV. The n,p cross section evaluation is based on a private communication from D. Barr at LASL. The

n,p cross section has a value of 51,000 barns at an incident neutron energy of 0.025 eV, and it deviates significantly from a $1/v$ dependence, especially at the higher energies.

n, α CROSS SECTION

The Q-value for the n, α reaction is 18.992 MeV. Because of the extremely large value of the n,p reaction at low energies, the n, α reaction was assumed to have a very small but nonzero value at low energies, and then to slowly increase to a maximum of 0.6 barns at 20 MeV. The small n, α cross section assigned at low energies is of no practical consequence for energies less than about 4 MeV because of the competition with the extremely large n,p cross section. The values assumed for the n, α cross section are highly uncertain, and are based completely on nuclear systematics.

PHOTON PRODUCTION FROM NEUTRON INDUCED INTERACTIONS

It was assumed that there was no photon production from neutron-induced reactions for this isotope.

Beryllium-7

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	10	9/15/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	16	9/15/74	0.0000+ 0	5.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	31	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	31	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,P	CROSS SECTION	113	2/16/70	1.6500+ 0	1.0000-10	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	11/12/74	1.6500+ 0	1.0000-10	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	11/12/74	1.6500+ 0	1.0000-10	2.0000+ 1
N,A	CROSS SECTION	9	9/15/74	1.8992+ 1	1.0000-10	2.0000+ 1
N,A	TOTAL ENERGY DEP.	2	11/12/74	1.8992+ 1	1.0000-10	2.0000+ 1
N,A	LOCAL ENERGY DEP.	2	11/12/74	1.8992+ 1	1.0000-10	2.0000+ 1

Beryllium-9

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^9_4\text{Be}$ are summarized in UCRL-50400, Vol. 3. The evaluated data for Be^9 are shown graphically in UCRL-50400, Vol. 15, Part B. The listings for the ECSIL data references are given in UCRL-50400, Vol. 2. This evaluation was done by S. T. Perkins and R. J. Howerton.

There are no measurements for the (n,np), (n,nd), (n,2t) and (n,nt) reactions; since the thresholds for these reactions are very high, their cross sections are considered negligible. Also, since He^5 is unstable (it decays to a neutron and an alpha particle with a ground-state half-life of about 2×10^{-21} s), the (n,n α) decay mode is a component of the (n,2n) reaction; therefore, it does not have to be considered separately. The inelastic scattering reaction is also a component of the (n,2n) reaction, since the Be^{9*} recoil nucleus always decays to a neutron and two alpha particles.

TOTAL CROSS SECTION

Experimental values of the total cross section are shown graphically on pages 1-58 to 1-70 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 1-73.

ELASTIC SCATTERING CROSS SECTION

Experimental values of the elastic cross section are shown graphically on pages 1-71 and 1-72 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 1-73. The free-atom cross section is used for all energies less than the usual upper limit set by the molecular binding energy (about 10 eV). Actually, this cross section only represents the nuclear part of the cross section for a stationary target. It should be strongly emphasized that these numbers are meaningless in the absence of a proper thermal treatment, either by the processing code or by the neutronics code that uses these numbers.

From 0.0001 eV to 0.01 MeV, the elastic scattering cross section was set equal to 6 barns. From 0.01 MeV to the (n, χ) threshold at 0.67 MeV, the elastic cross section is essentially equal to the total cross section, because the (n, γ) cross section is negligible. The total cross section used here was based on the data of ECSIL Refs. 50-63, 54-92, 62-720, 62-772, and 54-1002.

Above the (n, α) threshold, the scattering cross section was assumed to be the difference between the total and nonelastic cross sections,

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Beryllium-9 (Cont.)

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N.G	CROSS SECTION	151	12/14/71	6.8200+ 0	1.0000-10	2.0000+ 1
N.G	G ENERGY-ANGLE DIST.	2	10/25/72	6.8200+ 0	1.0000-10	2.0000+ 1
N.G	G MULTIPLICITY	2	10/25/72	6.8200+ 0	1.0000-10	2.0000+ 1
N.G	TOTAL ENERGY DEP.	2	11/21/76	6.8200+ 0	1.0000-10	2.0000+ 1
N.G	LOCAL ENERGY DEP.	2	11/21/76	6.8200+ 0	1.0000-10	2.0000+ 1

with the nonelastic cross section set equal to the sum of its parts. From 0.67 to 2 MeV, the evaluated total cross section was based on the previously mentioned references as well as Refs. 51-72, 51-336, and 59-1642. Above 2 MeV, we relied on the results of Ref. 68-3088 for the 2.7-MeV resonance and Ref. 67-750 for the energy region up to 15 MeV. The extension to 20 MeV was based on data from Refs. 54-107, 60-673, and 61-682.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies less than 7 MeV, experimental differential scattering data are given in Refs. 55-121, 56-151, 57-231, 55-296, 59-500, 60-571, 58-945, 64-1643, 60-1645, 61-1646, and 64-1647. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. These data were used to determine the normalized probabilities. Below the (n,2n) threshold, the scattering consists of only elastic scattering, since there is no inelastic scattering. We took into account the change in shape of the angular distribution in going through the scattering resonances. At 14 MeV, the elastic angular distributions were based on the results of Refs. 59-402, 66-2585, and 68-3106. A smooth extrapolation was made to 20 MeV. The

results at all incident energies are consistent with Wick's limit.

n,2n CROSS SECTION

The total (n,2n) cross section is based on the (n,2n) cross sections and nonelastic-minus-absorption cross sections listed by Perkins in AN-1443 (1965). The cross section measurements have been augmented by the more recent (n,2n) data of Refs. 69-763 and 72-3320. The nonelastic measurements of Refs. 68-2595 and 73-3321 were also taken into account. The 20-MeV point was obtained by

- Interpolating nonelastic cross sections between the 14-MeV value and the value at 25.5 MeV (see Ref. 58-356)
- Subtracting the other partial nonelastic reaction cross sections from the interpolated nonelastic cross section.

There have been two recent measurements on the partial cross sections involved in the Be(n,2n) breakup (D. M. Drake *et al.*, *Nucl. Sci. Eng.* 63, 401 [1977]; and F. O. Purser, private communication from Triangle Univ. Nucl. Lab. [1976]). Both references indicated that from about 6 to 12 MeV, the cross section for excitation of the 2.43-MeV level in Be is substantially lower (up to a factor of two) than was thought previously. In addition, the cross section for excitation of the 1.68-

MeV level has essentially disappeared at 6 MeV. This implies a relatively large cross section for excitation of the 4.7-MeV level when the incident neutron energy lies between 6 MeV and the threshold for excitation of the 6.76-MeV level.

The total (n,2n) cross section is subdivided into five partial reactions, each of which is described by the following time-sequential decay:

where the W_1 's are the level excitation energies, and n_1 and n_2 are the first and second emitted neutrons. The five decay channels are shown below.

Decay channels for the (n,2n) reaction.

W_9 , MeV	W_8 , MeV	Branching fraction, %
1.68	→ 0	100
2.43	→ 0	8-1/3%
	→ 2.94	91-2/3%
4.70	→ 2.94	100
6.76	→ 0	100
11.28	→ 11.4	100

The above branching ratios were measured by Perkins [see AN-1443 (1965)], except for the Be^{9*} (9.1 MeV) transition which has been replaced by Be^{9*} (11.28 MeV) and Be^{9*}

(4.70) decay. The latter measurements are based on the results of C. L. Cocke and P. R. Christensen [see *Nucl. Phys.* A111, 623 (1968)].

Most of the levels in both nuclei are wide. The center-of-mass widths used in the evaluation are given below.

Center-of-mass widths used in the evaluation.^a

W_9 , MeV	Γ_9 , MeV
1.68	0.21
2.43	0
4.70	0.74
6.76	2
11.28	0.575

W_8 , MeV	Γ_8 , MeV
0	0
2.94	1.56
11.4	7

^aF. Ajzenberg-Selove and T. Lauritzen, *Nucl. Phys.* 11, 1 (1959).

ENERGY AND ANGULAR DISTRIBUTIONS FROM THE n,2n REACTION

The five partial (n,2n) reactions include one narrow level and four wide levels. In each of these, the first neutron is described as the result of an inelastic scattering event. The experimental center-of-mass angular distribution of the first neutron from the narrow Be^{9*}

level (2.43 MeV) is described in a P_6 Legendre expansion. The neutrons from the other levels are assumed to be isotropic in their center-of-mass systems. The energy-angle correlation for first neutrons is preserved.

The description of the second neutron from each partial reaction neglects the energy-angle correlation. This is a valid approximation for this reaction, as has been discussed by S. T. Perkins in *Nucl. Sci. Eng.* 31, 156 (1968). All wide levels were described by single-level dispersion theory. After the theoretical level distributions were obtained for Be^{9*} and Be^{8*} , they were integrated, using the equations in AN-1443 (1965), to obtain the Legendre moments of the transference function, $\sigma_q(E, E')$, for the second neutron. The integration scheme uses excitation energy bins of equal probability; calculations were performed at the average excitation energy within each bin. (This mode of integration appeared to be the most economical one to use in this case.) This integration scheme introduces some discontinuities into the output spectra, particularly at low incident neutron energies. Since an increase in the number of bins did not appear to be economically feasible, these results were smoothed with a smoothing algorithm. The effective threshold values for the 6.76- and 11.28-MeV

level excitations were assumed to be at incident neutron energies of 7 and 12 MeV, respectively. This allows a better incorporation of the wide-level effects. In these calculations, the center-of-mass angular distribution of the recoiling Be^{9*} nucleus had to be consistent with the description of the first neutron mentioned above. The subsequent decay breakup (into Be^{8*} and a neutron) was assumed to be isotropic in the (Be^{8*}, n) center-of-mass system.

The angular distributions for second neutrons in the laboratory frame-of-reference were obtained from a P_9 Legendre expansion of the transference function. The Legendre moments from the P_9 Legendre expansion were integrated over the energy of the second neutron in order to obtain the Legendre coefficients of the laboratory system angular distributions, which then led directly to the angular distributions themselves.

n, p CROSS SECTION

This cross section was estimated from the known threshold value and the single measurement at 15.5 MeV (Ref. 63-913).

n, d CROSS SECTION

This cross section is based on the known threshold value and the measured data between 16.5 and 18.8 MeV (Ref. 69-3101).

n,t CROSS SECTION

The cross section for the (n,t) reaction is divided into (n,t₀) and (n,t₁) components, which proceed through the ground state and the 0.477-MeV level of Li^{7*}, respectively. The total (n,t) cross section near 14 MeV was determined from Refs. 58-496 and 61-650. Except for noting the variation of the cross section with energy, the results of Ref. 58-494 were neglected, due to the large uncertainties in these results.

The (n,t₁) cross section was based on results from F. S. Dietrich *et al.*, *Nucl. Sci. Eng.* 61, 267 (1976). The (n,t₀) cross section was drawn smoothly from zero at threshold to a value at 14 MeV that is the difference between the total (n,t) cross section and the (n,t₁) cross section; above 14 MeV, the (n,t₀) cross section decreases smoothly.

n,α CROSS SECTION

For neutron energies less than 8.6 MeV, the n,α cross section was based on the measurements reported in Refs. 58-494, 57-160, and 61-733. It was then smoothly joined to the three values given at 14 MeV (Refs. 61-650, 53-86, and 67-2367) and extrapolated to 20 MeV. Note that the measured cross section only applies to the production of the ⁶He ground state, which beta decays to

⁶Li; for higher states, ⁶He decays into an alpha particle and two neutrons.

n,γ CROSS SECTION

The n,γ cross section was assumed to be inversely proportional to incident neutron speed below 100 eV, with a 2200-m/s cross section of 9.5 mbarns. It was extrapolated linearly on a log-log basis to 0.1 mbarn at 1 keV, and then held constant at this value up to 20 MeV.

PHOTON PRODUCTION CROSS SECTIONS AND SPECTRA

Gamma rays in Be⁹ are produced by the (n,γ) and (n,t) reactions. At thermal neutron energy, Ref. 70-2415 lists the gamma-ray energies as 0.8535, 2.59, 3.368, 3.444, 5.958, and 6.81 MeV, and it gives the corresponding (n,Xγ) cross sections. The photon spectrum was assumed to be independent of incident neutron energy. The multiplicity M(E₀), however, varies with the incident neutron energy E₀ as follows:

$$M(E_0) = M(0) (E_{c-m} + Q_{n,\gamma}) / Q_{n,\gamma},$$

where M(0) is the multiplicity at thermal energies, Q_{n,γ} is the Q-value for the (n,γ) reaction, and E_{c-m} is the center-of-mass energy:

$$E_{c-m} = \frac{A}{A+1} E_0.$$

By using this recipe, we conserve energy. As the incident neutron energy increases, there are undoubtedly higher levels of Be^{10} that are also excited. However, these higher levels and their transitions have been only partially identified. The component relevant to the (n, t_1) cross section is in

fact equal to this cross section (since its multiplicity is unity).

The angular distribution of gamma rays from the (n, t_1) reaction is isotropic, as reported in Ref. 59-605. The angular distribution of the capture gamma rays is assumed to be isotropic.

Boron-10

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $_{5}B^{10}$ are listed in UCRL-50400, Vol. 3. The evaluated data for this isotope are shown graphically in UCRL-50400, Vol. 15, Part B. A list of the ECSIL data references is given in UCRL-50400, Vol. 2.

R. J. Howerton did the first evaluation for B^{10} in 1960; it was extensively revised by him in 1970. R. C. Haight entered the photon production data into the evaluation in 1972.

TOTAL CROSS SECTION

Experimental values of the B^{10} total cross section are shown graphically on pages 1-79 to 1-85 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 1-87.

ELASTIC SCATTERING CROSS SECTION

Only three measurements of the B^{10} cross section for elastic scattering have been made. These measurements, which fall in the energy range from 0.55 to 1.5 MeV, are reported in ECSIL Ref. 55-121. As with other light isotopes, it is assumed that the elastic scattering cross section is constant at 2 barns for energies less than 0.01 MeV. Because so few values were measured for the elastic

cross section, values at energies greater than 0.01 MeV were derived by subtracting the sum of all other reactions from the measured total cross section. In obtaining a total cross section from which the sum of the nonelastic reaction cross sections could be subtracted, the following ECSIL references were considered: 67-1550, 63-802, 51-72, 54-504, 62-642, 61-682, 56-141, and 54-107. The only measured nonelastic cross section, at 14.2 MeV, is reported in Ref. 57-319. This measurement was taken into account when deducing total nonelastic cross sections at other nearby energies.

Graphical values of the elastic scattering cross section are shown on page 1-86 of UCRL-50400, Vol. 7, Part A, rev. 1; some tabular values are given on page 1-87.

ELASTIC SCATTERING ANGULAR DISTRIBUTION

The only measurements of differential elastic cross sections for B^{10} are reported in Ref. 55-121. The measurements cover the energy range from 0.55 to 1.5 MeV. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. Since there are so few experimental elastic scattering angular distributions for this isotope, the

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Boron-10 (Cont.)

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,G	G ENERGY-ANGLE DIST.	2	11/01/72	1.1450+ 1	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	11/01/72	1.1450+ 1	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	1.1450+ 1	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	1.1450+ 1	1.0000-10	2.0000+ 1

evaluated file was based on experimental data for natural boron (and to some extent for B^{11}). The ECSIL references used were 56-231, 55-151, 62-1060, and 66-1648 for natural boron, and Refs. 70-3133 and 69-2999 for B^{11} . For incident neutron energies up to 0.33 MeV, the elastic scattering angular distribution was assumed to be isotropic in the center-of-mass system. For incident neutron energies above 0.33 MeV, the angular distributions were based on the experimental data described above.

INELASTIC SCATTERING CROSS SECTIONS

The only measurements of the inelastic scattering of neutrons from B^{10} are at 7.02 and 7.55 MeV (ECSIL Ref. 69-2999). Experimental data are presented in that reference for the excitation of the third through seventh levels, with the sixth and seventh being an unresolved cluster of levels. In the present evaluation, excitation functions are given for the first four levels (0.72, 1.74, 2.15 and 3.59 MeV), plus a continuum representation for the higher lying levels that begin at 5 MeV. As there were no experimental data for the first two levels, their excitation functions were estimated from systematics. For the third and fourth levels, the measured values at 7 and 7.5 MeV were taken into account

when estimating the excitation function over the entire energy range. The shape of the excitation function for neutrons inelastically scattering to the continuum of levels starting at 5 MeV was estimated largely from nuclear systematics, but a point of normalization was obtained at 14 MeV by subtracting the sum of the other nonelastic reaction cross sections from the measurement of the total nonelastic cross section (ECSIL Ref. 57-319).

Graphical values of the n,n' cross sections are shown on pages 1-47 and 1-48 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-56.

ENERGY AND ANGULAR DISTRIBUTIONS FROM INELASTIC SCATTERING

For the four inelastic levels contained in the evaluation, it was assumed that the angular distribution of the secondary neutrons was isotropic in the center-of-mass system. For the third and fourth levels, the angular distribution of the secondary neutrons was measured at 7 and 7.5 MeV (ECSIL Ref. 69-2999). These measurements indicated that the assumption of isotropy was incorrect at these incident energies. But with only two measurements, and with uncertainties in the angular distributions of the order of 30%, it was felt that inserting angular distributions based

on such meager data would not be warranted. Angular distributions of secondary neutrons from the continuum inelastic scattering process were assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons scattering from the discrete level can be calculated from the angular distributions by using reaction kinematics. For convenience, the energy distributions of secondary neutrons inelastically scattering from the continuum were obtained by using a temperature model calculation. We recognize that the temperature model formalism does not apply in this region of the periodic table, but the temperature model is a convenient construct.

PHOTON PRODUCTION FROM INELASTIC SCATTERING

Since the 0.717-MeV level is the first excited state in B^{10} , a single 0.717-MeV photon is produced by inelastic scattering from that level. This photon was assumed to be emitted isotropically. Photon production from the 1.74-MeV level was determined by using the branching ratios reported by F. Ajzenberg-Selove and T. Lauritsen in *Nucl. Phys. A227*, 1 (1974). This level is de-excited virtually 100% of the time by a cascade through the 0.717-MeV level. Both of the photons resulting from the excitation of this level were assumed to be emitted

isotropically. The production of photons from the 2.154- and 3.59-MeV levels was also determined by using the branching ratios reported in Ajzenberg-Selove and Lauritsen. Photon production associated with continuum inelastic scattering was obtained by estimating the multiplicity and spectra at appropriate incident neutron energies.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 9.28 MeV. The only n,2n measurement, at 14.1 MeV, is reported in ECSIL Ref. 69-2519. The n,2n reaction was assumed to rise in accordance with systematics, to pass through a maximum value of 0.025 barns at 15 MeV, and then to fall to a value of 0.02 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FROM THE n,2n REACTION

Secondary neutrons from the n,2n reaction were assumed to be isotropic in the laboratory system. Energy distributions from this reaction were calculated from the temperature model, using the assumptions described in UCRL-50400, Vol. 15, Part A, page 24 to obtain the appropriate nuclear temperatures.

n,n'd2α CROSS SECTION

The Q-value for the n,n'd2α reaction is -6.02 MeV. Measurements from

12.2 to 19.5 MeV are reported in ECSIL Ref. 56-144. This reaction is assumed to have a threshold at 6.7 MeV, and to rise in the usual sigmoid shape up to an energy range where measurements are available.

ENERGY AND ANGULAR DISTRIBUTIONS FROM THE $n, n'd2\alpha$ REACTION

The angular distributions of secondary neutrons from this reaction were assumed to be isotropic in the laboratory system. The energy distributions were derived from a four-body phase space calculation* that correlated the energy with the angles of secondary neutrons. However, since the correspondence of these calculations to reality is so uncertain, the assumption of isotropy in the laboratory system for the angular distributions seems adequate.

$n, t2\alpha$ CROSS SECTION

The Q-value for the $n, t2\alpha$ reaction is 0.33 MeV. Measurements of the cross section for this reaction are reported in ECSIL Refs. 61-742, 58-496, and 56-144; the measurements include incident neutron energies from 1.36 to 19.5 MeV. Although this

reaction is exoergic, it is assumed to have an effective threshold at 1.5 MeV because of competition from the extremely large n, α reaction, which has an even more positive Q-value. The reaction is assumed to rise gradually from the effective threshold at 1.5 MeV to a maximum in the neighborhood of 5.5 MeV, and then to fall gradually with increasing neutron energy in accordance with the measured values.

n, α CROSS SECTION

The Q-value for the n, α reaction is 2.8 MeV. Measurements of the n, α reaction are reported in ECSIL Refs. 72-3259, 63-802, 67-1020, 65-1649, 57-392, 56-278 and 69-2750, which cover the energy region from 0.004 to 4.78 MeV. In addition to direct measurements, the n, α cross section can also be obtained by measuring the total cross section for incident neutron energies below 0.004 MeV. Measurements of the total cross section from 4.6×10^{-9} MeV to 0.082 MeV are reported in ECSIL Refs. 60-805, 63-463, 60-385, 58-823, 67-1550, 52-252, and 63-802. Measurements of the absorption cross section, which at 0.0253 eV is attributed almost entirely to the n, α reaction, are reported in ECSIL Refs. 60-805, 60-891, 67-463, and 70-3218.

Because this reaction is used as a standard for flux monitoring in

*G. E. Uhlenbeck, S. Goudsmit, "Statistical Energy Distributions for a Small Number of Particles, *Pieter Zeeman Verhandelingen*, 's - Gravenhage, The Netherlands (1935), pp. 201-211.

neutron experiments, it has received much attention over the years. For incident neutron energies below 0.1 MeV, the (n,α) cross section is almost pure $1/v$ in its energy dependence. For energies between 0.1 MeV and 5 MeV, the (n,α) cross section is obtained from experiment. From 5 MeV to 7.6 MeV, the measurements reported in ECSIL Ref. 61-742 supply the cross section for the n,α_1 and the n,α_0 reactions. Fortunately, these two reactions comprise almost all of the total reaction cross section. A measurement at 14.4 MeV (reported in ECSIL Ref. 69-3282) provides an anchor point at the upper end of the energy region for this cross section.

Experimental values of the (n,α) cross section are shown graphically on pages 1-52 to 1-55 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-57.

PHOTON PRODUCTION FROM THE n,α REACTION

At low neutron energies, the n,α_1 reaction comprises more than 90% of the total n,α reaction, with this fraction gradually diminishing as the neutron energy increases. For incident neutron energies below 1 MeV, an experimental determination of the energy dependence of the ratio $n,\alpha_1/n,\alpha_0$ is reported in ECSIL Ref. 65-1052. For energies above 1 MeV, this ratio is determined from the 0.478-MeV

photon production data, using the values reported in ECSIL Ref. 70-3324.

CROSS SECTION FOR THE n,γ REACTION

The Q-value for the n,γ reaction is 11.45 MeV. There have been no direct measurements of this cross section, but various reactor experiments indicate that a value of about 450 mbarns is appropriate at an energy of 0.0253 eV. This value was used with a $1/v$ extrapolation in both directions from 0.0253 eV. In the upward extrapolation, a value of 7 mbarns was reached at 0.0001 MeV; above this point the cross section was assumed to trail off, falling to values of 1 mbarn at 0.01 MeV, 0.5 mbarns at 0.1 MeV, and 0.1 mbarns at 20 MeV.

PHOTON PRODUCTION FROM THE n,γ REACTION

Photon production from capture at thermal neutron energy was taken from ECSIL Ref. 70-2415, with a modification that equated the intensities of the 4.443- and 7.005-MeV gamma rays, as well as the intensities of the 4.710- and 6.759-MeV gamma rays. This modification was a guess, based to some extent on the data of Ref. 70-2415, which took cognizance of the fact that each pair of transitions is a gamma-ray cascade. At energies above thermal, the gamma-ray energies were kept constant, and the

gamma-ray multiplicities were varied according to the formula $m = m_{\text{thermal}} \times (E + Q) / Q$, where E is the neutron energy and Q is the Q -value for capture. Although this prescription does not describe the

physics, it does conserve energy, and it probably is adequate for most applied purposes. The saving feature of this particular evaluation is the fact that the (n,γ) cross section is small.

Boron-11

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{11}_5\text{B}$ are listed in UCRL-50400, Vol. 3. The evaluated data for this isotope are shown graphically in UCRL-50400, Vol. 15, Part B. The ECSIL data references are described in UCRL-50400, Vol. 2.

The $^{11}_5\text{B}$ evaluation was carried out by R. J. Howerton in 1972. Photon production data from neutron-induced processes were provided by R. C. Haight. Prior to the completion of this evaluation, the ENDL library contained evaluations for $^{10}_5\text{B}$ and $^{10}_{\text{B}}^{\text{Nat}}$. To allow the user to combine the isotopes of boron as he deemed appropriate, the natural boron evaluation was eliminated and was replaced by the $^{11}_5\text{B}$ evaluation.

TOTAL CROSS SECTION

Experimental total cross section values are shown graphically on pages 1-87 to 1-89 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 1-91.

ELASTIC SCATTERING CROSS SECTION

Experimental values of the elastic scattering cross section are shown graphically on page 1-90 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 1-92. Measurements of the elastic scattering cross section from 0.43 MeV to 1.5 MeV

are reported in ECSIL Ref. 55-121. One additional measurement at 7.55 MeV is reported in Ref. 69-2999. For incident neutron energies below 2 MeV, the elastic cross section can be determined from measurements of the total cross section, since the nonelastic cross section is very small in this energy region. Measurements of the total cross section for incident energies from 0.01 to 2 MeV are reported in ECSIL Refs. 66-2012 and 70-3133. For neutron energies below 0.02 MeV, it was assumed that the elastic scattering cross section was constant at a value of 5 barns, which is the value of the total cross section in the neighborhood of 0.01 MeV. This value is the lowest neutron energy at which the total cross section has been measured. Total cross section measurements from 14 to 18 MeV are reported in Refs. 52-81 and 54-107. At these higher energies, the elastic scattering cross section can be obtained by subtracting the sum of the measured inelastic cross sections from the measured total cross section. This still leaves the neutron energy ranges from 2 MeV to 7.5 MeV and 7.5 MeV to 14 MeV without measurements of either the total cross section or the elastic scattering cross section. Values for the elastic scattering cross section in

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Boron-11 (Cont.)

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N, G	LOCAL ENERGY DEP.	2	11/21/76	3.3700+ 0	1.0000-10	2.0000+ 1

these energy ranges were obtained from nuclear systematics.

ANGULAR DISTRIBUTIONS FOR ELASTIC SCATTERING

Angular distributions for elastic scattering in the energy range from 0.075 to 2.24 MeV are reported in ECSIL Ref. 70-3133; a measurement at 7.55 MeV is reported in Ref. 69-2999. In addition to these data, measurements from 0.06 to 1.5 MeV for natural boron are reported in Refs. 56-231 and 55-121. Elastic scattering angular distributions for natural boron at 14 MeV are reported in ECSIL Refs. 62-1060 and 66-1648. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. The evaluated B^{11} angular distributions are based on measurements where possible, and on nuclear systematics where there are no measurements.

INELASTIC SCATTERING CROSS SECTIONS

Inelastic scattering for B^{11} is represented in the evaluation by individual functions for scattering to the first three levels of excitation (2.14, 4.46, and 5.03 MeV), plus a continuum cross section for inelastic scattering to higher levels. The only experimental measurement (ECSIL Ref. 69-2999) for scattering to the first two levels was made at an incident neutron energy of 7.55 MeV.

All three of the level excitation functions, therefore, had to be estimated over the entire incident neutron energy range above their respective thresholds, with the first two excitation functions normalized to match the single measured data point for each. The cross section for the excitation of the third level was estimated in its entirety from nuclear systematics, as was the cross section for continuum inelastic scattering.

Experimental data on inelastic scattering are shown graphically on pages 1-58 and 1-59 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 1-60 and 1-61.

ENERGY AND ANGULAR DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distribution of secondary neutrons scattering from the first two excited levels of B^{11} has only been measured at an incident neutron energy of 7.55 MeV. Since this distribution was only measured at that one energy, and the measurement was over a limited range of angle and had an uncertainty of 25%, we could not determine an energy-dependent set of angular distributions for the two excited levels. Furthermore, the integral cross sections themselves had to be estimated everywhere except at 7.55 MeV. Thus the inelastic

scattering angular distributions were assumed to be isotropic in the center-of-mass system for all incident neutron energies. Angular distributions for secondary neutrons resulting from the excitation of the third level in B^{11} have not been measured at any energy, so it was also assumed that they were isotropic. Energy distributions for secondary neutrons resulting from inelastic level scattering can be determined with nuclear kinematics, using the assumed angular distributions. Secondary neutrons from the continuum inelastic scattering process were assumed to be isotropic in the laboratory system, and the energy distributions of these neutrons were derived from a temperature model representation, with the nuclear temperatures assigned in the manner described in UCRL-50400, Vol. 15, Part A, pages 19-22.

PHOTON PRODUCTION FROM INELASTIC SCATTERING

The spectra and multiplicities of gamma rays, which appear when the first three excited levels in B^{11} decay, were determined from data given by F. Ajzenberg-Selove and T. Lauritsen in *Nuclear Physics A114*, 1 (1968). For n, n' reactions to higher energy levels (represented in the evaluation as a continuum process) the multiplicities and spectra were estimated.

$n, 2n$ CROSS SECTION

The threshold for the $n, 2n$ reaction is 12.50 MeV. A single $n, 2n$ measurement at 14.1 MeV is reported in ECSIL Ref. 69-2519. The $n, 2n$ cross section was assumed to rise to a value of 0.02 barns at 14 MeV, and to remain constant at that value above 14 MeV.

ENERGY AND ANGULAR DISTRIBUTIONS FROM THE $n, 2n$ REACTION

Secondary neutrons produced by the $n, 2n$ reaction were assumed to be isotropic in the laboratory system. The energy distributions were derived from temperature model calculations, with the nuclear temperatures obtained by the procedures described in UCRL-50400, Vol. 15, Part A, page 24.

PHOTON PRODUCTION FROM THE $n, 2n$ REACTION

The $n, 2n$ reaction populates energy levels in B^{10} . Spectra and multiplicities for photons from this reaction were guessed.

n, p CROSS SECTION

The threshold for the n, p reaction is 11.70 MeV. The cross section for this reaction has been measured over the incident neutron energy range from 14 to 14.7 MeV (ECSIL Refs. 61-2574, 67-1651, and 62-88). The n, p reaction was assumed to rise from threshold to a value consistent with

measurement at 14 MeV, and to remain constant at this value above 14 MeV.

PHOTON PRODUCTION FROM THE n, p REACTION

This reaction populates energy levels in Be^{11} . The spectra multiplicities for photons from the n, p reaction were guessed.

n, t CROSS SECTION

The threshold for the n, t process is 10.43 MeV. A single measurement at 14 MeV is reported in ECSIL Ref. 58-496. The cross section for the n, t reaction was assumed to rise in a sigmoid shape to the measured value at 14 MeV, and to remain constant above 14 MeV.

n, α CROSS SECTION

The threshold for the n, α process is 7.24 MeV. The (n, α) reaction has been measured over the energy range from 12.6 to 20 MeV (ECSIL Refs. 56-145, 59-539, and 62-88). The reaction is assumed to rise in a sigmoid shape to match the measured value at 12.6 MeV, and to match the experimental data throughout the remainder of the incident neutron energy range. Experimental values of the (n, α) cross section are shown graphically on page 1-60 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-62.

PHOTON PRODUCTION FROM THE n, α REACTION

The n, α reaction populates energy levels in Li^8 , so some 0.98-MeV gamma rays are expected. The multiplicity of 0.98-MeV gamma rays was estimated to be 0.5 for incident neutron energies above 8.5 MeV; that is, the n, α reaction populates the ground state of Li^8 and the excited state at 0.98 MeV with the same number of particles. From threshold to 8.5 MeV, the multiplicity was assumed to vary linearly from a zero value at threshold to the assumed 0.5 value at 8.5 MeV.

n, γ CROSS SECTION

The Q -value for the n, γ process is 3.37 MeV. Measurements of the n, γ cross section at thermal energy and from 0.139 to 2.325 MeV are reported in ECSIL Ref. 62-690. The measured thermal value is 5 mbarns. This value was assigned at 0.025 eV, with a $1/v$ extrapolation in both directions over the energy range from 0.0001 to 1 eV. From 1 eV to 0.01 MeV, the cross section was assumed to remain constant at 0.8 mbarns, then to connect smoothly with the measured values through 2.3 MeV, then to decrease to a value of 0.1 mbarns at 5 MeV, and to a value of 0.01 mbarns at 20 MeV.

PHOTON PRODUCTION FROM THE n,γ REACTION

Since the n,γ reaction has a very small cross section, and since there are no experimental determinations of either the multiplicity or the spectrum from neutron capture, both of these quantities were estimated. The photon energy spectra at all incident neutron energies were assumed to be identical, rising from a zero value at zero photon energy to a flat value from 1 to 3 MeV, and then falling off again to zero at 3.37 MeV (the Q-

value for the reaction). The multiplicity at 0.0001 eV was assumed to be 1.69, which is the value required to conserve energy for the spectrum described above. For higher neutron energies, the multiplicity was assumed to be $1.69(E + Q)/Q$, where E is the incident neutron energy and Q is the Q-value for capture. This prescription does not describe the physics of the n,γ process, but it does conserve energy, and it is probably adequate for most applications.

Carbon-12

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^6\text{C}^{12}$ are listed in UCRL-50400, Vol. 3. The bibliographic references for these data are given in UCRL-50400, Vol. 2. The evaluated data for C^{12} are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation. This evaluation was based in large part on the extensive experimental data for neutron-induced reactions in carbon.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for carbon are shown graphically on pages 1-92 to 1-121 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on pages 1-123 and 1-124.

ELASTIC SCATTERING CROSS SECTION

Graphical values of experimental and evaluated elastic scattering cross sections are shown on pages 1-122 and 1-123 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on pages 1-124 and 1-125. For neutron energies below the excitation energy of the first inelastic level (4.43 MeV), the elastic cross section is, apart from the small capture cross section, equal to the total cross section.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For incident energies below 0.15 MeV, the elastic scattering process was assumed to be isotropic in the center-of-mass system. Extensive measurements of elastic scattering angular distributions exist that span the energy range from 0.5 to 20 MeV. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, an energy grid for the angular distributions was chosen so that a linear interpolation to the cosine of the scattering angle would have an accuracy compatible with that of the experimental measurements.

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering in C^{12} occurs mainly from excitation of the 4.43-MeV level, since excitation of the higher levels results in the breakup of the nucleus into three alpha particles rather than de-excitation to the ground state. However, both the inelastic scattering reaction and the breakup reaction contribute to the production of inelastically-scattered neutrons. Experimental and evaluated cross sections for the excitation of the 4.43-MeV level in C^{12} are shown graphically on pages 1-66 and 1-67 of UCRL-50400, Vol. 8, Rev. 1, Part A;

Carbon-12

05/09/78

	REACTION	POINTS	DATE	Q-VALUE	MIN.	MAX.	
N,ELASTIC	CROSS SECTION	123	3/15/77	0.0000+0	1.0000+1	2.0000+1	
N,ELASTIC	N ANGULAR DIST.	17	6/15/76	0.0000+0	1.0000+1	2.0000+1	
N,ELASTIC	N TOTAL ENERGY DEP.	25	11/12/74	0.0000+0	1.0000+17	2.0000+1	
N,ELASTIC	N LOCAL ENERGY DEP.	25	11/12/74	0.0000+0	1.0000+17	2.0000+1	
N,N'	CROSS SECTION	21	3/15/77	0.0000+0	4.8024+0	2.0000+1	LEVEL 4.4300+0 MEV
N,N'	N ANGULAR DIST.	5	6/15/76	0.0000+0	4.8024+0	2.0000+1	LEVEL 4.4300+0 MEV
N,N'	N TOTAL ENERGY DEP.	4	11/12/74	0.0000+0	4.8024+0	2.0000+1	LEVEL 4.4300+0 MEV
N,N'	N LOCAL ENERGY DEP.	4	11/12/74	0.0000+0	4.8024+0	2.0000+1	LEVEL 4.4300+0 MEV
N,N'3A	CROSS SECTION	9	3/15/77	7.3600+0	7.9800+0	2.0000+1	
N,N'3A	N ENERGY-ANGLE DIST.	1	11/12/74	7.3600+0	7.9800+0	2.0000+1	
N,N'3A	N TOTAL ENERGY DEP.	9	5/29/78	7.3600+0	7.9800+0	2.0000+1	
N,N'3A	N LOCAL ENERGY DEP.	9	5/29/78	7.3600+0	7.9800+0	2.0000+1	
N,N'3A	CROSS SECTION	4	10/09/76	7.3600+0	8.2930+0	2.0000+1	LEVEL 7.6500+0 MEV
N,N'3A	N ANGULAR DIST.	3	6/15/76	7.3600+0	8.2930+0	2.0000+1	LEVEL 7.6500+0 MEV
N,N'3A	N TOTAL ENERGY DEP.	6	2/08/73	7.3600+0	8.2930+0	2.0000+1	LEVEL 7.6500+0 MEV
N,N'3A	N LOCAL ENERGY DEP.	6	2/08/73	7.3600+0	8.2930+0	2.0000+1	LEVEL 7.6500+0 MEV
N,N'3A	CROSS SECTION	6	3/15/77	7.3600+0	1.0939+1	2.0000+1	LEVEL 9.6300+0 MEV
N,N'3A	N ANGULAR DIST.	3	6/15/76	7.3600+0	1.0939+1	2.0000+1	LEVEL 9.6300+0 MEV
N,N'3A	N TOTAL ENERGY DEP.	4	2/08/73	7.3600+0	1.0939+1	2.0000+1	LEVEL 9.6300+0 MEV
N,N'3A	N LOCAL ENERGY DEP.	4	2/08/73	7.3600+0	1.0939+1	2.0000+1	LEVEL 9.6300+0 MEV
N,N'3A	CROSS SECTION	4	10/09/76	7.3600+0	1.0949+1	2.0000+1	LEVEL 1.0100+1 MEV
N,N'3A	N ANGULAR DIST.	2	6/15/76	7.3600+0	1.0949+1	2.0000+1	LEVEL 1.0100+1 MEV
N,N'3A	N TOTAL ENERGY DEP.	2	2/08/73	7.3600+0	1.0949+1	2.0000+1	LEVEL 1.0100+1 MEV
N,N'3A	N LOCAL ENERGY DEP.	2	2/08/73	7.3600+0	1.0949+1	2.0000+1	LEVEL 1.0100+1 MEV
N,N'3A	CROSS SECTION	4	10/09/76	7.3600+0	1.1751+1	2.0000+1	LEVEL 1.0840+1 MEV
N,N'3A	N ANGULAR DIST.	3	6/15/76	7.3600+0	1.1751+1	2.0000+1	LEVEL 1.0840+1 MEV
N,N'3A	N TOTAL ENERGY DEP.	3	2/08/73	7.3600+0	1.1751+1	2.0000+1	LEVEL 1.0840+1 MEV
N,N'3A	N LOCAL ENERGY DEP.	3	2/08/73	7.3600+0	1.1751+1	2.0000+1	LEVEL 1.0840+1 MEV
N,N'3A	CROSS SECTION	3	10/09/76	7.3600+0	1.2814+1	2.0000+1	LEVEL 1.1820+1 MEV
N,N'3A	N ANGULAR DIST.	2	6/15/76	7.3600+0	1.2814+1	2.0000+1	LEVEL 1.1820+1 MEV
N,N'3A	N TOTAL ENERGY DEP.	2	2/08/73	7.3600+0	1.2814+1	2.0000+1	LEVEL 1.1820+1 MEV
N,N'3A	N LOCAL ENERGY DEP.	2	2/08/73	7.3600+0	1.2814+1	2.0000+1	LEVEL 1.1820+1 MEV
N,P	CROSS SECTION	4	6/15/70	-1.2580+1	1.3630+1	2.0000+1	
N,P	G ENERGY-ANGLE DIST.	5	11/01/72	-1.2580+1	1.3630+1	2.0000+1	
N,P	G MULTIPLICITY	2	5/29/78	-1.2580+1	1.3630+1	2.0000+1	
N,P	N TOTAL ENERGY DEP.	2	5/29/78	-1.2580+1	1.3630+1	2.0000+1	
N,P	N LOCAL ENERGY DEP.	2	5/29/78	-1.2580+1	1.3630+1	2.0000+1	
N,D	CROSS SECTION	4	6/15/70	-1.3720+1	1.4870+1	2.0000+1	
N,D	G ENERGY-ANGLE DIST.	3	11/01/72	-1.3720+1	1.4870+1	2.0000+1	
N,D	G MULTIPLICITY	4	11/01/72	-1.3720+1	1.4870+1	2.0000+1	
N,D	N TOTAL ENERGY DEP.	2	5/29/78	-1.3720+1	1.4870+1	2.0000+1	
N,D	N LOCAL ENERGY DEP.	2	5/29/78	-1.3720+1	1.4870+1	2.0000+1	
N,A	CROSS SECTION	11	3/15/77	-5.7000+0	5.1700+0	2.0000+1	
N,A	N TOTAL ENERGY DEP.	2	5/29/78	-5.7000+0	5.1700+0	2.0000+1	
N,A	N LOCAL ENERGY DEP.	2	5/29/78	-5.7000+0	5.1700+0	2.0000+1	
N,G	CROSS SECTION	11	11/01/72	4.9460+0	1.0000+10	2.0000+1	
N,G	G ENERGY-ANGLE DIST.	2	11/01/72	4.9460+0	1.0000+10	2.0000+1	
N,G	G MULTIPLICITY	2	11/01/72	4.9460+0	1.0000+10	2.0000+1	
N,G	N TOTAL ENERGY DEP.	2	11/21/75	4.9460+0	1.0000+10	2.0000+1	
N,G	N LOCAL ENERGY DEP.	2	11/21/75	4.9460+0	1.0000+10	2.0000+1	
N,XG	CROSS SECTION	20	11/01/72	0.0000+0	4.8024+0	2.0000+1	PHOTON = 4.4300+0 MEV

Carbon-12 (Cont.)

06/09/78

N, XG	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
0	ANGULAR DIST.	9	11/01/72	0.0000+0	4.8024+0	2.0000+1
						PHOTON = 4.4300+0 MEV

some tabular experimental values are given on pages 1-70 and 1-71. A graphical display of the total inelastic scattering cross section, including the decay of this cross section into its n,n' and $n,n'\alpha$ components, is shown on page 46 of UCRL-50400, Vol. 15, Part B. The evaluated $n,n'\alpha$ breakup reaction includes contributions from levels at 7.65, 9.63, 10.1, 10.84 and 11.82 MeV, as well as a continuum contribution.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

Numerous measurements have been made of inelastic scattering from the 4.43-MeV level in carbon. Most of these measurements were made for an incident neutron energy near 14 MeV, and most of them involve a measurement of the inelastically scattered neutron rather than the emitted gamma ray. In the evaluation, the angular distribution for n,n' scattering from the 4.43-MeV level was assumed to be isotropic at threshold, and was made to follow the shape of the experimental angular distribution at 14 MeV, with a uniform interpolation between these energies, and with an extrapolation to 20 MeV. The measured angular distributions for the 10.1- and 11.82-MeV $n,n'\alpha$ breakup levels are consistent with isotropy, whereas the measured angular distributions

for the 7.65- and 9.63-, and 10.84-MeV levels are markedly anisotropic; these experimental results were followed in the evaluation.

Energy distributions for neutrons inelastically scattered from discrete level excitations are based on the kinematics of the reaction. Energy distributions for the $n,n'\alpha$ continuum breakup cross section were obtained from the measurements of F. Cocu *et al.* as given in the report CEA-R-4746 (1976).

PHOTON PRODUCTION FROM INELASTIC SCATTERING

It was assumed in the evaluation that all gamma rays from this reaction were included in the (n,XY) cross section. The gamma ray produced in the greatest abundance is the 4.43-MeV gamma from the first excited state in C^{12} . Higher states decay mostly by breakup into three α particles. The 15.11-MeV ($T = 1$) state decays mostly by gamma emission to the ground state; however, for lack of data this transition was neglected.

n,p CROSS SECTION

The threshold for the (n,p) reaction in carbon is 13.64 MeV. Experimental and evaluated values for this cross section are shown graphically on page 1-69 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated

experimental values are given on page 1-72. The experimental measurements cover the same range of energies as the evaluation.

PHOTON PRODUCTION FROM THE n,p REACTION

Photon production from (n,p) reactions was estimated on the basis of the decay systematics of B^{12} , with the branching ratios for these decays taken from the compilation of F. Ajzenberg-Selove and T. Lauritsen in *Nucl. Phys. A114*, 1 (1968). It is assumed that the population densities of the excited states were proportional to a $(2J + 1)$ dependence when the incident neutron energies were more than 1 MeV above the excitation thresholds. The angular distributions for the gamma rays were assumed to be isotropic.

n,d AND $n,n'p$ CROSS SECTIONS

The threshold for the (n,d) reaction is 14.88 MeV, and the threshold for the similar $(n,n'p)$ reaction is 17.29 MeV. Since there are no experimental data for these reactions, a small (n,d) cross section was deduced from systematics; this cross section rises linearly from threshold to a value of 0.1 barns at 20 MeV.

PHOTON PRODUCTION FROM THE n,d AND $n,n'p$ REACTIONS

The B^{11} nucleus has an excited state at 2.14 MeV, and higher excited states at 4.46 MeV and above. In the evaluation the gamma rays from the higher excited states were included in the experimental $(n,X\gamma)$ cross section. Also, it was assumed that the 2.14-MeV level and the ground state were populated according to the ratio of their spectroscopic factors, which were determined at higher energies (see D. Bachelier *et al.*, *Inter. Nucl. Phys. Conf. Gatlinburg, Tennessee*, R. L. Becker, Ed., p. 865 (1966)). Finally, it was assumed that the angular distribution of the gamma rays from the excitation of the 2.14-MeV level was isotropic.

n,α CROSS SECTION

The threshold for the (n,α) reaction is 6.18 MeV. Values for this cross section are shown graphically on page 1-70 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-72.

PHOTON PRODUCTION FROM THE n,α REACTION

No gamma rays were considered for this reaction because the excited states of the residual nucleus, Be^9 , decay by neutron emission.

CROSS SECTION FOR THE n,γ REACTION

The capture cross section at thermal neutron energies is taken from Ajzenberg-Selove and Lauritsen, as cited above. It was assumed to vary as $1/v$ from 10^{-10} to 10^{-6} MeV, and then to decline linearly to an estimated value of 10^{-5} barns at 20 MeV.

PHOTON PRODUCTION FROM n,γ REACTIONS

At all neutron energies, the spectrum of photons from the capture process was assumed to be the same as the thermal neutron spectrum measured by V. J. Orphan *et al.* in Gulf General Atomic report GA-10248 (1970). This spectrum will be in error at neutron energies above the kilovolt region, but there are no experimental data with which to improve this approximation. To conserve energy, the multiplicity of the gamma rays was chosen to be $M(E) = M_{\text{thermal}} \times (E+Q)/Q$, where E is the incident neutron energy and Q is the energy released in the neutron capture reaction.

$n,X\gamma$ CROSS SECTION

Experimental values of the $(n,X\gamma)$ excitation cross section for the 4.43-MeV level in C^{12} are shown graphically on page 1-68 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values for this and other levels are given on page 1-72. The experimental measurements cover a range of photon energies from 2.64 to 7.5 MeV.

ANGULAR DISTRIBUTIONS FOR THE $n,X\gamma$ REACTION

D. M. Drake *et al.*, *Nuclear Science and Engineering* **40**, 294 (1970), have measured a series of gamma-ray angular distributions for neutron energies between 5.8 and 7.5 MeV; these angular distributions were inserted into the evaluation. Below 5.8 MeV, the angular distribution at 5.8 MeV was assumed; and above 7.5 MeV, the angular distribution at 7.5 MeV was assumed.

Nitrogen-14

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{14}_7\text{N}$ are listed in UCRL-50400, Vol. 3. The evaluated data for N^{14} are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did this evaluation, except as noted below.

The photon production part of the ENDL evaluation for nitrogen was taken from an evaluation by P. G. Young and D. G. Foster, Jr. [see LA-4725 (1972)]. The Young and Foster work was also the basis for the DNA MAT 4133 and the ENDF/B MAT 1275 evaluations. Some revisions to the work reported in LA-4725 were made in 1973 to take into account the photon production cross sections reported by Dickens, Love and Morgan in ORNL-4864 (1973).

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for N^{14} are shown graphically on pages 1-127 to 1-134 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on page 1-136.

ELASTIC SCATTERING CROSS SECTION

Experimental and evaluated elastic scattering cross sections are shown on page 1-135 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on

page 1-136. The values for the elastic scattering cross section are based on the experimental data.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. For energies below 0.5 MeV, the elastic scattering angular distributions were assumed to be isotropic. From 0.5 to 14.8 MeV, the angular distributions were obtained from the experimental data on nitrogen. From 14.8 to 20 MeV, an extrapolation was made based on the trends observed at the lower energies.

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering in the nitrogen evaluation occurs as a result of the excitation of the first ten discrete levels of N^{14} , as shown on page 52 of UCRL-50400, Vol. 15, Part B. Experimental data on n, n' reactions in nitrogen are shown in graphical form on pages 1-85 and 1-86 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-95. The cross sections for these levels are based on the experimental data and on nuclear systematics.

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Nitrogen-14 (Cont.)

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	REACTION	POINTS	DATE	Q VALUE	E-MIN	E-MAX	
N.XG	CROSS SECTION	20	11/21/74	0.000+ 0	9.6590+ 0	2.000+ 1	PHOTON = 3.684+ 0 MEV
N.XG	ANGULAR DIST.	2	11/21/74	0.000+ 0	9.6590+ 0	2.000+ 1	PHOTON = 3.684+ 0 MEV
N.XG	CROSS SECTION	26	11/21/74	0.000+ 0	9.3520+ 0	2.000+ 1	PHOTON = 3.800+ 0 MEV
N.XG	ANGULAR DIST.	2	11/21/74	0.000+ 0	9.3520+ 0	2.000+ 1	PHOTON = 3.800+ 0 MEV
N.XG	CROSS SECTION	17	11/21/74	0.000+ 0	5.9000+ 0	2.000+ 1	PHOTON = 3.850+ 0 MEV
N.XG	ANGULAR DIST.	51	11/21/74	0.000+ 0	5.9000+ 0	2.000+ 1	PHOTON = 3.850+ 0 MEV
N.XG	CROSS SECTION	51	11/21/74	0.000+ 0	6.6440+ 0	2.000+ 1	PHOTON = 3.884+ 0 MEV
N.XG	ANGULAR DIST.	2	11/21/74	0.000+ 0	6.6440+ 0	2.000+ 1	PHOTON = 3.884+ 0 MEV
N.XG	CROSS SECTION	76	11/21/74	0.000+ 0	4.2400+ 0	2.000+ 1	PHOTON = 3.980+ 0 MEV
N.XG	ANGULAR DIST.	18	11/21/74	0.000+ 0	9.0630+ 0	2.000+ 1	PHOTON = 4.1385+ 0 MEV
N.XG	CROSS SECTION	127	11/21/74	0.000+ 0	9.0630+ 0	2.000+ 1	PHOTON = 4.1385+ 0 MEV
N.XG	ANGULAR DIST.	60	11/21/74	0.000+ 0	7.4510+ 0	2.000+ 1	PHOTON = 4.4500+ 0 MEV
N.XG	CROSS SECTION	71	11/21/74	0.000+ 0	2.6810+ 0	2.000+ 1	PHOTON = 4.5134+ 0 MEV
N.XG	ANGULAR DIST.	113	11/21/74	0.000+ 0	5.5490+ 0	2.000+ 1	PHOTON = 5.0189+ 0 MEV
N.XG	CROSS SECTION	68	11/21/74	0.000+ 0	5.4740+ 0	2.000+ 1	PHOTON = 5.1059+ 0 MEV
N.XG	ANGULAR DIST.	62	11/21/74	0.000+ 0	6.1010+ 0	2.000+ 1	PHOTON = 5.6910+ 0 MEV
N.XG	CROSS SECTION	56	11/21/74	0.000+ 0	6.2600+ 0	2.000+ 1	PHOTON = 5.8340+ 0 MEV
N.XG	ANGULAR DIST.	33	11/21/74	0.000+ 0	8.7410+ 0	2.000+ 1	PHOTON = 5.8716+ 0 MEV
N.XG	CROSS SECTION	42	11/21/74	0.000+ 0	5.8620+ 0	2.000+ 1	PHOTON = 5.0945+ 0 MEV
N.XG	ANGULAR DIST.	51	11/21/74	0.000+ 0	6.6440+ 0	2.000+ 1	PHOTON = 5.1976+ 0 MEV
N.XG	CROSS SECTION	26	11/21/74	0.000+ 0	9.3520+ 0	2.000+ 1	PHOTON = 5.4416+ 0 MEV
N.XG	ANGULAR DIST.	47	11/21/74	0.000+ 0	6.9080+ 0	2.000+ 1	PHOTON = 5.4436+ 0 MEV
N.XG	CROSS SECTION	47	11/21/74	0.000+ 0	5.9080+ 0	2.000+ 1	PHOTON = 5.4436+ 0 MEV
N.XG	ANGULAR DIST.	62	11/21/74	0.000+ 0	5.410+ 0	2.000+ 1	PHOTON = 5.7281+ 0 MEV
N.XG	CROSS SECTION	62	11/21/74	0.000+ 0	3.970+ 0	2.000+ 1	PHOTON = 5.7700+ 0 MEV
N.XG	ANGULAR DIST.	33	11/21/74	0.000+ 0	7.0000+ 0	2.000+ 1	PHOTON = 7.0117+ 0 MEV
N.XG	CROSS SECTION	41	11/21/74	0.000+ 0	7.5340+ 0	2.000+ 1	PHOTON = 7.2680+ 0 MEV
N.XG	ANGULAR DIST.	45	11/21/74	0.000+ 0	7.9900+ 0	2.000+ 1	PHOTON = 7.2680+ 0 MEV
N.XG	CROSS SECTION	32	11/21/74	0.000+ 0	7.1940+ 0	2.000+ 1	PHOTON = 7.3270+ 0 MEV
N.XG	ANGULAR DIST.	33	11/21/74	0.000+ 0	8.2400+ 0	2.000+ 1	PHOTON = 7.9650+ 0 MEV
N.XG	CROSS SECTION	33	11/21/74	0.000+ 0	8.2400+ 0	2.000+ 1	PHOTON = 7.9650+ 0 MEV
N.XG	ANGULAR DIST.	2	11/21/74	0.000+ 0	6.7410+ 0	2.000+ 1	PHOTON = 7.9980+ 0 MEV
N.XG	CROSS SECTION	2	11/21/74	0.000+ 0	6.7410+ 0	2.000+ 1	PHOTON = 7.9980+ 0 MEV

Nitrogen-14 (Cont.)

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,XG	CROSS SECTION	28	11/21/74	0.0000+ 0	9.3520+ 0	2.0000+ 1	PHOTON = 8.5660+ 0 MEV
N,XG	G ANGULAR DIST.	2	11/21/74	0.0000+ 0	9.3520+ 0	2.0000+ 1	PHOTON = 8.5660+ 0 MEV
N,XG	CROSS SECTION	25	11/21/74	0.0000+ 0	9.7360+ 0	2.0000+ 1	PHOTON = 8.9250+ 0 MEV
N,XG	G ANGULAR DIST.	2	11/21/74	0.0000+ 0	9.7360+ 0	2.0000+ 1	PHOTON = 8.9250+ 0 MEV

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. The energy distributions of the inelastically scattered neutrons were derived from the kinematics of the reaction.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 11.31 MeV. Experimental values of the n,2n cross section are shown graphically on pages 1-86 to 1-88 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 9-95.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons produced by the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are derived from temperature model calculations, with the assigned temperatures consistent with the nuclear systematics described in UCRL-50400, Vol. 15, Part A, page 24.

n,n'p CROSS SECTION

The threshold for the n,n'p reaction is 8.09 MeV. A single experimental value for this reaction is

given on page 1-95 of UCRL-50400, Vol. 8, Rev. 1, Part A; the evaluated cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. The cross sections for this evaluation were deduced from nuclear systematics.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n'p REACTION

The angular distribution of secondary neutrons from the n,n'p reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The (n,p) reaction in N^{14} is exothermic. Experimental cross section values for this reaction are shown graphically on pages 1-79 and 1-80 (for natural nitrogen) and pages 1-89 and 1-90 (for N^{14}) of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-96. The evaluated (n,p) cross sections are shown in UCRL-50400, Vol. 15, Part B, and are based on experimental data where available.

n,d CROSS SECTION

The threshold for the n,d reaction is 5.71 MeV. The evaluated n,d cross sections are based on nuclear systematics.

n,t CROSS SECTION

The threshold for the (n,t) reaction is 4.30 MeV. Experimental values for the (n,t) cross section are shown in graphical form on pages 1-90 and 1-91 of UCRL-50400, Vol. 8, Rev. 1, Part A, with some tabulated values listed on page 1-96. The evaluated (n,t) cross sections are based on the experimental data where available; otherwise, on nuclear systematics.

n, α CROSS SECTION

The threshold for the (n, α) reaction is 0.17 MeV. Experimental values for the (n, α) cross section are shown in graphical form on pages 1-80 and 1-81 (natural nitrogen) and pages 1-92 to 1-94 (N^{14}) of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on pages 1-83 and 1-96. The evaluated (n, α) cross sections are based on the experimental data where available; otherwise, on nuclear systematics.

n, γ CROSS SECTION

An experimental value for the capture cross section measured at an

incident neutron energy of 95 keV is given on page 1-136 of UCRL-50400, Vol. 7, Part A, Rev. 1. However, since this value has a 100% uncertainty, the evaluated capture cross sections are based on a measured thermal neutron value of 75 mbarn; the cross sections are extrapolated in both directions on the basis of nuclear systematics.

PHOTON PRODUCTION FROM n, γ REACTIONS

The low-energy capture gamma spectrum was taken from the work of Young and Foster (LA-4725). This spectrum and its associated multiplicity was used for neutron energies up to 0.25 MeV. In the neutron energy range between 1 and 20 MeV, where the capture cross section is very small, the capture gamma spectrum was represented by a single photon line that conserves energy. For neutrons in the energy range between 0.25 and 1 MeV, an interpolation procedure was used.

n,X γ CROSS SECTION

A total of 44 discrete lines were included in the evaluation for the n,X γ cross section; this evaluation ranges in energy from 0.17 to 8.925 MeV. The cross section values for these gamma-ray lines were taken from the Young and Foster evaluation (as

initially reported in LA-4725) and were later modified to include the data of Dickens, Love, and Morgan (ORNL 4864).

n,X γ ANGULAR DISTRIBUTION

The angular distributions for the 44 discrete lines were assumed to be isotropic.

Oxygen-16

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ^{16}O are listed in UCRL-50400, Vol. 10; the evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B.

R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Extensive measurements of the total cross section for natural oxygen are shown graphically on pages 1-141 to 1-154 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 1-156. Some corresponding values for isotropic ^{16}O are given on pages 1-157 (graphical) and 1-158 (tabular) of this reference. The evaluated total cross sections for oxygen are illustrated on pages 1-141 to 1-154 and 1-157 of the cited reference, and also in UCRL-50400, Vol. 15, Part B. For neutron energies greater than 0.02 MeV, the total cross sections are based on the experimental measurements; for neutron energies less than 0.02 MeV the total cross section is assumed to be constant, an assumption consistent with the sparse measurements in this lower energy range.

ELASTIC SCATTERING CROSS SECTION

Experimental and evaluated elastic scattering cross sections are shown

graphically on pages 1-155 and 1-156 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 1-157. The evaluated elastic scattering data were obtained, for the most part, by subtracting the sum of the evaluated nonelastic cross sections from the well-measured total cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 0.16 MeV, the elastic scattering angular distributions were assumed to be isotropic. Elastic angular distributions have been measured for many incident neutron energies up to 14 MeV, and the evaluated angular distributions up to 14 MeV are based on these experimental values. Angular distributions for neutron energies above 14 MeV were obtained by extrapolating from the trends observed at the lower energies. Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19.

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering cross section in the oxygen evaluation includes contributions from discrete levels at 6.1, 7.0, 8.88 and 11.1 MeV plus a continuum contribution. The

Oxygen-16

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B-0 -16
ATOMIC MASS = 1.5995* 1
GROUND STATE
STABLE

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	QUALIFIER
N,ELASTIC	CROSS SECTION	264	12/22/76	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	35	8/10/72	0.0000+ 0	1.6000- 1	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	42	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	42	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	9	1/24/74	0.0000+ 0	1.2000+ 1	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	4	1/24/74	0.0000+ 0	1.2000+ 1	2.0000+ 1	
N,N'	N TOTAL ENERGY DEP.	4	12/03/76	0.0000+ 0	1.2000+ 1	2.0000+ 1	
N,N'	N LOCAL ENERGY DEP.	3	12/03/76	0.0000+ 0	1.2000+ 1	2.0000+ 1	
N,N'	CROSS SECTION	21	8/20/70	0.0000+ 0	6.4847+ 0	2.0000+ 1	LEVEL = 6.1000+ 0 MEV
N,N'	N ANGULAR DIST.	2	1/22/70	0.0000+ 0	6.4847+ 0	2.0000+ 1	LEVEL = 6.1000+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	3	12/03/76	0.0000+ 0	6.4847+ 0	2.0000+ 1	LEVEL = 6.1000+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	3	12/03/76	0.0000+ 0	6.4847+ 0	2.0000+ 1	LEVEL = 6.1000+ 0 MEV
N,N'	CROSS SECTION	18	8/20/70	0.0000+ 0	7.4414+ 0	2.0000+ 1	LEVEL = 7.0000+ 0 MEV
N,N'	N ANGULAR DIST.	2	1/22/70	0.0000+ 0	7.4414+ 0	2.0000+ 1	LEVEL = 7.0000+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	3	12/03/76	0.0000+ 0	7.4414+ 0	2.0000+ 1	LEVEL = 7.0000+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	3	12/03/76	0.0000+ 0	7.4414+ 0	2.0000+ 1	LEVEL = 7.0000+ 0 MEV
N,N'	CROSS SECTION	13	8/20/70	0.0000+ 0	9.4400+ 0	2.0000+ 1	LEVEL = 8.8800+ 0 MEV
N,N'	N ANGULAR DIST.	2	1/22/70	0.0000+ 0	9.4400+ 0	2.0000+ 1	LEVEL = 8.8800+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	3	12/03/76	0.0000+ 0	9.4400+ 0	2.0000+ 1	LEVEL = 8.8800+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	3	12/03/76	0.0000+ 0	9.4400+ 0	2.0000+ 1	LEVEL = 8.8800+ 0 MEV
N,N'	CROSS SECTION	7	8/20/70	0.0000+ 0	1.1800+ 1	2.0000+ 1	LEVEL = 1.1100+ 1 MEV
N,N'	N ANGULAR DIST.	2	1/22/70	0.0000+ 0	1.1800+ 1	2.0000+ 1	LEVEL = 1.1100+ 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.1800+ 1	2.0000+ 1	LEVEL = 1.1100+ 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.1800+ 1	2.0000+ 1	LEVEL = 1.1100+ 1 MEV
N,2N	CROSS SECTION	3	1/22/70	-1.5670+ 1	1.6658+ 1	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	3	3/17/70	-1.5670+ 1	1.6658+ 1	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	3	12/03/76	-1.5670+ 1	1.6658+ 1	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	3	12/03/76	-1.5670+ 1	1.6658+ 1	2.0000+ 1	
N,N'P	CROSS SECTION	4	1/24/74	-1.2120+ 1	1.2884+ 1	2.0000+ 1	
N,N'P	N ENERGY-ANGLE DIST.	4	9/11/72	-1.2120+ 1	1.2884+ 1	2.0000+ 1	
N,N'P	N TOTAL ENERGY DEP.	4	12/03/76	-1.2120+ 1	1.2884+ 1	2.0000+ 1	
N,N'P	N LOCAL ENERGY DEP.	4	12/03/76	-1.2120+ 1	1.2884+ 1	2.0000+ 1	
N,N'A	CROSS SECTION	10	12/22/76	-7.1500+ 0	7.6009+ 0	2.0000+ 1	
N,N'A	N ENERGY-ANGLE DIST.	6	9/11/72	-7.1500+ 0	7.6009+ 0	2.0000+ 1	
N,N'A	N TOTAL ENERGY DEP.	8	12/03/76	-7.1500+ 0	7.6009+ 0	2.0000+ 1	
N,N'A	N LOCAL ENERGY DEP.	8	12/03/76	-7.1500+ 0	7.6009+ 0	2.0000+ 1	
N,P	CROSS SECTION	13	1/22/70	-9.6100+ 0	1.0220+ 1	2.0000+ 1	
N,P	G ENERGY-ANGLE DIST.	3	11/01/72	-9.6100+ 0	1.0220+ 1	2.0000+ 1	
N,P	G MULTIPLICITY	4	11/01/72	-9.6100+ 0	1.0220+ 1	2.0000+ 1	
N,P	N TOTAL ENERGY DEP.	2	12/03/76	-9.6100+ 0	1.0220+ 1	2.0000+ 1	
N,P	N LOCAL ENERGY DEP.	2	12/03/76	-9.6100+ 0	1.0220+ 1	2.0000+ 1	
N,D	CROSS SECTION	4	12/22/76	-9.8900+ 0	1.0510+ 1	2.0000+ 1	
N,D	N TOTAL ENERGY DEP.	2	12/03/76	-9.8900+ 0	1.0510+ 1	2.0000+ 1	
N,D	N LOCAL ENERGY DEP.	2	12/03/76	-9.8900+ 0	1.0510+ 1	2.0000+ 1	
N,A	CROSS SECTION	56	12/22/76	-2.2100+ 0	2.3500+ 0	2.0000+ 1	
N,A	N TOTAL ENERGY DEP.	2	12/03/76	-2.2100+ 0	2.3500+ 0	2.0000+ 1	
N,A	N LOCAL ENERGY DEP.	2	12/03/76	-2.2100+ 0	2.3500+ 0	2.0000+ 1	
N,XG	CROSS SECTION	3	11/01/72	0.0000+ 0	1.2000+ 1	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	2	11/01/72	0.0000+ 0	1.2000+ 1	2.0000+ 1	
N,XG	CROSS SECTION	17	11/01/72	0.0000+ 0	6.2600+ 0	2.0000+ 1	PHOTON = 1.8000- 1 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	6.2600+ 0	2.0000+ 1	PHOTON = 1.8000- 1 MEV

Oxygen-16 (Cont.)

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,XG	CROSS SECTION	33	11/01/72	0.0000+ 0	6.5200+ 0	2.0000+ 1	PHOTON = 5.1100+ 1 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	6.5200+ 0	2.0000+ 1	PHOTON = 5.1100+ 1 MEV
N,XG	CROSS SECTION	5	11/01/72	0.0000+ 0	9.4500+ 0	2.0000+ 1	PHOTON = 1.8000+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	9.4500+ 0	2.0000+ 1	PHOTON = 1.8000+ 0 MEV
N,XG	CROSS SECTION	7	11/01/72	0.0000+ 0	9.4300+ 0	2.0000+ 1	PHOTON = 2.7400+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	9.4300+ 0	2.0000+ 1	PHOTON = 2.7400+ 0 MEV
N,XG	CROSS SECTION	21	11/01/72	0.0000+ 0	5.6300+ 0	2.0000+ 1	PHOTON = 4.0900+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	5.6300+ 0	2.0000+ 1	PHOTON = 4.0900+ 0 MEV
N,XG	CROSS SECTION	18	11/01/72	0.0000+ 0	6.2600+ 0	2.0000+ 1	PHOTON = 3.7300+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	6.2600+ 0	2.0000+ 1	PHOTON = 3.7300+ 0 MEV
N,XG	CROSS SECTION	5	11/01/72	0.0000+ 0	1.2300+ 1	2.0000+ 1	PHOTON = 4.4400+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.2300+ 1	2.0000+ 1	PHOTON = 4.4400+ 0 MEV
N,XG	CROSS SECTION	35	11/01/72	0.0000+ 0	6.6200+ 0	2.0000+ 1	PHOTON = 6.1300+ 0 MEV
N,XG	G ANGULAR DIST.	4	11/01/72	0.0000+ 0	6.6200+ 0	2.0000+ 1	PHOTON = 6.1300+ 0 MEV
N,XG	CROSS SECTION	25	11/01/72	0.0000+ 0	7.3600+ 0	2.0000+ 1	PHOTON = 6.9200+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	7.3600+ 0	2.0000+ 1	PHOTON = 6.9200+ 0 MEV
N,XG	CROSS SECTION	16	11/01/72	0.0000+ 0	7.5700+ 0	2.0000+ 1	PHOTON = 7.1200+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	7.5700+ 0	2.0000+ 1	PHOTON = 7.1200+ 0 MEV
N,XG	CROSS SECTION	6	11/01/72	0.0000+ 0	9.4300+ 0	2.0000+ 1	PHOTON = 6.8700+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	9.4300+ 0	2.0000+ 1	PHOTON = 6.8700+ 0 MEV

values for these cross sections are based on the experimental data listed in UCRL-50400, Vol. 3. The evaluated inelastic scattering cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

Angular distributions of the inelastically scattered neutrons have been measured for the first three discrete n, n' levels cited above (see ECSIL Refs. 761, 1681, and 3222 listed in UCRL-50400, Vol. 2). These experimental secondary neutron angular distributions are shown in UCRL-50400, Vol. 19. The evaluated angular distributions for these three discrete levels are based on the experimental data, and the angular distributions for the fourth level at 11.1 MeV were assumed to be isotropic. The energy distributions for the four discrete levels are based on the kinematics of the reaction. The energy distributions for the neutrons from the continuum reaction were obtained from a temperature model.

$n, 2n$ CROSS SECTION

The threshold for the $n, 2n$ reaction is 16.65 MeV. Experimental data and evaluated cross sections for the $n, 2n$ reaction are shown on page 1-106 of UCRL-50400, Vol. 8, Rev. 1, Part A.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 2n$ REACTION

The angular distribution of secondary neutrons from the $n, 2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

$n, n'p$ CROSS SECTION

The threshold for the $n, n'p$ reaction is 12.89 MeV. The evaluated $n, n'p$ cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. In the absence of experimental data, this cross section was assumed to have a constant value of 0.01 barns over most of its energy range.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, n'p$ REACTION

The angular distribution of secondary neutrons from the $n, n'p$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n' α CROSS SECTION

The threshold for the n,n' α reaction is 7.61 MeV. The evaluated cross sections for this reaction are shown graphically in UCRL-50400, Vol. 15, Part B. In the absence of experimental data, the cross section was assumed to rise rapidly above threshold, and to remain at a constant value of 0.13 barns at the higher energies.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n' α REACTION

The angular distribution of secondary neutrons for the n,n' α reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction is 10.24 MeV. Experimental data for this reaction are shown graphically on pages 1-107 and 1-108 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values given on pages 1-104 (natural element) and 1-111 (O^{16}) of this reference. The evaluated n,p cross sections are based on the experimental data, and are shown

graphically in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM THE n,p REACTION

Photon production from the n,p reaction was obtained by using the decay systematics of N^{16} . The branching ratios for these decays were taken from the compilation of F. Ajzenberg-Selove and T. Lauritsen, *Nucl. Phys. A166*, 1 (1971). The angular distributions for these gamma rays were assumed to be isotropic.

n,d CROSS SECTION

The threshold for the n,d reaction is 10.52 MeV. A single data point for this reaction is listed on page 1-111 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,d cross sections are based on nuclear systematics; the single data point is used for normalization. The cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The threshold for the n, α reaction is 2.35 MeV. Measured values of the n, α cross section are shown graphically on pages 1-100 and 1-101 (natural element) and on pages 1-109 and 1-110 (O^{16}) of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 1-112. The evaluated n, α cross sections are based on

experimental data where available; otherwise, on nuclear systematics. The n, γ excitation function is shown graphically in UCRL-50400, Vol. 5, Part B.

n, γ CROSS SECTION

The evaluated n, γ cross sections include a continuum component plus contributions from 11 discrete levels. These cross sections were taken from an evaluation by W. Dickinson (private communication, 1972). Gamma rays produced by the neutron capture process were neglected by both Dickinson and us because the thermal neutron capture cross section is only 0.0002 barns. Experimental values of the n, γ cross section are shown graphically on pages 1-98 and 1-99 of UCRL-50400, Vol. 8, Rev. 1,

Part A; some tabulated values are given on pages 1-102 and 1-103 (natural element) and on page 1-111 (O^{16}).

ANGULAR DISTRIBUTIONS FOR THE n, γ REACTION

The angular distributions for the gamma rays from the n, γ reaction were assumed to be isotropic except in the case of the 6.13-MeV gamma ray. An angular distribution for the 6.13-MeV gamma line was taken from the measurements of D. M. Drake *et al.*, *Nucl. Sci. Eng.* 40, 294 (1970); this angular distribution was assumed to be symmetric about 90° (the data only extend from 30° to 90°), and to be the same for all incident neutron energies.

Fluorine-19

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^9\text{F}^{19}$ are listed in UCRL-50400, Vol. 10. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B.

In the evaluation for F^{19} many of the cross sections were taken, with some modifications, from the fluorine evaluation of C. Y. Fu, C. Larson, and F. G. Perey, Oak Ridge National Laboratory (1974).

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for fluorine are shown graphically on pages 1-161 to 1-166 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on pages 1-167 and 1-168.

ELASTIC SCATTERING CROSS SECTION

The elastic scattering data on fluorine are meager. Thus the elastic scattering cross section was obtained over most of the energy range by taking the difference between the total and nonelastic cross sections. The evaluated elastic scattering cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

The available experimental elastic scattering angular distribution data are shown in UCRL-50400, Vol. 19. These data are quite meager; they are limited to energies below 3 MeV plus some measurements at 14 MeV. The evaluated angular distributions are assumed to be isotropic for neutron energies below 10 keV. Anisotropic angular distributions are inserted into the evaluation at 20 neutron energies above 10 keV; these angular distributions are taken directly from the evaluation of Fu *et al.* cited above.

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering data are shown graphically on pages 1-114 and 1-115 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-127. The evaluated inelastic scattering cross sections include contributions from 20 discrete levels plus the continuum. These evaluated cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. They are taken directly from the ONRL evaluation of Fu *et al.*

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN.	E-MAX.	
N,ELASTIC	CROSS SECTION	259	11/30/74	0.0000+0	1.0000+0	1.0000+0	
N,ELASTIC	ANGULAR DIST.	20	11/30/74	0.0000+0	1.0000+0	1.0000+0	
N,ELASTIC	TOTAL ENERGY DEP.	32	11/30/74	0.0000+0	1.0000+0	1.0000+0	
N,ELASTIC	LOCAL ENERGY DEP.	32	11/30/74	0.0000+0	1.0000+0	1.0000+0	
N,N'	CROSS SECTION	29	11/30/74	0.0000+0	6.2585+0	6.2585+0	
N,N'	ENERGY-ANGLE DIST.	10	11/30/74	0.0000+0	6.2585+0	6.2585+0	
N,N'	TOTAL ENERGY DEP.	9	12/03/76	0.0000+0	6.2585+0	6.2585+0	
N,N'	LOCAL ENERGY DEP.	9	12/03/76	0.0000+0	6.2585+0	6.2585+0	
N,N'	CROSS SECTION	111	11/30/74	0.0000+0	1.1584+0	1.1584+0	1.1584+0
N,N'	ANGULAR DIST.	14	11/30/74	0.0000+0	1.1584+0	1.1584+0	1.1584+0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.1584+0	1.1584+0	1.1584+0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.1584+0	1.1584+0	1.1584+0
N,N'	CROSS SECTION	77	11/30/74	0.0000+0	8.0746+0	8.0746+0	8.0746+0
N,N'	ANGULAR DIST.	14	11/30/74	0.0000+0	8.0746+0	8.0746+0	8.0746+0
N,N'	TOTAL ENERGY DEP.	9	12/03/76	0.0000+0	8.0746+0	8.0746+0	8.0746+0
N,N'	LOCAL ENERGY DEP.	9	12/03/76	0.0000+0	8.0746+0	8.0746+0	8.0746+0
N,N'	CROSS SECTION	25	11/30/74	0.0000+0	1.4527+0	1.4527+0	1.4527+0
N,N'	ANGULAR DIST.	14	11/30/74	0.0000+0	1.4527+0	1.4527+0	1.4527+0
N,N'	TOTAL ENERGY DEP.	7	12/03/76	0.0000+0	1.4527+0	1.4527+0	1.4527+0
N,N'	LOCAL ENERGY DEP.	7	12/03/76	0.0000+0	1.4527+0	1.4527+0	1.4527+0
N,N'	CROSS SECTION	26	11/30/74	0.0000+0	1.5354+0	1.5354+0	1.5354+0
N,N'	ANGULAR DIST.	13	11/30/74	0.0000+0	1.5354+0	1.5354+0	1.5354+0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.5354+0	1.5354+0	1.5354+0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.5354+0	1.5354+0	1.5354+0
N,N'	CROSS SECTION	18	11/30/74	0.0000+0	1.6369+0	1.6369+0	1.6369+0
N,N'	ANGULAR DIST.	14	11/30/74	0.0000+0	1.6369+0	1.6369+0	1.6369+0
N,N'	TOTAL ENERGY DEP.	7	12/03/76	0.0000+0	1.6369+0	1.6369+0	1.6369+0
N,N'	LOCAL ENERGY DEP.	7	12/03/76	0.0000+0	1.6369+0	1.6369+0	1.6369+0
N,N'	CROSS SECTION	32	11/30/74	0.0000+0	2.0370+0	2.0370+0	2.0370+0
N,N'	ANGULAR DIST.	17	11/30/74	0.0000+0	2.0370+0	2.0370+0	2.0370+0
N,N'	TOTAL ENERGY DEP.	4	12/03/76	0.0000+0	2.0370+0	2.0370+0	2.0370+0
N,N'	LOCAL ENERGY DEP.	4	12/03/76	0.0000+0	2.0370+0	2.0370+0	2.0370+0
N,N'	CROSS SECTION	37	11/30/74	0.0000+0	4.1144+0	4.1144+0	4.1144+0
N,N'	ANGULAR DIST.	11	11/30/74	0.0000+0	4.1144+0	4.1144+0	4.1144+0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	4.1144+0	4.1144+0	4.1144+0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	4.1144+0	4.1144+0	4.1144+0
N,N'	CROSS SECTION	27	11/30/74	0.0000+0	4.2103+0	4.2103+0	4.2103+0
N,N'	ANGULAR DIST.	11	11/30/74	0.0000+0	4.2103+0	4.2103+0	4.2103+0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	4.2103+0	4.2103+0	4.2103+0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	4.2103+0	4.2103+0	4.2103+0
N,N'	CROSS SECTION	29	11/30/74	0.0000+0	4.2461+0	4.2461+0	4.2461+0
N,N'	ANGULAR DIST.	11	11/30/74	0.0000+0	4.2461+0	4.2461+0	4.2461+0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	4.2461+0	4.2461+0	4.2461+0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	4.2461+0	4.2461+0	4.2461+0
N,N'	CROSS SECTION	29	11/30/74	0.0000+0	4.6104+0	4.6104+0	4.6104+0
N,N'	ANGULAR DIST.	11	11/30/74	0.0000+0	4.6104+0	4.6104+0	4.6104+0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	4.6104+0	4.6104+0	4.6104+0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	4.6104+0	4.6104+0	4.6104+0
N,N'	CROSS SECTION	19	11/30/74	0.0000+0	4.7958+0	4.7958+0	4.7958+0
N,N'	ANGULAR DIST.	11	11/30/74	0.0000+0	4.7958+0	4.7958+0	4.7958+0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	4.7958+0	4.7958+0	4.7958+0

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06/09/78

	REACTION	POINTS	DATE	G-VALUE	E MEV	E MEV
N,N,A	N LOCAL ENERGY DEP.	14	5/29/78	-4.8780+0	5.1500+0	2.0000+1
N,P	CROSS SECTION	34	11/30/74	-4.0360+0	4.2503+0	2.0000+1
N,P	TOTAL ENERGY DEP.	2	5/29/78	-4.0360+0	4.2503+0	2.0000+1
N,P	LOCAL ENERGY DEP.	2	5/29/78	-4.0360+0	4.2503+0	2.0000+1
N,D	CROSS SECTION	15	11/30/74	-5.7680+0	6.0742+0	2.0000+1
N,D	TOTAL ENERGY DEP.	2	5/29/78	-5.7680+0	6.0742+0	2.0000+1
N,D	LOCAL ENERGY DEP.	2	5/29/78	-5.7680+0	6.0742+0	2.0000+1
N,T	CROSS SECTION	9	11/30/74	-7.5570+0	7.9582+0	2.0000+1
N,T	TOTAL ENERGY DEP.	2	5/29/78	-7.5570+0	7.9582+0	2.0000+1
N,T	LOCAL ENERGY DEP.	2	5/29/78	-7.5570+0	7.9582+0	2.0000+1
N,A	CROSS SECTION	17	11/30/74	-1.5230+0	1.6039+0	2.0000+1
N,A	TOTAL ENERGY DEP.	2	5/29/78	-1.5230+0	1.6039+0	2.0000+1
N,A	LOCAL ENERGY DEP.	2	5/29/78	-1.5230+0	1.6039+0	2.0000+1
N,G	CROSS SECTION	870	11/30/74	6.6000+0	1.0000+10	2.0000+1
N,G	G ENERGY DIST.	2	11/01/72	6.6000+0	1.0000+10	2.0000+1
N,G	G MULTIPLICITY	2	11/01/72	6.6000+0	1.0000+10	2.0000+1
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.6000+0	1.0000+10	2.0000+1
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.6000+0	1.0000+10	2.0000+1
N,XG	CROSS SECTION	6	1/04/73	0.0000+0	4.0000+0	2.0000+1
N,XG	G ENERGY-ANGLE DIST.	8	1/04/73	0.0000+0	4.0000+0	2.0000+1
N,XG	CROSS SECTION	11	1/04/73	0.0000+0	1.1600+1	2.0000+1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+0	1.1600+1	2.0000+1
N,XG	CROSS SECTION	6	1/04/73	0.0000+0	2.5000+1	2.0000+1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+0	2.5000+1	2.0000+1
N,XG	CROSS SECTION	9	1/04/73	0.0000+0	1.4310+0	2.0000+1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+0	1.4310+0	2.0000+1
N,XG	CROSS SECTION	7	1/04/73	0.0000+0	1.5360+0	2.0000+1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+0	1.5360+0	2.0000+1
N,XG	CROSS SECTION	4	1/04/73	0.0000+0	1.5360+0	2.0000+1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+0	1.5360+0	2.0000+1
N,XG	CROSS SECTION	4	1/04/73	0.0000+0	2.9300+0	2.0000+1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+0	2.9300+0	2.0000+1

PHOTON = 1.1000+1 MEV
 PHOTON = 1.1000+1 MEV
 PHOTON = 1.9700+1 MEV
 PHOTON = 1.9700+1 MEV
 PHOTON = 1.2400+0 MEV
 PHOTON = 1.2400+0 MEV
 PHOTON = 1.3600+0 MEV
 PHOTON = 1.4600+0 MEV
 PHOTON = 2.5800+0 MEV

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

Angular distributions were inserted into the evaluation at 20 inelastic n,n' levels; the distributions were obtained from the ORNL evaluation. The energy distributions for the discrete levels can be calculated from the kinematics of the reaction. The angular distributions for the continuum part of the n,n' reaction were assumed to be isotropic; the energy distributions were obtained from a temperature model.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is 10.98 MeV. Experimental values of the $n,2n$ cross section are shown graphically on pages 1-116 to 1-120 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-128. The evaluated $n,2n$ cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons were obtained from the ORNL evaluation.

$n,n'p$ CROSS SECTION

The threshold for the $n,n'p$ reaction is 8.41 MeV. The evaluated cross sections for this reaction are shown graphically in UCRL-50400, Vol. 15, Part B. These cross sections were obtained from the ORNL evaluation.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'p$ REACTION

The angular distribution of secondary neutrons from the $n,n'p$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons were obtained from the ORNL evaluation.

$n,n'\alpha$ CROSS SECTION

The threshold for the $n,n'\alpha$ reaction is 4.22 MeV. The evaluated cross sections for this reaction are shown graphically in UCRL-50400, Vol. 15, Part B. These cross sections were obtained from the ORNL evaluation.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'\alpha$ REACTION

The angular distribution of secondary neutrons from the $n,n'\alpha$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons were obtained from the ORNL evaluation.

n,p CROSS SECTION

The threshold for the n,p reaction is 4.25 MeV. Experimental data for this reaction are shown graphically on pages 1-123 and 1-124 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-129. The evaluated n,p cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These cross sections were obtained from the ORNL evaluation.

n,D CROSS SECTION

The threshold for the n,D reaction is 6.07 MeV. Evaluated cross sections for this reaction are shown graphically in UCRL-50400, Vol. 15, Part B. These cross sections were obtained from the ORNL evaluation.

n,T CROSS SECTION

The threshold for the n,T reaction is 7.96 MeV. Evaluated cross sections for this reaction are shown graphically in UCRL-50400, Vol. 15, Part B. These cross sections were obtained from the ORNL evaluation.

n, α CROSS SECTION

The threshold for the n, α reaction is 1.60 MeV. Experimental cross sections for this reaction are shown graphically on pages 1-125 to 1-127 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on

page 1-129. The evaluated n, α cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections were obtained from the ORNL evaluation.

n, γ CROSS SECTION

The evaluated capture cross sections for fluorine are shown in UCRL-50400, Vol. 15, Part B. These cross sections were taken from the ORNL evaluation.

PHOTON PRODUCTION FROM n, γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the study of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). It was assumed that this spectrum applied to all neutron energies, since there were no data for neutron incident energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

n,X γ CROSS SECTION

Experimental values of the n,X γ cross section in fluorine are shown graphically on pages 1-121 and 1-122 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 1-128. It was assumed in the

evaluation that the $n, X\gamma$ cross section included all photons except those produced in the capture reaction. The evaluated $n, X\gamma$ cross sections included six discrete lines plus a continuum contribution that started at 4 MeV. The discrete lines all arise from the deexcitation of excited states in F^{19} — states that are produced by n, n' reactions. There are no experimental data on the cross sections for the excitation of energy levels between 4 and 14 MeV in F^{19} , so the cross sections had to be estimated.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The angular distributions of the photons produced from the $n, X\gamma$ reaction were assumed to be isotropic. The energy distributions of the discrete photons were based on the kinematics of the reaction. The energy distributions of the photons in the continuum component of the reaction were calculated from the procedures described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975).

Sodium-23

DATA SUMMARY AND GENERAL COMMENTS

References to the experimental data for $^{23}_{11}\text{Na}$ are summarized in UCRL-50400, Vol. 3; the data are listed in UCRL-50400, Vol. 10. The evaluated data for this isotope are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did this evaluation.

TOTAL CROSS SECTION

Experimental total cross sections for sodium are shown graphically on pages 2-1 to 2-14 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 2-17. Evaluated total cross sections are also shown graphically on pages 2-1 to 2-14. These cross sections — covering incident neutron energies up to 9.5 MeV — have now been replaced by total cross sections obtained by summing the evaluated elastic cross sections of Paik and Pitterle (at room temperature) and the evaluated nonelastic cross sections that are described below. For neutron energies above 9.5 MeV, the evaluated total cross sections are based on experimental data that have been interpolated smoothly.

ELASTIC SCATTERING CROSS SECTION

Experimental values for the elastic scattering cross section are

shown graphically on page 2-15 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on pages 2-17 and 2-18. For the neutron energy range from 10^{-4} eV to 9.5 MeV, the evaluated elastic cross sections were taken from an evaluation of Paik and Pitterle (after broadening to room temperature); the Paik and Pitterle evaluation was also used for the ENDF/B-IV MAT 1156 data file. For neutron energies greater than 9.5 MeV, the evaluated elastic cross sections were obtained by subtracting the sums of the nonelastic reaction cross sections from the total cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

The experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. Since these data span most of the neutron energy range up to 14 MeV, the evaluated angular distributions at 14 MeV and below were based on the experimental data. An extrapolation to 20 MeV was made on the basis of the trend at lower energies.

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering data are shown graphically on pages 2-2 to 2-6 of UCRL-50400, Vol. 8, Rev. 1, Part A;

Sodium-23

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	PEACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	1262	10/01/77	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	10	10/15/70	0.0000+ 0	4.0000- 2	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	24	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	24	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N	CROSS SECTION	27	8/18/72	0.0000+ 0	2.1710+ 0	2.0000+ 1	
N,N	N ENERGY-ANGLE DIST.	15	8/18/72	0.0000+ 0	2.1710+ 0	2.0000+ 1	
N,N	N TOTAL ENERGY DEP.	15	12/03/76	0.0000+ 0	2.1710+ 0	2.0000+ 1	
N,N	N LOCAL ENERGY DEP.	14	12/03/76	0.0000+ 0	2.1710+ 0	2.0000+ 1	
N,N	CROSS SECTION	115	10/01/77	0.0000+ 0	4.5850- 1	2.0000+ 1	LEVEL 4 3920 1 MEV
N,N	N ANGULAR DIST.	21	8/18/72	0.0000+ 0	4.5850- 1	2.0000+ 1	LEVEL 4 3920 1 MEV
N,N	N TOTAL ENERGY DEP.	4	12/03/76	0.0000+ 0	4.5850- 1	2.0000+ 1	LEVEL 4 3920 1 MEV
N,N	N LOCAL ENERGY DEP.	4	12/03/76	0.0000+ 0	4.5850- 1	2.0000+ 1	LEVEL 4 3920 1 MEV
N,2N	CROSS SECTION	14	8/19/70	-1.2434+ 1	1.2980+ 1	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	4	8/19/70	-1.2434+ 1	1.2980+ 1	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	4	12/03/76	-1.2434+ 1	1.2980+ 1	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	4	12/03/76	-1.2434+ 1	1.2980+ 1	2.0000+ 1	
N,N,P	CROSS SECTION	33	8/19/70	-8.7940+ 0	9.1800+ 0	2.0000+ 1	
N,N,P	N ENERGY-ANGLE DIST.	5	8/19/70	-8.7940+ 0	9.1800+ 0	2.0000+ 1	
N,N,P	N TOTAL ENERGY DEP.	7	5/29/78	-8.7940+ 0	9.1800+ 0	2.0000+ 1	
N,N,P	N LOCAL ENERGY DEP.	7	5/29/78	-8.7940+ 0	9.1800+ 0	2.0000+ 1	
N,N,A	CROSS SECTION	8	10/01/77	-1.0498+ 1	1.1000+ 1	2.0000+ 1	
N,N,A	N ENERGY-ANGLE DIST.	5	8/19/70	-1.0498+ 1	1.0959+ 1	2.0000+ 1	
N,N,A	N TOTAL ENERGY DEP.	5	5/29/78	-1.0498+ 1	1.1000+ 1	2.0000+ 1	
N,N,A	N LOCAL ENERGY DEP.	5	5/29/78	-1.0498+ 1	1.1000+ 1	2.0000+ 1	
N,P	CROSS SECTION	93	10/01/77	3.5970+ 0	3.7600+ 0	2.0000+ 1	
N,P	N TOTAL ENERGY DEP.	2	5/29/78	3.5970+ 0	3.7600+ 0	2.0000+ 1	
N,P	N LOCAL ENERGY DEP.	2	5/29/78	3.5970+ 0	3.7600+ 0	2.0000+ 1	
N,A	CROSS SECTION	22	10/01/77	-3.8800+ 0	4.8000+ 0	2.0000+ 1	
N,A	N TOTAL ENERGY DEP.	2	5/29/78	-3.8800+ 0	4.8000+ 0	2.0000+ 1	
N,A	N LOCAL ENERGY DEP.	2	5/29/78	-3.8800+ 0	4.8000+ 0	2.0000+ 1	
N,G	CROSS SECTION	130	4/03/76	6.9700+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	11/01/72	6.9700+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	11/01/72	6.9700+ 0	1.0000-10	2.0000+ 1	
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.9700+ 0	1.0000-10	2.0000+ 1	
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.9700+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	6	2/21/73	0.0000+ 0	4.3000+ 0	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	5	1/04/73	0.0000+ 0	4.3000+ 0	2.0000+ 1	
N,XG	CROSS SECTION	47	1/04/73	0.0000+ 0	4.5850- 1	2.0000+ 1	PHOTON 4.3900- 1 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	4.5850- 1	2.0000+ 1	PHOTON 4.3900- 1 MEV
N,XG	CROSS SECTION	7	1/04/73	0.0000+ 0	2.1680+ 0	2.0000+ 1	PHOTON 1.6400+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.1680+ 0	2.0000+ 1	PHOTON 1.6400+ 0 MEV
N,XG	CROSS SECTION	7	1/04/73	0.0000+ 0	2.1680+ 0	2.0000+ 1	PHOTON 2.0800+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.1680+ 0	2.0000+ 1	PHOTON 2.0800+ 0 MEV
N,XG	CROSS SECTION	4	1/04/73	0.0000+ 0	2.3000+ 0	2.0000+ 1	PHOTON 2.3000+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.3000+ 0	2.0000+ 1	PHOTON 2.3000+ 0 MEV
N,XG	CROSS SECTION	4	1/04/73	0.0000+ 0	2.6000+ 0	2.0000+ 1	PHOTON 2.6000+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.6000+ 0	2.0000+ 1	PHOTON 2.6000+ 0 MEV
N,XG	CROSS SECTION	4	1/04/73	0.0000+ 0	3.0000+ 0	2.0000+ 1	PHOTON 3.0000+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	3.0000+ 0	2.0000+ 1	PHOTON 3.0000+ 0 MEV

some tabular values are given on pages 2-17 and 2-18. The evaluated inelastic scattering cross section includes contributions from one discrete level at 0.44 MeV and from a continuum that is assumed to begin at 2.17 MeV, which is the threshold for excitation of the second level in sodium. The evaluated inelastic cross sections (UCRL-50400, Vol. 15, Part B) have been revised with respect to the excitation function of the 0.44-MeV level for neutron energies of 2.2 MeV and below. Since the experimental data are sparse above 2.2 MeV, the continuum inelastic cross section was based largely upon systematics, with a normalization point at 5.0 MeV.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

Extensive measurements have been made of the angular distributions of inelastically scattered neutrons produced by the excitation of the 0.44-MeV level in sodium. These measurements are summarized in UCRL-50400, Vol. 3, and graphs of the measurements are given in UCRL-50400, Vol. 19. In the evaluation, angular distributions were assigned (based on experimental data) to inelastically scattered neutrons produced from excitation of the 0.44-MeV level. The energy distributions for these neutrons were estimated on the basis of the kinematics of the reaction.

The angular distributions for the continuum neutrons were assumed to be isotropic. For incident neutron energies below 4.5 MeV, the energy distributions of the continuum neutrons represented the excitation of the second through seventh levels in sodium. This way of representing level excitations limits the number of entries in cases where there are large uncertainties in the level excitation functions. For incident neutron energies above 4.5 MeV, the energy distributions of the continuum neutrons — given in tabular form — are obtained from a temperature model calculation.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 12.96 MeV. Experimental values of the n,2n cross section are shown on page 2-7 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 2-19. The evaluated n,2n cross sections, which are shown graphically in UCRL-50400, Vol. 15, Part B, are based on the experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons produced from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary

neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

$n,n'p$ CROSS SECTION

The threshold for the $n,n'p$ reaction is 9.17 MeV. The evaluated $n,n'p$ cross sections are shown in UCRL-50400, Vol. 15, Part B. In the absence of experimental data, the $n,n'p$ cross section was assumed to rise roughly linearly from threshold to a value of about 0.25 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'p$ REACTION

The angular distribution of secondary neutrons produced from the $n,n'p$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

$n,n'\alpha$ CROSS SECTION

The threshold for the $n,n'\alpha$ reaction is 10.92 MeV. Experimental values for the $n,n'\alpha$ cross section are shown graphically in UCRL-50400,

Vol. 15, Part B. The evaluated $n,n'\alpha$ cross sections from 12.6 to 19 MeV are based on the experimental data, and a smooth extrapolation is used over the remainder of the energy range.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'\alpha$ REACTION

The angular distribution of secondary neutrons produced from the $n,n'\alpha$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction is 3.75 MeV. Experimental data for this reaction are shown graphically on pages 2-12 and 2-13 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 2-19 and 2-20. The evaluated n,p cross sections are shown in UCRL-50400, Vol. 15, Part B.

n,α CROSS SECTION

The threshold for the n,α reaction is 4.03 MeV. Experimental data for this reaction are shown graphically on pages 2-14 and 2-15 of UCRL-50400,

some tabular values are given on pages 2-17 and 2-18. The evaluated inelastic scattering cross section includes contributions from one discrete level at 0.44 MeV and from a continuum that is assumed to begin at 2.17 MeV, which is the threshold for excitation of the second level in sodium. The evaluated inelastic cross sections (UCRL-50400, Vol. 15, Part B) have been revised with respect to the excitation function of the 0.44-MeV level for neutron energies of 2.2 MeV and below. Since the experimental data are sparse above 2.2 MeV, the continuum inelastic cross section was based largely upon systematics, with a normalization point at 5.0 MeV.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

Extensive measurements have been made of the angular distributions of inelastically scattered neutrons produced by the excitation of the 0.44-MeV level in sodium. These measurements are summarized in UCRL-50400, Vol. 3, and graphs of the measurements are given in UCRL-50400, Vol. 19. In the evaluation, angular distributions were assigned (based on experimental data) to inelastically scattered neutrons produced from excitation of the 0.44-MeV level. The energy distributions for these neutrons were estimated on the basis of the kinematics of the reaction.

The angular distributions for the continuum neutrons were assumed to be isotropic. For incident neutron energies below 4.5 MeV, the energy distributions of the continuum neutrons represented the excitation of the second through seventh levels in sodium. This way of representing level excitations limits the number of entries in cases where there are large uncertainties in the level excitation functions. For incident neutron energies above 4.5 MeV, the energy distributions of the continuum neutrons -- given in tabular form -- are obtained from a temperature model calculation.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 12.96 MeV. Experimental values of the n,2n cross section are shown on page 2-7 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 2-19. The evaluated n,2n cross sections, which are shown graphically in UCRL-50400, Vol. 15, Part B, are based on the experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons produced from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary

neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

$n,n'p$ CROSS SECTION

The threshold for the $n,n'p$ reaction is 9.17 MeV. The evaluated $n,n'p$ cross sections are shown in UCRL-50400, Vol. 15, Part B. In the absence of experimental data, the $n,n'p$ cross section was assumed to rise roughly linearly from threshold to a value of about 0.25 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'p$ REACTION

The angular distribution of secondary neutrons produced from the $n,n'p$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

$n,n'\alpha$ CROSS SECTION

The threshold for the $n,n'\alpha$ reaction is 10.92 MeV. Experimental values for the $n,n'\alpha$ cross section are shown graphically in UCRL-50400,

Vol. 15, Part B. The evaluated $n,n'\alpha$ cross sections from 12.6 to 19 MeV are based on the experimental data, and a smooth extrapolation is used over the remainder of the energy range.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'\alpha$ REACTION

The angular distribution of secondary neutrons produced from the $n,n'\alpha$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction is 3.75 MeV. Experimental data for this reaction are shown graphically on pages 2-12 and 2-13 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 2-19 and 2-20. The evaluated n,p cross sections are shown in UCRL-50400, Vol. 15, Part B.

n,α CROSS SECTION

The threshold for the n,α reaction is 4.03 MeV. Experimental data for this reaction are shown graphically on pages 2-14 and 2-15 of UCRL-50400,

Vol. 8, Rev. 1, Part A; some tabular values are given on page 2-20. The evaluated n,α cross sections are shown in UCRL-50400, Vol. 15, Part B.

n,γ CROSS SECTION

Experimental neutron capture cross sections are shown graphically on page 2-16 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 2-18. The evaluated capture cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. They are, in general, based on experimental data where such data exist, and otherwise on systematics.

PHOTON PRODUCTION FROM n,γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the measurements of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply to all neutron energies, since there were no data for neutron incident energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

$n,X\gamma$ CROSS SECTION

Experimental values of the $n,X\gamma$ cross section for sodium are shown

graphically on pages 2-9 to 2-11 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 2-19. In the evaluation, the $n,X\gamma$ cross section was assumed to include all photons except those produced in the neutron capture reaction. The evaluated $n,X\gamma$ cross sections include six discrete lines plus a continuum contribution that starts at 4 MeV. The discrete lines arise when the excited states produced by n,n' reactions in Na^{23} are deexcited. These six discrete lines were evaluated in the following manner:

0.439 MeV

This gamma ray is a product of the (n,n') reaction that populates the first excited state of Na^{23} . For neutron energies below 2.1 MeV, the 0.439-MeV level can only be populated by direct (n,n') reactions. At higher neutron energies, the 0.439-MeV level can be populated by cascade reactions from higher-level excitations, but in practice this level seems to be populated only by the direct (n,n') reaction for neutron energies up to about 3 MeV. Thus, in the evaluation, the production of the 0.439-MeV gamma ray for neutron energies below 3 MeV was represented by the 0.439-MeV excitation function; above 3 MeV, we used experimental data at 4.0, 4.1 MeV [W. E. Tucker, private communication (1968); ORO-2791-30 (1969)] and

ORO-2791-32 (1971)] and 14.1 MeV [P. W. Martin and D. T. Stewart, *J. Nucl. Energy, Parts A/B* 19, 447 (1965)], together with interpolations and extrapolations based on these data.

1.64 MeV

This gamma ray is a product of the transition ($2.078 \rightarrow 0.439$) in Na^{23} . For neutron energies up to 3.3 MeV, the evaluation was based on experimental data [D. A. Lind and R. B. Day, *Ann. Phys.* 12, 485 (1961); UCOL-P-503 (1961) and UCOL-P-504 (1961)]. Above 3.3 MeV, the production cross sections were estimated.

2.08 MeV

This gamma ray comes from the decay of the 2.078-MeV state in Na^{23} to the ground state of sodium. Its intensity is 11% of the 1.64-MeV gamma ray [P. M. Endt and C. Van der Leun, *Nucl. Phys.* A105, 1 (1967)] and was evaluated accordingly.

2.8, 2.6, and 3.0 MeV

Experimental data (W. E. Tucker, cited above) can be used to obtain production cross sections for gamma rays with energies of 2.267, 2.393, 2.550, 2.640, 2.988, and 3.243 MeV

when incident neutron energies are between 4 and 5 MeV. For simplicity, these gamma rays were grouped together into pairs, and an effective average energy was assigned to each pair. The thresholds for the production of these gamma rays were calculated based on the decay scheme of Na^{23} , taking into account that the levels were excited by n, n' reactions.

The n, γ cross sections for the continuum component were calculated with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton, *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n, γ PROCESS

The angular distributions of the photons produced by the n, γ reaction were assumed to be isotropic. The energy distributions of the discrete photons were estimated based on the kinematics of the reaction. The energy distributions of the photons produced by the continuum component of the reaction were calculated based on the systematics of Perkins, Haight, and Howerton, as described above.

Magnesium

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural magnesium are summarized in UCRL-50400, Vol. 3. The evaluated data for the natural element are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did this evaluation.

TOTAL CROSS SECTION

Experimental total cross sections for natural magnesium are shown graphically on pages 2-19 to 2-27 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on pages 2-27 and 2-28. Experimental total cross sections for Mg^{25} and Mg^{26} are shown on page 2-29 of this reference. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B. It is assumed that these cross sections are constant below about 15 keV; they follow ECSIL-534 from there to 300 keV; then ECSIL-451 to about 500 keV; then ECSIL-2197 to 1.5 MeV; and finally ECSIL-750 at the higher energies up to 20 MeV. These ECSIL data references are listed in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

Tabular experimental values for the elastic scattering cross section are shown on page 2-28 of UCRL-50400, Vol. 7, Part A, Rev. 1. These values

are useful in determining the magnitude of the elastic scattering cross section, but the detailed shape of the evaluated elastic cross sections was obtained by taking differences between the measured total cross section and the sum of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 1 keV, the elastic scattering was assumed to be isotropic in the center-of-mass system. From 1 keV to 20 MeV, the angular distributions were calculated from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees, as given in *Phys. Rev.* 182, 1190 (1969).

INELASTIC SCATTERING CROSS SECTION

Experimental inelastic scattering data for the various isotopes of magnesium are shown graphically on pages 2-23 to 2-25, 2-29, 2-36, and 2-38 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 2-27 and 2-35. In the magnesium evaluation, the inelastic scattering cross section was represented by three discrete levels whose thresholds started at 1.37, 1.61, and 1.83 MeV plus a continuum that started at 3 MeV. The three discrete levels

Magnesium (Cont.)

06/09/78

	REACTION	POINTS	DATE	2-VALUE	E-MIN	E-MAX
N,P	CROSS SECTION	15	9/22/74	1 7300+ 0	4.9300+ 0	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	5/29/78	1 1 7300+ 0	4.9300+ 0	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	5/29/78	1 1 7300+ 0	4.9300+ 0	2.0000+ 1

represent contributions from Mg^{24} , Mg^{25} , and Mg^{26} , respectively, and the cross sections for these excitations were obtained from the experimental data. The cross sections for the continuum component of the inelastic scattering were obtained largely from nuclear systematics.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions of secondary neutrons produced by inelastic scattering to the 1.37-MeV level in Mg^{24} were taken from experiment; it was assumed that the distributions were independent of the energy of the incident neutron. The angular distributions produced by inelastic scattering to the 1.61-MeV level in Mg^{25} and to the 1.83-MeV level in Mg^{26} were assumed to be isotropic. The energy distributions for these three reactions were estimated based on the kinematics of the reactions. The angular distributions for the continuum inelastic scattering were assumed to be isotropic, and the energy distributions were obtained from temperature model calculations.

n,2n CROSS SECTION

It was assumed that the threshold for the n,2n reaction in the magnesium evaluation was 7.62 MeV, which is the threshold for Mg^{25} ; the Mg^{24} and Mg^{26} thresholds are 17.22 and 11.52

MeV, respectively. The only experimental data, which are for Mg^{24} , are shown on page 2-30 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,2n cross sections for natural magnesium are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons produced by the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The n,p thresholds in Mg^{24} , Mg^{25} , and Mg^{26} are 4.93, 3.17, and 8.22 MeV, respectively. Experimental values of the n,p cross section for magnesium are given on the following pages of UCRL-50400, Vol. 8, Rev. 1, Part A: natural magnesium, 2-28; Mg^{24} , 2-32 to 2-36; Mg^{25} , 2-37; and Mg^{26} , 2-39. The evaluated n,p cross sections, which were obtained by summing the experimental data for the individual isotopes, are shown in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

Experimental neutron capture cross sections are tabulated on page 2-28 (natural element) and on page 2-30 (Mg^{26} isotope) of UCRL-50400, Vol. 7, Part A, Rev. 1. The evaluated capture cross sections are shown in UCRL-50400, Vol. 15, Part B. They are based on experimental data where such data exist; otherwise they are based on systematics.

PHOTON PRODUCTION FROM n, γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the measurements of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply to all neutron energies, since there are no data for neutron incident energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

n,X γ CROSS SECTION

Experimental values of the n,X γ cross section for magnesium are shown graphically on pages 2-25 (natural element) and 2-31 (Mg^{24}) of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 2-27 and 2-28 (natural element) and page 2-35 (Mg^{24}). In the evaluation,

the n,X γ cross section was assumed to include all photons except those produced in the neutron capture reaction. The evaluated n,X γ cross sections include seven discrete lines plus a continuum contribution that starts at 3.5 MeV. The seven discrete lines were evaluated in the following manner:

1.369 MeV

This gamma ray arises from the transition of the 1.369-MeV level to the ground state in Mg^{24} . Below 4.2 MeV, the production cross section for this transition was set equal to the evaluated n,n' cross section for the 1.369-MeV level. At higher energies, it was assumed that other n,n' and n,2n reactions could contribute to the excitation of the 1.369-MeV level. At 14.1 MeV, we inserted into the evaluation experimental data by J. W. Boring and M. T. McEllistrem, *Phys. Rev.* 124, 1531 (1961), and by D. T. Stewart and P. W. Martin, *Nucl. Phys.* 60, 349 (1964); these results were also assumed to apply to the cross section at 20 MeV.

1.61 MeV

This gamma ray arises from the transition of the 1.61-MeV level to the ground state in Mg^{25} . Below 3 MeV, the production cross section for this transition was set equal to the

evaluated n,n' cross section for the 1.61-MeV state. A cross section value for this gamma-ray transition was then estimated at 20 MeV, and intermediate values were obtained by interpolation.

the cross section was obtained as described above. A value was estimated at 20 MeV, and intermediate values were obtained by interpolation.

1.83 MeV

This gamma ray arises from the transition of 1.83-MeV level to the ground state in Mg^{26} . Below 3.5 MeV,

Other Lines

Four other gamma-ray lines were included, based on level excitations in Mg^{24} :

Gamma-ray lines.

Gamma-energy, MeV	Transition in Mg^{24}	Percentage of 1.368-MeV gammas at high energies
2.8	4.23 $\rightarrow$ 1.369 and 4.12 $\rightarrow$ 1.369	8
3.86	5.22 $\rightarrow$ 1.369	5
4.23	4.23 $\rightarrow$ g. s.	8
4.63	6.00 $\rightarrow$ 1.369	10

Weak branches that compete with these transitions were neglected. Guides for estimating the cross sections for these transitions were obtained from the structure of Mg^{24} , as given in P. M. Endt and C. Van der Leun, *Nucl. Phys.* **A105**, 1 (1967), and from the inelastic proton scattering data of G. Crawley (thesis) and G. Crawley and G. T. Garvey, *Phys. Rev.* **160**, 981 (1967) and **167**, 1070 (1968). In using the proton data, it was assumed that the relative cross sections for states excited by the n,n' reaction

at neutron energies above 10 MeV were similar to the relative cross sections for states excited by the p,p' reaction at a proton energy of 17.5 MeV.

The n,γ cross sections for the continuum component were obtained from the NXGAM code, using the systematics developed by Perkins, Haight, and Howerton, *Nucl. Sci. Eng.* **57**, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n, γ PROCESS

The angular distribution of the 1.369 MeV gamma-ray was taken from the measurements of W. E. Tucker, private communication (1968), ORO-2791-30 (1969), and ORO-2791-32 (1971). These measurements show a constant anisotropy for neutron energies between 3 and 4.35 MeV. In the evaluation, the anisotropy was assumed to be constant for all energies between threshold and 20 MeV. The angular distribution of the 1.83-MeV gamma ray for energies below 3 MeV was also taken from measurements by Tucker. Tucker's data indicate

isotropy for this gamma ray at a neutron energy of 4.35 MeV, so an isotropic angular distribution was used for neutron energies between 4.35 MeV and 20 MeV. All other gamma rays were assumed to have isotropic angular distributions. The energy distributions of these discrete gamma rays were estimated based on the kinematics of the reaction. The angular distributions for the continuum gamma rays were assumed to be isotropic, and the energy distributions were calculated based on the nuclear systematics of Perkins, Haight, and Howerton, as described above.

Aluminum-27

DATA SUMMARY AND GENERAL COMMENTS

The extensive experimental data for $^{27}_{13}\text{Al}$, which are summarized in UCRL-50400, Vol. 3, are listed in UCRL-50400, Vol. 10. The evaluated data for this isotope are shown graphically in UCRL-50400, Vol. 15, Part B.

In the evaluation for Al^{27} , most of the data were taken, with some modifications, from the aluminum evaluation of D. G. Foster, Jr., and P. G. Young, Los Alamos Rept. LA-4726 (1972).

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for aluminum are shown graphically on pages 2-30 to 2-52 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on pages 2-55 and 2-56.

ELASTIC SCATTERING CROSS SECTION

Experimental and evaluated values for the elastic scattering cross section are shown graphically on page 2-53 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on pages 2-56 and 2-57. Since the experimental data are meager, the detailed shape of the elastic cross section was obtained by taking the difference between the total and nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTION

The extensive measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. The evaluated elastic angular distributions were assumed to be isotropic for incident neutron energies below 100 keV. Anisotropic angular distributions were inserted into the evaluation at 33 neutron energies above 100 keV; these angular distributions were taken directly from the evaluation of Foster and Young cited above.

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering cross section data are shown graphically on pages 2-43 to 2-51 of UCRL-50400, Vol. 6, Rev. 1, Part A; some tabular values are given on pages 2-66 to 2-68. The evaluated inelastic scattering cross sections include contributions from 13 discrete levels, taken from the LASL evaluation of Foster and Young, plus a continuum contribution that starts at 5.25 MeV. To simplify the presentation, the continuum contribution was used above 5 MeV instead of the pseudo-levels used by Foster and Young. The evaluated cross sections are shown in UCRL-50400, Vol. 15, Part B.

Aluminum-27

06/09/78

REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC						
N,ELASTIC	N	CROSS SECTION	17.3	10/18/74	0.0000+0	1.0000-10
N,ELASTIC	N	ANGULAR DIST.	34	10/18/74	0.0000+0	1.0000-1
N,ELASTIC	N	TOTAL ENERGY DEP.	29	11/12/74	0.0000+0	1.0000-10
N,ELASTIC	N	LOCAL ENERGY DEP.	29	11/12/74	0.0000+0	1.0000-10
N,N'		CROSS SECTION	17	10/18/74	0.0000+0	5.2500+0
N,N'	N	ENERGY-ANGLE DIST.	9	10/20/74	0.0000+0	5.2500+0
N,N'	N	TOTAL ENERGY DEP.	8	12/03/76	0.0000+0	5.2500+0
N,N'	N	LOCAL ENERGY DEP.	6	12/03/76	0.0000+0	5.2500+0
N,N'		CROSS SECTION	57	10/18/74	0.0000+0	8.7500-1
N,N'	N	ANGULAR DIST.	18	10/18/74	0.0000+0	8.7500-1
N,N'	N	TOTAL ENERGY DEP.	15	12/03/76	0.0000+0	8.7500-1
N,N'	N	LOCAL ENERGY DEP.	16	12/03/76	0.0000+0	8.7500-1
N,N'		CROSS SECTION	50	10/18/74	0.0000+0	1.0510+0
N,N'	N	ANGULAR DIST.	18	10/18/74	0.0000+0	1.0510+0
N,N'	N	TOTAL ENERGY DEP.	16	12/03/76	0.0000+0	1.0510+0
N,N'	N	LOCAL ENERGY DEP.	16	12/03/76	0.0000+0	1.0510+0
N,N'		CROSS SECTION	36	10/18/74	0.0000+0	2.2930+0
N,N'	N	ANGULAR DIST.	18	10/18/74	0.0000+0	2.2930+0
N,N'	N	TOTAL ENERGY DEP.	11	12/03/76	0.0000+0	2.2930+0
N,N'	N	LOCAL ENERGY DEP.	11	12/03/76	0.0000+0	2.2930+0
N,N'		CROSS SECTION	51	10/18/74	0.0000+0	2.8340+0
N,N'	N	ANGULAR DIST.	8	10/18/74	0.0000+0	2.8340+0
N,N'	N	TOTAL ENERGY DEP.	4	12/03/76	0.0000+0	2.8340+0
N,N'	N	LOCAL ENERGY DEP.	4	12/03/76	0.0000+0	2.8340+0
N,N'		CROSS SECTION	51	10/18/74	0.0000+0	3.0510+0
N,N'	N	ANGULAR DIST.	11	10/18/74	0.0000+0	3.0510+0
N,N'	N	TOTAL ENERGY DEP.	10	12/03/76	0.0000+0	3.0510+0
N,N'	N	LOCAL ENERGY DEP.	10	12/03/76	0.0000+0	3.0510+0
N,N'		CROSS SECTION	38	10/18/74	0.0000+0	3.1130+0
N,N'	N	ANGULAR DIST.	11	10/18/74	0.0000+0	3.1130+0
N,N'	N	TOTAL ENERGY DEP.	10	12/03/76	0.0000+0	3.1130+0
N,N'	N	LOCAL ENERGY DEP.	10	12/03/76	0.0000+0	3.1130+0
N,N'		CROSS SECTION	27	10/18/74	0.0000+0	3.6150+0
N,N'	N	ANGULAR DIST.	2	10/18/74	0.0000+0	3.6150+0
N,N'	N	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	3.6150+0
N,N'	N	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	3.6150+0
N,N'		CROSS SECTION	34	10/18/74	0.0000+0	4.1040+0
N,N'	N	ANGULAR DIST.	9	10/18/74	0.0000+0	4.1040+0
N,N'	N	TOTAL ENERGY DEP.	5	12/03/76	0.0000+0	4.1040+0
N,N'	N	LOCAL ENERGY DEP.	5	12/03/76	0.0000+0	4.1040+0
N,N'		CROSS SECTION	53	10/18/74	0.0000+0	4.2070+0
N,N'	N	ANGULAR DIST.	9	10/18/74	0.0000+0	4.2070+0
N,N'	N	TOTAL ENERGY DEP.	5	12/03/76	0.0000+0	4.2070+0
N,N'	N	LOCAL ENERGY DEP.	5	12/03/76	0.0000+0	4.2070+0
N,N'		CROSS SECTION	46	10/18/74	0.0000+0	4.5740+0
N,N'	N	ANGULAR DIST.	8	10/18/74	0.0000+0	4.5740+0
N,N'	N	TOTAL ENERGY DEP.	5	12/03/76	0.0000+0	4.5740+0
N,N'	N	LOCAL ENERGY DEP.	5	12/03/76	0.0000+0	4.5740+0
N,N'		CROSS SECTION	35	10/18/74	0.0000+0	4.6770+0
N,N'	N	ANGULAR DIST.	8	10/18/74	0.0000+0	4.6770+0
N,N'	N	TOTAL ENERGY DEP.	5	12/03/76	0.0000+0	4.6770+0

Aluminum-27 (Cont.)

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,N'	N LOCAL ENERGY DEP.	5	12/03/76	0.0000+ 0	4.6770+ 0	2.0000+ 1	LEVEL = 4.5080+ 0 MEV
N,N'	N CROSS SECTION	32	10/18/74	0.0000+ 0	4.7510+ 0	2.0000+ 1	LEVEL = 4.5800+ 0 MEV
N,N'	N ANGULAR DIST.	8	10/18/74	0.0000+ 0	4.7510+ 0	2.0000+ 1	LEVEL = 4.5300+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	5	12/03/76	0.0000+ 0	4.7510+ 0	2.0000+ 1	LEVEL = 4.5800+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	5	12/03/76	0.0000+ 0	4.7510+ 0	2.0000+ 1	LEVEL = 4.5800+ 7 MEV
N,N'	N CROSS SECTION	30	10/18/74	0.0000+ 0	4.9910+ 0	2.0000+ 1	LEVEL = 4.9110+ 0 MEV
N,N'	N ANGULAR DIST.	6	10/18/74	0.0000+ 0	4.9910+ 0	2.0000+ 1	LEVEL = 4.8110+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	6	12/03/76	0.0000+ 0	4.9910+ 0	2.0000+ 1	LEVEL = 4.8110+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	6	12/03/76	0.0000+ 0	4.9910+ 0	2.0000+ 1	LEVEL = 4.8110+ 0 MEV
N,2N	N CROSS SECTION	14	10/18/74	-1.3057+ 1	1.3545+ 1	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	8	10/18/74	-1.3057+ 1	1.3545+ 1	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	4	12/03/76	-1.3057+ 1	1.3545+ 1	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	4	12/03/76	-1.3057+ 1	1.3545+ 1	2.0000+ 1	
N,P	N CROSS SECTION	147	10/18/74	-1.8278+ 0	1.8961+ 0	2.0000+ 1	
N,P	N TOTAL ENERGY DEP.	2	5/29/78	-1.8278+ 0	1.8961+ 0	2.0000+ 1	
N,P	N LOCAL ENERGY DEP.	2	5/29/78	-1.8278+ 0	1.8961+ 0	2.0000+ 1	
N,D	N CROSS SECTION	24	10/18/74	-6.0460+ 0	6.2720+ 0	2.0000+ 1	
N,D	N TOTAL ENERGY DEP.	2	5/29/78	-6.0460+ 0	6.2720+ 0	2.0000+ 1	
N,D	N LOCAL ENERGY DEP.	2	5/29/78	-6.0460+ 0	6.2720+ 0	2.0000+ 1	
N,T	N CROSS SECTION	14	10/18/74	-1.0884+ 1	1.1291+ 1	2.0000+ 1	
N,T	N TOTAL ENERGY DEP.	2	5/29/78	-1.0884+ 1	1.1291+ 1	2.0000+ 1	
N,T	N LOCAL ENERGY DEP.	2	5/29/78	-1.0884+ 1	1.1291+ 1	2.0000+ 1	
N,A	N CROSS SECTION	32	10/18/74	-3.1316+ 0	3.2487+ 0	2.0000+ 1	
N,A	N TOTAL ENERGY DEP.	2	5/29/78	-3.1316+ 0	3.2487+ 0	2.0000+ 1	
N,A	N LOCAL ENERGY DEP.	2	5/29/78	-3.1316+ 0	3.2487+ 0	2.0000+ 1	
N,G	N CROSS SECTION	168	10/18/74	7.7300+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	11/01/72	7.7300+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	11/01/72	7.7300+ 0	1.0000-10	2.0000+ 1	
N,G	N TOTAL ENERGY DEP.	2	11/21/76	7.7300+ 0	1.0000-10	2.0000+ 1	
N,XG	N CROSS SECTION	9	1/05/73	0.0000+ 0	3.0600+ 0	2.0000+ 1	
N,XG	G ENERGY DIST.	5	1/05/73	0.0000+ 0	3.0600+ 0	2.0000+ 1	
N,XG	N CROSS SECTION	12	1/05/73	0.0000+ 0	8.7+00- 1	2.0000+ 1	PHOTON = 8.4000- 1 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	8.7+00- 1	2.0000+ 1	PHOTON = 8.4000- 1 MEV
N,XG	N CROSS SECTION	9	1/05/73	0.0000+ 0	1.0560+ 0	2.0000+ 1	PHOTON = 1.0130+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.0560+ 0	2.0000+ 1	PHOTON = 1.0130+ 0 MEV
N,XG	N CROSS SECTION	8	1/05/73	0.0000+ 0	2.8300+ 0	2.0000+ 1	PHOTON = 1.7200+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.8300+ 0	2.0000+ 1	PHOTON = 1.7200+ 0 MEV
N,XG	N CROSS SECTION	8	1/05/73	0.0000+ 0	2.2920+ 0	2.0000+ 1	PHOTON = 2.2100+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.2920+ 0	2.0000+ 1	PHOTON = 2.2100+ 0 MEV
N,XG	N CROSS SECTION	8	1/05/73	0.0000+ 0	3.0000+ 0	2.0000+ 1	PHOTON = 3.0000+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	3.0000+ 0	2.0000+ 1	PHOTON = 3.0000+ 0 MEV

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

Angular distributions taken from the LASL evaluation were given for the 13 discrete n, n' levels. The energy distributions for these discrete levels were estimated based on the kinematics of the reaction. The angular distributions for the continuum part of the n, n' reaction were assumed to be isotropic in the laboratory system. The energy distributions reproduce the average and maximum secondary neutron energies for the reaction.

$n, 2n$ CROSS SECTION

The threshold for the $n, 2n$ reaction is 13.54 MeV. Experimental values of the $n, 2n$ cross section are shown graphically on page 2-52 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated $n, 2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. They were taken from the LASL evaluation.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 2n$ REACTION

The angular distribution of secondary neutrons produced by the $n, 2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons were obtained from the LASL evaluation.

n, p CROSS SECTION

The threshold for the n, p reaction is 1.90 MeV. Experimental and evaluated n, p cross sections are shown graphically on pages 2-54 to 2-58 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated experimental values are given on pages 2-70 and 2-71. The evaluated n, p cross sections, which are shown in UCRL-50400, Vol. 15, Part B, were obtained from the LASL evaluation.

n, d CROSS SECTION

The threshold for the n, d reaction is 6.27 MeV. The evaluated n, d cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections were obtained from the LASL evaluation.

n, t CROSS SECTION

The threshold for the n, t reaction is 11.29 MeV. Some tabulated experimental values for this cross section are shown on page 2-71 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n, t cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections were taken from the LASL evaluation.

n, α CROSS SECTION

The threshold for the n, α reaction is 3.25 MeV. Extensive experimental values of this cross section are given

graphically on pages 2-58 to 2-65 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 2-72. The evaluated n,α cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections were taken from the LASL evaluation.

n,γ CROSS SECTION

Experimental and evaluated capture cross sections are shown on pages 2-54 and 2-55 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on page 2-57. The evaluated n,γ cross sections are shown in UCRL-50400, Vol. 15, Part B. These were taken from the LASL evaluation.

PHOTON PRODUCTION FROM n,γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the measurements of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies, since there are no data for neutron incident energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

$n,X\gamma$ CROSS SECTION

Experimental values of the $n,X\gamma$ cross section in aluminum are shown graphically on pages 2-53 and 2-54 of

UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 2-68 to 2-70. In the evaluation, the $n,X\gamma$ cross section was assumed to include all photons except those produced in the neutron capture reaction. The evaluated $n,X\gamma$ cross sections include five discrete lines plus a continuum contribution that starts just above 3 MeV (which is the energy of the highest discrete line). The $n,X\gamma$ cross sections were obtained from the data of V. J. Orphan and C. G. Hoot, Gulf Radiation Technology Rept. Gulf-RT-A10743 (DNA 2736F) (1971). These data are in some disagreement with the data of D. O. Nellis and P. S. Buchanan, Texas Nuclear Rept. DASA01-68-C-0128 (1971), at 9 and 11 MeV; and also with the data of W. E. Tucker, ORO-2791-30 (1969) and ORO-2791-32 (1971), at 14.1 MeV. However, the Orphan and Hoot data are in good agreement with the data of D. Drake *et al.*, *Nucl. Sci. Eng.* **40**, 294 (1970), at 6.0 and 7.5 MeV. The recent Oak Ridge measurements of J. K. Dickens, T. A. Love, and G. L. Morgan, ORNL-TM-4232 (1973) are much closer to the data of Orphan and Hoot than to the data of Nellis and Buchanan or to the data of Tucker.

In the $n,X\gamma$ evaluation, cross sections for the excitation of discrete gamma-ray lines at 0.84, 1.103, 1.72, 2.21, and 3.0 MeV were entered into the evaluation, based on the data of

Table 19 in the Orphan and Hoot report. The energies of these evaluated "lines" were deduced in part from information contained in Tables 15 and 16 of Orphan and Hoot. The continuum gamma rays were taken from Table 18 of Orphan and Hoot after the discrete lines had been subtracted. (In the 1.663- to 1.902-MeV E_γ bin of Table 18, the discrete line had apparently already been subtracted, and therefore it wasn't subtracted again.)

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The angular distribution of the photons produced by the $n, X\gamma$ reaction was assumed to be isotropic. The energy distributions of the discrete photons were estimated based on the kinematics of the reaction. The energy distributions of the photons from the continuum component of the reaction were calculated using the systematics developed by Perkins, Haight, and Howerton, *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

Silicon

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for Si, which are summarized in UCRL-50400, Vol. 3, are listed in UCRL-50400, Vol. 10. The data include measurements on natural silicon, as well as some measurements on various isotopes of silicon. The evaluation is for the natural element. The evaluated data for silicon are shown in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for natural silicon are shown graphically on pages 2-58 to 2-69 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on page 2-71. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections are based on the following specific ECSIL data sets: ECSIL-69 from 0.1 to 0.5 MeV; ECSIL-1755 from 0.5 to 1.25 MeV; ECSIL-64 from 1.25 to 2 MeV; ECSIL-29 from 2 to 2.5 MeV; ECSIL-750 from 2.5 to 5.5 MeV; and ECSIL-1747 from 5.5 to 14 MeV. These ECSIL data references are given in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

Experimental elastic scattering cross section values for natural silicon are shown graphically on page 2-70 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 2-71. Some tabular elastic cross sections for Si²⁸ are given on page 72. The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections, which follow the general shape of the total cross sections, are obtained by subtracting the total cross sections from the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic angular distribution was assumed to be isotropic for neutron energies below 60 keV. Above 60 keV, the evaluated elastic scattering angular distributions were based on experimental data, supplemented at the higher energies by spherical optical model calculations. The calculation used the best-fit

Silicon

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	871	8/19/70	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	ANGULAR DIST.	24	5/25/71	0.0000+ 0	6.0000- 2	2.0000+ 1	
N,ELASTIC	TOTAL ENERGY DEP.	36	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	LOCAL ENERGY DEP.	36	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	17	3/04/72	0.0000+ 0	2.1030+ 0	2.0000+ 1	
N,N'	ENERGY-ANGLE DIST.	8	3/04/72	0.0000+ 0	2.1030+ 0	2.0000+ 1	
N,N'	TOTAL ENERGY DEP.	8	12/03/76	0.0000+ 0	2.1030+ 0	2.0000+ 1	
N,N'	LOCAL ENERGY DEP.	6	12/03/76	0.0000+ 0	2.1030+ 0	2.0000+ 1	
N,N'	CROSS SECTION	13	1/09/73	0.0000+ 0	1.3187+ 0	4.0200+ 0	LEVEL = 1.2730+ 0 MEV
N,N'	ANGULAR DIST.	2	8/19/70	0.0000+ 0	1.3187+ 0	4.0200+ 0	LEVEL = 1.2730+ 0 MEV
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.3187+ 0	4.0200+ 0	LEVEL = 1.2730+ 0 MEV
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.3187+ 0	4.0200+ 0	LEVEL = 1.2730+ 0 MEV
N,N'	CROSS SECTION	190	8/19/70	0.0000+ 0	1.8430+ 0	2.0000+ 1	LEVEL = 1.7787+ 0 MEV
N,N'	ANGULAR DIST.	2	5/25/71	0.0000+ 0	1.8430+ 0	2.0000+ 1	LEVEL = 1.7787+ 0 MEV
N,N'	TOTAL ENERGY DEP.	3	12/03/76	0.0000+ 0	1.8430+ 0	2.0000+ 1	LEVEL = 1.7787+ 0 MEV
N,N'	LOCAL ENERGY DEP.	3	12/03/76	0.0000+ 0	1.8430+ 0	2.0000+ 1	LEVEL = 1.7787+ 0 MEV
N,2N	CROSS SECTION	6	11/15/72	-8.4840+ 0	8.7887+ 0	2.0000+ 1	
N,2N	ENERGY-ANGLE DIST.	5	3/04/72	-8.4840+ 0	8.7887+ 0	2.0000+ 1	
N,2N	TOTAL ENERGY DEP.	10	12/03/76	-8.4840+ 0	8.7887+ 0	2.0000+ 1	
N,2N	LOCAL ENERGY DEP.	9	12/03/76	-8.4840+ 0	8.7887+ 0	2.0000+ 1	
N,N'P	CROSS SECTION	50	8/19/70	-1.1573+ 1	1.2000+ 1	2.0000+ 1	
N,N'P	ENERGY-ANGLE DIST.	5	10/15/70	-1.1573+ 1	1.2000+ 1	2.0000+ 1	
N,N'P	TOTAL ENERGY DEP.	3	5/29/78	-1.1573+ 1	1.2000+ 1	2.0000+ 1	
N,N'P	LOCAL ENERGY DEP.	3	5/29/78	-1.1573+ 1	1.2000+ 1	2.0000+ 1	
N,P	CROSS SECTION	363	8/19/70	-2.8932+ 0	3.0600+ 0	2.0000+ 1	
N,P	TOTAL ENERGY DEP.	1	5/29/78	-2.8932+ 0	3.0600+ 0	2.0000+ 1	
N,P	LOCAL ENERGY DEP.	1	5/25/78	-2.8932+ 0	3.0600+ 0	2.0000+ 1	
N,D	CROSS SECTION	81	12/15/71	-9.3583+ 0	9.6970+ 0	2.0000+ 1	
N,D	TOTAL ENERGY DEP.	2	5/29/78	-9.3583+ 0	9.6970+ 0	2.0000+ 1	
N,D	LOCAL ENERGY DEP.	2	5/29/78	-9.3583+ 0	9.6970+ 0	2.0000+ 1	
N,A	CROSS SECTION	373	2/02/72	-3.2700- 2	3.3800- 2	2.0000+ 1	
N,A	TOTAL ENERGY DEP.	2	5/29/78	-3.2700- 2	3.3800- 2	2.0000+ 1	
N,A	LOCAL ENERGY DEP.	2	5/25/73	-3.2700- 2	3.3800- 2	2.0000+ 1	
N,G	CROSS SECTION	4F	8/19/70	8.7680+ 0	1.0000-10	2.0000+ 1	
N,G	ENERGY DIST.	2	11/01/72	8.7680+ 0	1.0000-10	2.0000+ 1	
N,G	MULTIPLICITY	2	11/01/72	8.7680+ 0	1.0000-10	2.0000+ 1	
N,G	TOTAL ENERGY DEP.	2	11/21/76	8.7680+ 0	1.0000-10	2.0000+ 1	
N,G	LOCAL ENERGY DEP.	2	11/21/76	8.7680+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	5	2/21/73	0.0000+ 0	4.6900+ 0	2.0000+ 1	
N,XG	ENERGY-ANGLE DIST.	5	1/09/73	0.0000+ 0	4.6900+ 0	2.0000+ 1	
N,XG	CROSS SECTION	13	1/08/73	0.0000+ 0	1.3178+ 0	2.0000+ 1	PHOTON = 1.2730+ 0 MEV
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.3178+ 0	2.0000+ 1	PHOTON = 1.2730+ 0 MEV
N,XG	CROSS SECTION	140	1/09/73	0.0000+ 0	1.8430+ 0	2.0000+ 1	PHOTON = 1.7787+ 0 MEV
N,XG	ANGULAR DIST.	9	1/09/73	0.0000+ 0	1.8430+ 0	2.0000+ 1	PHOTON = 1.7787+ 0 MEV
N,XG	CROSS SECTION	7	1/09/73	0.0000+ 0	4.7740+ 0	2.0000+ 1	PHOTON = 2.8300+ 0 MEV
N,XG	ANGULAR DIST.	5	1/09/73	0.0000+ 0	4.7740+ 0	2.0000+ 1	PHOTON = 2.8300+ 0 MEV
N,XG	CROSS SECTION	6	1/09/73	0.0000+ 0	5.1470+ 0	2.0000+ 1	PHOTON = 3.1900+ 0 MEV
N,XG	ANGULAR DIST.	3	5/31/73	0.0000+ 0	5.1470+ 0	2.0000+ 1	PHOTON = 3.1900+ 0 MEV
N,XG	CROSS SECTION	3	1/09/73	0.0000+ 0	6.4900+ 0	2.0000+ 1	PHOTON = 4.4900+ 0 MEV
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	6.4900+ 0	2.0000+ 1	PHOTON = 4.4900+ 0 MEV
N,XG	CROSS SECTION	4	1/09/73	0.0000+ 0	7.1200+ 0	2.0000+ 1	PHOTON = 5.1000+ 0 MEV

Silicon (Cont.)

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	7.1200+ 0	2.0000+ 1	PHOTON = 5.1000+ 0 MEV
N,XG	CROSS SECTION	4	1/09/73	0.0000+ 0	7.1200+ 0	2.0000+ 1	PHOTON = 6.8800+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	7.1200+ 0	2.0000+ 1	PHOTON = 6.8800+ 0 MEV

optical model parameters of Becchetti and Greenlees, *Phys. Rev.* 182, 1190 (1969).

INELASTIC SCATTERING CROSS SECTION

Experimental inelastic scattering data for natural silicon are shown graphically on pages 2-74 and 2-75 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 2-78. Corresponding values for Si^{28} are given on pages 2-80 to 2-82 (graphical) and 2-101 (tabular). In the silicon evaluation, inelastic scattering was represented by

- Two discrete levels of excitation at 1.273 and 1.7787 MeV (corresponding to the thresholds of the levels in Si^{29} and Si^{28} , respectively).
- A continuum contribution that starts at 2.1 MeV, which is the energy that corresponds to the threshold of the second level in Si^{29} .

The cross sections for these inelastic excitations were based on both experimental data and nuclear systematics.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

Angular distributions produced by inelastic scattering to the two discrete inelastic levels at 1.273 and 1.7787 MeV were taken from experiment. The energy distributions for these two reactions were estimated based on

the kinematics of the reactions. The angular distributions for the continuum inelastic scattering were assumed to be isotropic, and the energy distributions were obtained from temperature model calculations.

n,2n CROSS SECTION

The threshold for the n,2n reaction in the silicon evaluation was set equal to 8.77 MeV, which is the threshold for Si^{29} . The experimental data (which are only available for Si^{28}) are shown on page 2-83 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,2n cross sections for natural silicon are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons produced by the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n'p CROSS SECTION

The threshold for the n,n'p reaction was set equal to 12.0 MeV, which is the threshold for this reaction in

the Si^{28} isotope. Experimental data for the $\text{n}, \text{n}'\text{p}$ reaction in Si^{28} are given on page 2-101 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated $\text{n}, \text{n}'\text{p}$ cross sections for natural silicon are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $\text{n}, \text{n}'\text{p}$ REACTION

The angular distribution of secondary neutrons produced by the $\text{n}, \text{n}'\text{p}$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with the nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n, p CROSS SECTION

The threshold for the n, p reaction was set equal to 3.0 MeV, which is the threshold for Si^{29} . Experimental cross sections for the n, p reaction in the various isotopes of silicon are given on pages 2-79, 2-85 to 2-91, 2-102, 2-107, and 2-108 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n, p cross sections are shown in UCRL-50400, Vol. 15, Part B.

n, d CROSS SECTION

The threshold for the n, d reaction was set equal to 10.46 MeV, which is

the threshold for Si^{29} . The evaluated n, d cross sections for natural silicon are shown in UCRL-50400, Vol. 15, Part B. In the absence of experimental data, these cross sections are obtained from nuclear systematics.

n, α CROSS SECTION

The effective threshold for the n, α cross section in natural silicon was set equal to about 2.4 MeV, which is the average of the thresholds for Si^{28} , Si^{29} , and Si^{30} . Extensive experimental data for the n, α reaction in these isotopes are given on pages 2-92 to 2-100, 2-103 to 2-106, and 2-108 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n, α cross sections for natural silicon are shown in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

Experimental neutron capture cross sections are tabulated on page 2-71 (natural element) and on page 2-72 (Si^{30} isotope) of UCRL-50400, Vol. 7, Part A, Rev. 1. The evaluated capture cross sections for natural silicon are shown in UCRL-50400, Vol. 15, Part B. They are based on experimental data where such data exist; otherwise they are based on nuclear systematics.

PHOTON PRODUCTION FROM n, γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies

was taken from the data of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies, since there are no data for incident neutron energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

n, γ CROSS SECTION

Experimental values of the n, γ cross section for silicon and its various isotopes are given on pages 2-76, 2-77, 2-78, 2-84, 2-85, 2-102, 2-103, 2-106, and 2-107 of UCRL-50400, Vol. 8, Rev. 1, Part A. Cross sections for seven discrete lines were included in the evaluation together with a continuum component that started at 4 MeV. The seven discrete lines were evaluated in the following manner:

1.273 MeV

This gamma ray arises from the transition of the 1.273-MeV level to the ground state in Si^{29} . For incident neutron energies below 2.10 MeV, the gamma ray is produced entirely from the n, n' reaction. Between 2.10 and 4 MeV, it is still produced primarily from the n, n' reaction.

Therefore, the cross section for the production of this gamma ray was set

equal to the n, n' cross section for all neutron energies below 4 MeV. Above 4 MeV the cross section was estimated.

1.7787 MeV

This gamma ray arises from the transition of the 1.7787-MeV level to the ground state in Si^{28} . For incident neutron energies up to 4.775 MeV, the gamma ray is produced entirely by the n, n' reaction. Thus, the cross section for producing this gamma ray was set equal to the n, n' cross section for neutron energies up to 4.775 MeV. At higher energies this gamma ray was entered as a discrete line, but without specifying how it was produced. Data of Drake *et al.*, *Nucl. Sci. Eng.* 40, 294 (1970), below 7.67 MeV, and of Benveniste *et al.*, UCID-4619 (1963), at 14.1 MeV, were used as guides in the evaluation.

2.83 MeV

This gamma ray arises from the transition of the 4.61-MeV level to the 1.7787-MeV level in Si^{28} . The data of Drake *et al.*, cited above, were used to determine the cross section up to 7.67 MeV, and the cross section was guessed at the higher energies.

Other Lines

Four other lines were entered into the evaluation:

<u>Nucleus</u>	<u>Transition</u>	<u>Energy, MeV</u>
Si ²⁸	4.97 → 1.7787	3.19
Si ²⁸	6.27 → 1.7787	4.49
Si ²⁸	6.88 → 1.7787	5.10
Si ²⁸	6.88 → ground state	6.88

The n,Xγ cross sections for the continuum component were calculated with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton, *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. In the evaluation, the continuum was assumed to start at 4 MeV, becoming 40% of the calculated value at 10 MeV, and continuing at 40% to 20 MeV. This procedure gave results at 14.8 MeV that are in good agreement with

the measurements of W. E. Tucker, ORO-2791-30 (1969) and ORO-2791-32 (1971).

SPECTRA OF PHOTONS FROM THE n,Xγ PROCESS

Angular distributions for the 1.7787-MeV and 2.83-MeV gamma rays were entered into the evaluation. The distributions were based on the data of Drake cited above. The angular distributions for the other discrete lines and for the continuum gamma rays were assumed to be isotropic. The energy distributions for the discrete lines were estimated from the kinematics of the reaction. The energy distributions for the continuum gamma rays were calculated with the nuclear systematics of Perkins, Haight, and Howerton described above.

Phosphorus-31

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{31}_{15}\text{P}$ are summarized in UCRL-50400, Vol. 3; they are listed in UCRL-50400, Vol. 10. The evaluated data for this isotope are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for $^{31}_{15}\text{P}$ are shown graphically on pages 2-75 to 2-79 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on page 2-80. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections are based on the following specific ECSIL data sets: ECSIL-15 from 6 to 20 keV; ECSIL-819 from 40 to 90 keV; ECSIL-99 from 100 to 800 keV; ECSIL-455 from 800 keV to 1.2 MeV; and ECSIL-750 from 2 to 20 MeV. These ECSIL data references are given in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

Two elastic scattering data points are listed on page 2-80 of UCRL-50400, Vol. 7, Part A, Rev. 1. In view of the scarcity of experimental data, the elastic cross section was obtained by differencing the evaluated total

cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies below 100 keV. Above 100 keV, the evaluated elastic scattering angular distributions were based on experimental data, supplemented at the higher energies by spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Some inelastic scattering cross section data are shown graphically on pages 2-109 and 2-110 of UCRL-50400, Vol. 8, Rev. 1, Part A. In view of the scarcity of experimental data, inelastic scattering was represented in the evaluation by a continuum contribution that starts at 1.31 MeV. The evaluated n,n' continuum cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

Phosphorus-31

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	123	8/19/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	20	1/03/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	30	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	30	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	10	8/19/72	0.0000+ 0	1.3100+ 0	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	10	8/19/72	0.0000+ 0	1.3100+ 0	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	13	12/03/76	0.0000+ 0	1.3100+ 0	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	11	12/03/76	0.0000+ 0	1.3100+ 0	2.0000+ 1
N,2N	CROSS SECTION	8	8/19/72	-1.2310+ 1	1.2711+ 1	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	4	8/19/72	-1.2310+ 1	1.2711+ 1	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	4	12/03/76	-1.2310+ 1	1.2711+ 1	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	4	12/03/76	-1.2310+ 1	1.2711+ 1	2.0000+ 1
N,N'/P	CROSS SECTION	4	8/19/72	-7.3000+ 0	7.5377+ 0	2.0000+ 1
N,N'/P	N ENERGY-ANGLE DIST.	5	8/19/72	-7.3000+ 0	7.5377+ 0	2.0000+ 1
N,N'/P	N TOTAL ENERGY DEP.	10	12/03/76	-7.3000+ 0	7.5377+ 0	2.0000+ 1
N,N'/P	N LOCAL ENERGY DEP.	10	12/03/76	-7.3000+ 0	7.5377+ 0	2.0000+ 1
N,P	CROSS SECTION	29	9/28/77	-7.1000+ 1	1.5000+ 0	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	12/03/76	-7.1000+ 1	1.5000+ 0	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	12/03/76	-7.1000+ 1	1.5000+ 0	2.0000+ 1
N,A	CROSS SECTION	8	9/28/77	-1.9400+ 0	3.0000+ 0	2.0000+ 1
N,A	TOTAL ENERGY DEP.	2	12/03/76	-1.9400+ 0	3.0000+ 0	2.0000+ 1
N,A	LOCAL ENERGY DEP.	2	12/03/76	-1.9400+ 0	3.0000+ 0	2.0000+ 1
N,G	CROSS SECTION	HH	4/03/76	-7.9300+ 1	1.0000+ 1	2.0000+ 1
N,G	G ENERGY DIST.	0	11/01/72	-7.9300+ 0	1.000+ 10	2.0000+ 1
N,G	G MULTIPLICITY	0	11/01/72	-7.9300+ 0	1.0000+ 10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	0	11/01/72	-7.9300+ 1	1.0000+ 10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	0	11/01/72	-7.9300+ 0	1.0000+ 10	2.0000+ 1
N,XG	CROSS SECTION	5	1/11/73	0.0000+ 0	4.4000+ 0	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	5	1/11/73	0.0000+ 0	4.4000+ 0	2.0000+ 1
N,XG	CROSS SECTION	0	1/11/73	0.0000+ 0	4.4000+ 0	2.0000+ 1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	4.4000+ 0	2.0000+ 1
N,XG	CROSS SECTION	5	1/11/73	0.0000+ 0	4.4000+ 0	2.0000+ 1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 1	4.4000+ 1	2.0000+ 1

PHOTON 1.02660+ 0 MEV
PHOTON 1.2660+ 0 MEV
PHOTON 2.12340+ 0 MEV
PHOTON 2.12340+ 0 MEV

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for the continuum inelastic scattering were assumed to be isotropic. The energy distributions for incident neutron energies below 5 MeV were chosen so as to reproduce the average and maximum secondary neutron energies for the reaction. The energy distributions at 5 MeV and above were obtained from temperature model calculations, with contributions from preequilibrium processes estimated (see UCRL-50400, Vol. 15, Part A, pages 19 to 22).

n,2n CROSS SECTION

The threshold for the n,2n reaction is 12.70 MeV. Experimental values of the n,2n cross section are shown graphically on page 2-111 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 2-116. The evaluated n,2n cross sections are shown on page 98 of UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons produced by the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature

model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n'p CROSS SECTION

The threshold for the n,n'p reaction is 7.53 MeV. Two experimental n,n'p data points are listed on page 1-116 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,n'p cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n'p REACTION

The angular distribution of secondary neutrons produced by the n,n'p reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction is 0.73 MeV. Experimental and evaluated n,p cross sections are shown graphically on pages 2-112 and 2-113 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated experimental values are given on page 2-117. The evaluated n,p cross sections are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The threshold for the n, α reaction is 2.01 MeV. Experimental values of the n, α cross section are shown graphically on pages 2-114 and 2-115 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 2-117. The evaluated n, α cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

A few experimental values of the neutron capture cross section are given on page 2-80 of UCRL-50400, Vol. 7, Part A, Rev. 1. The evaluated capture cross sections are shown in UCRL-50400, Vol. 15, Part B. They are based mainly on nuclear systematics.

PHOTON PRODUCTION FROM n, γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the data of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies, since there are no data for incident neutron energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

$n, X\gamma$ CROSS SECTION

A few $n, X\gamma$ angular and energy distributions are listed on page 1-60 of UCRL-50400, Vol. 3, Rev. 2. In the P^{31} evaluation, the $n, X\gamma$ cross section was assumed to include all photons except those produced in the neutron capture reaction. The evaluated $n, X\gamma$ cross sections include two discrete lines plus a continuum component that starts at 3.3 MeV. The discrete lines were evaluated as shown below.

1.266 MeV

This gamma ray arises from the transition of the 1.266-MeV level to the ground state in P^{31} . For incident neutron energies below 2.234 MeV, the gamma ray is produced entirely from the n, n' reaction. Thus, the $n, X\gamma$ cross section for producing this line was set equal to the n, n' cross section for energies below 2.234 MeV. At higher energies, the inelastic scattering data of K. Tsukada *et al.*,* G. C. Bonazzola and E. Chiavassa,[†] and A. Mittler *et al.*** were used as guides in the evaluation.

*Paper SM-18/12 of the Vienna Conf. on "Physics of Fast and Intermediate Reactors" (1961).

[†]*Nucl. Phys.* **68**, 369 (1965).

***Bull. Am. Phys. Soc.* **13**, 1420 (1968).

2.234 MeV

This gamma ray originates from the transition of the 2.234-MeV level to the ground state in P^{31} . The cross section for producing this gamma ray was calculated based on the inelastic scattering data of K. Tsukada *et al.*, and R. L. Caldwell *et al.*, *Nucl. Sci. Eng.* 8, 173 (1960), as well as data obtained from the evaluated n,n' cross section.

The $n,X\gamma$ cross sections for the continuum component were calculated with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton, *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. In the evaluation, the continuum was assumed to start at 3.3 MeV, to

become 50% of the calculated value at 8 MeV, and to continue at 50% to 20 MeV; between 3.3 and 8 MeV, it was assumed that the interpolation was linear. This procedure gives results that are in reasonable agreement with the experimental data of Caldwell *et al.* at 14.8 MeV.

SPECTRA OF PHOTONS FROM THE $n,X\gamma$ PROCESS

The angular distributions of the photons produced by the $n,X\gamma$ reaction were assumed to be isotropic. The energy distributions of the discrete photons were estimated using the kinematics of the reaction. The energy distributions of the photons from the continuum component of the reaction were calculated with the nuclear systematics of Perkins, Haight, and Howerton cited above.

Sulfur-32

DATA SUMMARY AND GENERAL COMMENTS

The references to the experimental data for $^{32}_{16}\text{S}$ are summarized in UCRL-50400, Vol. 3. They are listed in UCRL-50400, Vol. 10. The data consist primarily of measurements for natural sulfur, but they also include measurements for isotopes S^{32} and S^{34} . The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for S^{32} are shown graphically on pages 2-81 to 2-91 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on pages 2-92 and 2-93. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Some experimental elastic scattering data are shown graphically on page 2-92 of UCRL-50400, Vol. 7, Part A, Rev. 1; additional tabulated values are given on page 2-93. The evaluated elastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated elastic cross sections were obtained for the most part by differencing the evaluated total cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies below 50 keV. Above 50 keV, the evaluated elastic scattering angular distributions were based on experimental data, supplemented at the higher energies by spherical optical model calculations in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering data for natural sulfur are shown on pages 2-119 (graphical) and 2-121 (tabular) of UCRL-50400, Vol. 8, Rev. 1, Part A; corresponding quantities for S^{32} are shown on pages 2-123 and 2-130. In view of the scarcity of the experimental data, inelastic scattering was represented in the evaluation by a continuum contribution that starts at 213. MeV. The evaluated n,n' continuum cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

Sulfur-32

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	201	8/23/72	0.0000+0	1.0000-10	2.0000+1
N,ELASTIC	ANGULAR DIST.	15	1/03/72	0.0000+0	5.0000-2	2.0000+1
N,ELASTIC	TOTAL ENERGY DEP.	30	11/12/74	0.0000+0	1.0000-10	2.0000+1
N,ELASTIC	LOCAL ENERGY DEP.	30	11/12/74	0.0000+0	1.0000-10	2.0000+1
N,N'	CROSS SECTION	13	8/23/72	0.0000+0	2.3100+0	2.0000+1
N,N'	ENERGY-ANGLE DIST.	9	8/23/72	0.0000+0	2.3100+0	2.0000+1
N,N'	TOTAL ENERGY DEP.	10	12/03/76	0.0000+0	2.3100+0	2.0000+1
N,N'	LOCAL ENERGY DEP.	9	12/03/76	0.0000+0	2.3100+0	2.0000+1
N,2N	CROSS SECTION	6	1/09/73	-1.5588+1	1.5560+1	2.0000+1
N,2N	ENERGY-ANGLE DIST.	2	1/09/73	-1.5088+1	1.5560+1	2.0000+1
N,2N	TOTAL ENERGY DEP.	3	12/03/76	-1.5088+1	1.5564+1	2.0000+1
N,2N	LOCAL ENERGY DEP.	3	12/03/76	-1.5088+1	1.5564+1	2.0000+1
N,N'P	CROSS SECTION	3	8/23/72	-8.8600+0	9.1400+0	2.0000+1
N,N'P	ENERGY-ANGLE DIST.	5	8/23/72	-8.8600+0	9.1400+0	2.0000+1
N,N'P	TOTAL ENERGY DEP.	8	5/29/78	-8.8600+0	9.1400+0	2.0000+1
N,N'P	LOCAL ENERGY DEP.	8	5/29/78	-8.8600+0	9.1400+0	2.0000+1
N,P	CROSS SECTION	37	9/28/77	-9.2000+1	1.6000+0	2.0000+1
N,P	TOTAL ENERGY DEP.	2	5/29/78	-9.2000+1	1.6000+0	2.0000+1
N,P	LOCAL ENERGY DEP.	2	5/29/78	-9.2000+1	1.6000+0	2.0000+1
N,T	CROSS SECTION	3	8/23/72	-1.2670+1	1.3100+1	2.0000+1
N,T	TOTAL ENERGY DEP.	2	5/29/78	-1.2670+1	1.3100+1	2.0000+1
N,T	LOCAL ENERGY DEP.	2	5/29/78	-1.2670+1	1.3100+1	2.0000+1
N,A	CROSS SECTION	45	8/23/72	1.5300+0	1.0000-10	2.0000+1
N,A	TOTAL ENERGY DEP.	2	5/29/78	1.5300+0	1.0000-10	2.0000+1
N,A	LOCAL ENERGY DEP.	2	5/29/78	1.5300+0	1.0000-10	2.0000+1
N,G	CROSS SECTION	130	8/23/72	8.6400+0	1.0000-10	2.0000+1
N,G	ENERGY DIST.	2	11/01/72	8.6400+0	1.0000-10	2.0000+1
N,G	MULTIPLICITY	2	11/01/72	8.6400+0	1.0000-10	2.0000+1
N,G	TOTAL ENERGY DEP.	2	11/21/76	8.6400+0	1.0000-10	2.0000+1
N,G	LOCAL ENERGY DEP.	2	11/21/76	8.6400+0	1.0000-10	2.0000+1
N,XG	CROSS SECTION	6	2/21/73	0.0000+0	9.0000+1	2.0000+1
N,XG	ENERGY-ANGLE DIST.	1	1/11/73	0.0000+0	9.0000+1	2.0000+1
N,XG	CROSS SECTION	4	1/09/73	0.0000+0	3.9000+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	3.9000+0	2.0000+1
N,XG	CROSS SECTION	11	1/09/73	0.0000+0	2.3100+0	2.0000+1
N,XG	ANGULAR DIST.	2	1/09/73	0.0000+0	2.3100+0	2.0000+1
N,XG	CROSS SECTION	4	1/09/73	0.0000+0	5.1660+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	5.1660+0	2.0000+1
N,XG	CROSS SECTION	3	1/11/73	0.0000+0	2.0000+0	2.0000+1
N,XG	ANGULAR DIST.	2	1/09/73	0.0000+0	5.0000+0	2.0000+1
N,XG	CROSS SECTION	5	1/09/73	0.0000+0	4.4200+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	4.4200+0	2.0000+1

PHOTON 1.5400+0 MEV
 PHOTON 1.5400+0 MEV
 PHOTON 2.2370+0 MEV
 PHOTON 2.2370+0 MEV
 PHOTON 2.7700+0 MEV
 PHOTON 2.7700+0 MEV
 PHOTON 3.7860+0 MEV
 PHOTON 3.7860+0 MEV
 PHOTON 4.2900+0 MEV
 PHOTON 4.2900+0 MEV

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for the continuum inelastic scattering were assumed to be isotropic. The energy distributions for incident neutron energies below 5 MeV were chosen so as to reproduce the average and maximum secondary neutron energies for the reaction. The energy distributions at 5 MeV and above were obtained from temperature model calculations; contributions from preequilibrium processes were estimated (see UCRL-50400, Vol. 15, Part A, pages 19 to 22).

n,2n CROSS SECTION

The threshold for the n,2n reaction is 15.56 MeV. Experimental values of the n,2n cross section are shown graphically on page 2-124 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 2-130. The evaluated n,2n cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model

calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n'p CROSS SECTION

The threshold for the n,n'p reaction is 9.14 MeV. One experimental data point for natural sulfur is listed on page 2-122 of UCRL-50400, Vol. 8, Rev. 1, Part A; a data point for S^{32} is listed on page 2-131. The evaluated n,n'p cross sections, which are shown in UCRL-50400, Vol. 15, Part B, were estimated by using nuclear systematics.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n'p REACTION

The angular distribution of secondary neutrons produced by the n,n'p reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction is 0.96 MeV. Experimental n,p cross sections are shown graphically on pages 2-120 (natural sulfur), 2-126 and 2-127 (S^{32}), and 2-133 (S^{34}) of

UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated experimental values are given on pages 2-122 (natural sulfur), 2-131 (S^{32}), and 2-134 (S^{34}). The evaluated n,p cross sections for S^{32} are based on the experimental data, and are shown in UCRL-50400, Vol. 15, Part B.

n,t CROSS SECTION

The threshold for the n,t reaction is 13.09 MeV. Experimental values of the n,t cross section are shown graphically on page 2-128 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 2-132. The evaluated n,t cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The threshold for the n, α reaction is -1.53 MeV, so this reaction is exothermic. Experimental n, α cross sections for S^{32} are shown on pages 2-129 (graphical) and 2-132 (tabular) of UCRL-50400, Vol. 8, Rev. 1, Part A; some corresponding cross sections for S^{34} are given on pages 2-133 and 2-134. The evaluated n, α cross sections for S^{32} are shown in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

A few capture cross section data points for natural sulfur, S^{32} , and

S^{34} are given on pages 2-93, 2-95, and 2-96, respectively, of UCRL-50400, Vol. 7, Part A, Rev. 1. The evaluated neutron capture cross sections for S^{32} , which are based in large part on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the data of V. J. Orphar, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies, since there are no data for incident neutron energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

n,X γ CROSS SECTION

The only experimental n,X γ data points for sulfur are listed on page 2-122 of UCRL-50400, Vol. 8, Rev. 1, Part A. In the evaluation for sulfur, the n,X γ cross section was assumed to include all photons except those produced in the neutron capture reaction. Also, although the evaluation for sulfur is listed as S^{32} (the reason being that S^{32} is by far the dominant isotope in natural sulfur), some

gamma ray lines from the scarce isotopes S^{33} , S^{34} , and S^{36} were also considered in the evaluation of the $n,X\gamma$ cross sections. The evaluated $n,X\gamma$ cross sections include five discrete lines plus a continuum contribution that starts at 0.9 MeV. The discrete lines were evaluated as follows.

2.237 MeV

This gamma ray arises from the transition of the 2.237-MeV level to the ground state in S^{32} . For incident neutron energies below approximately 4 MeV, the gamma ray is produced entirely from the n,n' reaction. Thus, the $n,X\gamma$ cross section for producing this gamma ray was set equal to the n,n' cross section for energies below 4 MeV. The corresponding cross section at 14 MeV was taken from the study by J. Benveniste *et al.*, UCID-4619 (1963). Cross sections at the other energies were obtained by interpolation and extrapolation.

1.54 MeV

This gamma ray arises from the transition of the second to the first excited state in S^{32} . At 14 MeV, the cross section for producing this gamma ray was assumed to be 6% of the cross section for producing the 2.237-MeV gamma ray. The assumption was based on the inelastic proton scattering data of G. Crawley and

G. T. Garvey, *Phys. Rev.* 160, 981 (1967) and 167, 1070 (1968). At other neutron energies, the cross section was guessed.

3.78 MeV

This gamma ray arises from the transition of the 3.78-MeV level to the ground state in S^{32} . The cross section at 7.6 MeV was given in a private communication from F. G. Perey (1968). The cross section at other energies was guessed.

4.29 MeV

This gamma ray arises from the transition of the 4.29-MeV level to the ground state in S^{32} . The cross section at 7.6 MeV was given in the private communication of F. G. Perey cited above. The cross section at 14 MeV was deduced by making the same assumptions for the 4.29-MeV line as for the 1.54-MeV line; the data of Crawley and Garvey were used as a guide.

2.77 MeV

This gamma ray arises from the transition of the 5.01-MeV level to the 2.237-MeV level in S^{32} . Two references* give different values for the cross section at 14 MeV.

*W. E. Thompson and F. C. Engesser, USNRDL-TR-1043 (1966), and V. N. Bochkarev and V. V. Nefédov, *Yad. Fiz.* 1, 803 (1965).

Bochkarev's value was chosen, using Crawley and Garvey's p,p' data, cited above, as a guide. At other energies the cross section was guessed.

All discrete lines in the n,Xy evaluation came from the S^{32} isotope. However, gamma rays from S^{33} , S^{34} , and S^{36} were considered in the evaluation of the continuum component. The n,Xy cross sections for the continuum component were obtained from the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton, *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. In the evaluation, the continuum was assumed to start at 0.9 MeV, becoming 0.4% of the calculated value at 3 MeV, 2% at 5 MeV, and 41% at 10 MeV and above. The continuum gamma rays at the lower energies come from n,n' reactions in the rare isotopes S^{33} , S^{34} , and S^{36} .

At 14.8 MeV, the procedure followed here gives results that are in reasonable agreement with the results of W. E. Tucker, ORO-2791-30 (1969) and ORO-2791-32 (1971).

SPECTRA OF PHOTONS FROM THE n,Xy PROCESS

The angular distributions of the 2.237-, 4.29-, and 3.78-MeV gamma rays were taken from the measurements of F. G. Perey (private communication, 1968) at 7.6 MeV. The angular distributions of the 1.54- and 2.77-MeV gamma rays were assumed to be isotropic. The energy distributions of these discrete photon lines were estimated based on the kinematics of the reaction. The angular distributions of the continuum photons were assumed to be isotropic, and the corresponding energy distributions were calculated from the systematics of Perkins, Haight, and Howerton cited above.

Chlorine

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural chlorine and for some of its isotopes are summarized on pages 1-65 to 1-67 of UCRL-50400, Vol. 3, Rev. 2; they are listed in UCRL-50400, Vol. 10, Rev. 1. The evaluated data, which are for natural chlorine, are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did this evaluation.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for chlorine are shown graphically on pages 2-96 to 2-103 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on page 2-104. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections are based in part on the following specific ECSIL data sets: ECSIL-304 from thermal energies to about 2 keV; ECSIL-3684 up to 20 keV; ECSIL-154 from 50 to 100 keV; ECSIL-95 from 100 keV to 1 MeV; ECSIL 2517 from 1 to 3 MeV; and ECSIL-504 from 3 to 10 MeV. These ECSIL data references are given in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

The only elastic scattering data (two points) are given on page 2-104

of UCRL-50400, Vol. 7, Part A, Rev. 1. The evaluated elastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections were obtained by subtracting the evaluated total cross sections from the sums of the evaluated non-elastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

There are no experimental measurements of elastic scattering angular distributions in chlorine. Hence the evaluated elastic scattering angular distributions were based on spherical optical model calculations in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)]. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies below 200 keV.

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering data for natural chlorine are shown on pages 2-134 to 2-136 of UCRL-50400, Vol. 8, Rev. 1, Part A; inelastic scattering data for Cl^{35} and Cl^{37} are given on pages 2-140 and 2-143, respectively, of this reference. In view of the scarcity of the experimental data, inelastic scattering was represented

Chlorine

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E MIN.	E MAX.
N,ELASTIC	CROSS SECTION	825	8/15/75	0.0000+0	1.0000-10	2.0000+0
N,ELASTIC	ANGULAR DIST.	4	8/19/70	0.0000+0	0.0000-1	1.0000+0
N,ELASTIC	TOTAL ENERGY DEP.	28	11/12/74	0.0000+0	1.0000-10	2.0000+0
N,ELASTIC	LOCAL ENERGY DEP.	28	11/12/74	0.0000+0	1.0000-10	2.0000+0
N,N'	CROSS SECTION	27	1/12/73	0.0000+0	0.6000-1	2.0000+0
N,N'	ENERGY-ANGLE DIST.	9	8/23/72	0.0000+0	0.6000-1	2.0000+0
N,N'	TOTAL ENERGY DEP.	13	12/03/76	0.0000+0	0.6000-1	2.0000+0
N,N'	LOCAL ENERGY DEP.	13	12/03/76	0.0000+0	0.6000-1	2.0000+0
N,2N	CROSS SECTION	14	8/19/70	-1.2650+1	1.3010-1	2.0000+0
N,2N	ENERGY-ANGLE DIST.	4	8/19/70	-1.2650+1	1.3010-1	2.0000+0
N,2N	TOTAL ENERGY DEP.	4	12/03/76	-1.2650+1	1.3010-1	2.0000+0
N,2N	LOCAL ENERGY DEP.	4	12/03/76	-1.2650+1	1.3010-1	2.0000+0
N,N'P	CROSS SECTION	20	8/19/70	-6.3700+0	6.5512+0	2.0000+0
N,N'P	ENERGY-ANGLE DIST.	5	8/19/70	-6.3700+0	6.5512+0	2.0000+0
N,N'P	TOTAL ENERGY DEP.	14	12/03/76	-6.3700+0	6.5512+0	2.0000+0
N,N'P	LOCAL ENERGY DEP.	14	12/03/76	-6.3700+0	6.5512+0	2.0000+0
N,N'A	CROSS SECTION	22	8/19/70	-6.9900+0	7.1900+0	2.0000+0
N,N'A	ENERGY-ANGLE DIST.	5	8/23/72	-6.9900+0	7.1900+0	2.0000+0
N,N'A	TOTAL ENERGY DEP.	9	12/03/76	-6.9900+0	7.1900+0	2.0000+0
N,N'A	LOCAL ENERGY DEP.	9	12/03/76	-6.9900+0	7.1900+0	2.0000+0
N,P	CROSS SECTION	466	12/13/71	6.1000+1	1.0000-10	2.0000+0
N,P	TOTAL ENERGY DEP.	2	12/03/76	6.1000+1	1.0000-10	2.0000+0
N,P	LOCAL ENERGY DEP.	2	12/03/76	6.1000+1	1.0000-10	2.0000+0
N,A	CROSS SECTION	48	8/19/70	9.3000+1	1.0000+0	2.0000+0
N,A	TOTAL ENERGY DEP.	2	12/03/76	9.3000+1	1.0000+0	2.0000+0
N,A	LOCAL ENERGY DEP.	2	12/03/76	9.3000+1	1.0000+0	2.0000+0
N,G	CROSS SECTION	246	12/13/71	8.5800+0	1.0000-10	2.0000+0
N,G	ENERGY DIST.	2	11/21/76	8.5800+0	1.0000-10	2.0000+0
N,G	MULTIPLICITY	2	11/21/76	8.5800+0	1.0000-10	2.0000+0
N,G	TOTAL ENERGY DEP.	2	11/21/76	8.5800+0	1.0000-10	2.0000+0
N,G	LOCAL ENERGY DEP.	2	11/21/76	8.5800+0	1.0000-10	2.0000+0
N,XG	CROSS SECTION	5	2/21/77	0.0000+0	2.7000+0	2.0000+0
N,XG	ENERGY-ANGLE DIST.	1	1/12/73	0.0000+0	2.7000+0	2.0000+0
N,XG	CROSS SECTION	6	1/12/73	0.0000+0	1.2500+0	2.0000+0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	1.2500+0	2.0000+0
N,XG	CROSS SECTION	5	1/12/73	0.0000+0	1.7750+0	2.0000+0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	1.7750+0	2.0000+0
N,XG	CROSS SECTION	3	1/12/73	0.0000+0	6.4000+0	2.0000+0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	6.4000+0	2.0000+0

PHOTON = 1.2200+0 MEV
 PHOTON = 1.2200+0 MEV
 PHOTON = 1.7500+0 MEV
 PHOTON = 1.7500+0 MEV
 PHOTON = 2.1270+0 MEV
 PHOTON = 2.1270+0 MEV

in the evaluation by a continuum contribution that starts at 0.86 MeV, the energy of the first excited state in Cl^{37} . The evaluated n,n' continuum cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for the continuum inelastic scattering were assumed to be isotropic. The energy distributions for incident neutron energies below 5 MeV were chosen so as to reproduce the average and maximum secondary neutron energies for the reaction. The energy distributions at 5 MeV and above were obtained from temperature model calculations, with contributions from preequilibrium processes estimated by following the procedures described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction in Cl^{35} is 13.01 MeV. The $n,2n$ thresholds for the other isotopes of chlorine are somewhat lower, but these isotopes are not expected to contribute as prominently to the $n,2n$ reaction. Furthermore, there are no experimental data for them. Accordingly, the $n,2n$ threshold in the evaluation was set equal to 13.01 MeV. Experimental $n,2n$ cross sections for Cl^{35} are shown

graphically on page 2-137 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 2-140 and 2-141. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n' CROSS SECTION

The threshold for the n,n' reaction is 6.55 MeV in Cl^{35} ; it is at a somewhat higher energy in each of the other isotopes of chlorine. There are no experimental data for this reaction. The evaluated n,n' cross sections, which were obtained from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n' REACTION

The angular distribution of secondary neutrons from the n,n' reaction was assumed to be isotropic

in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n, n' CROSS SECTION

The threshold for the n, n' reaction is 7.19 MeV in Cl^{35} ; it is somewhat higher for the other isotopes. There are no experimental data for this reaction. The evaluated n, n' cross sections, which were obtained from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n, n' REACTION

The angular distribution of secondary neutrons from the n, n' reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n, p CROSS SECTION

The threshold for the n, p reaction in Cl^{35} is -0.62 MeV. The negative value means that the reaction is

exoergic. Experimental n, p cross sections for Cl^{35} are shown on pages 2-138 and 2-141 of UCRL-50400, Vol. 8, Rev. 1, Part A; n, p cross sections for Cl^{37} are shown on pages 2-142 and 2-143. The evaluated n, p cross sections, which are based on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The n, α reaction in Cl^{35} is exoergic. Experimental data for the n, α reaction in Cl^{35} are given on pages 2-139 and 2-141 of UCRL-50400, Vol. 8, Rev. 1, Part A; some n, α data for Cl^{37} are given on page 2-143. The evaluated n, α cross sections for chlorine are shown in UCRL-50400, Vol. 15, Part B. These cross sections are based partly on the data and partly on nuclear systematics.

n, γ CROSS SECTION

Capture cross sections for natural chlorine are given on page 2-103 (graphical) and on page 2-105 (tabular) of UCRL-50400, Vol. 7, Part A, Rev. 1; some capture cross sections for Cl^{37} are given on pages 2-105 (graphical) and 2-106 (tabular). The evaluated capture cross sections for natural chlorine, which are based in large part on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the data of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum is assumed to apply at all neutron energies, since there are no data for incident neutron energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

$n,X\gamma$ CROSS SECTION

The only $n,X\gamma$ experimental data for chlorine consist of three data points listed on page 2-136 of UCRL-50400, Vol. 8, Rev. 1, Part A. In the evaluation, the $n,X\gamma$ cross section was assumed to include all photons except those produced in the neutron capture reaction. The evaluated $n,X\gamma$ cross sections include three discrete lines plus a continuum contribution that starts at 2.7 MeV. The discrete lines were evaluated as follows.

1.22 MeV

This gamma ray arises from the transition of the 1.22-MeV level to the ground state in Cl^{35} . For neutron energies below about 1.8 MeV, the gamma ray is produced entirely from the n,n' reaction. Thus, the

$n,X\gamma$ cross section for producing this gamma ray was set equal to the n,n' cross section for energies below 1.8 MeV. At 14.7 MeV, the cross section for producing this gamma ray was measured by W. E. Thompson and F. C. Engesser, USNRDL-TR-1043 (1966). Values of the cross section between 1.8 MeV and 14.7 MeV were obtained by interpolation, and the cross section at 20 MeV was guessed.

1.75 MeV

The second excited state in Cl^{35} is 1.762 MeV, and the first excited state in Cl^{37} is 1.726 MeV. Both states decay to their respective ground states. In the evaluation, the contributions from these two states were lumped together as a single 1.75-MeV gamma-ray line. The cross section at 2.5 MeV was derived by assuming that the inelastic cross section was the sum of the composite gamma ray and the 1.22-MeV gamma ray discussed above. At 2.97 MeV and 14.7 MeV the data of Thompson and Engesser and of D. B. Nichols *et al.*, *Bull. Am. Phys. Soc.* 9, 347 (1964), were inserted into the evaluation. Between these points, linear interpolation was used. The cross section at 20 MeV was guessed.

2.127 MeV

The first excited state in S^{34} , which is reached when $n,n'p$ and n,d

reactions in Cl^{35} , results in the production of the 2.127-MeV gamma ray—many of which appear in the 14.7-MeV data of Thompson and Engesser cited above. The cross section for this gamma ray was assumed to increase linearly from threshold to the 14.7-MeV datum. At 20 MeV, this cross section was guessed.

The $n, X\gamma$ cross sections for the continuum component were obtained from the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. In the evaluation, the _____ was assumed to start at 2.7 MeV, and a linearly

increasing fraction of the calculated value was taken until 10 MeV, where 50% of the calculated cross section was used. This fraction was then held constant from 10 to 20 MeV.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The angular distributions of the photons produced by the $n, X\gamma$ reaction were assumed to be isotropic. The energy distributions of the discrete photons were estimated based on the kinematics of the reaction. The energy distributions of the photons from the continuum component of the reaction were calculated from the nuclear systematics of Perkins, Haight, and Howerton cited above.

Argon

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural argon and for some of its isotopes are summarized in UCRL-50400, Vol. 3; they are listed in UCRL-50400, Vol. 10. The evaluated data, which are for natural argon, are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did this evaluation.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for argon are shown graphically on pages 2-106 to 2-108 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on page 2-109. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections are based in part on the following specific ECSIL data sets: ECSIL-777 near thermal neutron energies; ECSIL-2998 from 0.08 to 6 eV; ECSIL-53 from 200 eV to 10 keV; ECSIL-98 from 0.5 to 1.1 MeV; and ECSIL-570 from 1.1 to 20 MeV. These ECSIL data references are given in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

The only elastic scattering data point in the argon evaluation was measured at an incident neutron

energy of 14 MeV (page 2-109 of UCRL-50400, Vol. 7, Part A, Rev. 1). Thus, the evaluated elastic scattering cross sections were obtained by subtracting the evaluated total cross sections from the sums of the evaluated nonelastic cross sections. These evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

The experimental data on elastic scattering angular distributions in argon consist of one measurement at 14 MeV. Hence the evaluated elastic scattering angular distributions were obtained for the most part from spherical optical model calculations in which the best-fit optical model parameters of Becchetti and Greenlees were used [Phys. Rev. 182, 1190 (1969)]. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies below 10 keV.

INELASTIC SCATTERING CROSS SECTION

There are no n,n' experimental data for argon. Accordingly, the inelastic scattering cross section was represented in the evaluation by a continuum reaction that starts at 1.5 MeV (the approximate energy of the lowest level in A^{40}). The

Argon

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	93	8/23/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	16	4/05/76	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	35	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	35	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	14	8/23/72	0.0000+ 0	1.5000+ 0	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	5	8/23/72	0.0000+ 0	1.5000+ 0	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	11	12/03/76	0.0000+ 0	1.5000+ 0	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	10	12/03/76	0.0000+ 0	1.5000+ 0	2.0000+ 1
N,2N	CROSS SECTION	8	8/23/72	-9.8700+ 0	1.0500+ 1	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	5	8/23/72	-9.8700+ 0	1.0500+ 1	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	5	12/03/76	-9.8700+ 0	1.0500+ 1	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	5	12/03/76	-9.8700+ 0	1.0500+ 1	2.0000+ 1
N,P	CROSS SECTION	5	8/23/72	-6.7200+ 0	8.0000+ 0	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	5/29/78	-6.7200+ 0	8.0000+ 0	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	5/29/78	-6.7200+ 0	8.0000+ 0	2.0000+ 1
N,A	CROSS SECTION	6	8/23/72	-2.4900+ 0	2.5000+ 0	2.0000+ 1
N,A	TOTAL ENERGY DEP.	2	5/29/78	-2.4900+ 0	2.5000+ 0	2.0000+ 1
N,A	LOCAL ENERGY DEP.	2	5/29/78	-2.4900+ 0	2.5000+ 0	2.0000+ 1
N,G	CROSS SECTION	72	8/23/72	6.1000+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	1/16/73	6.1000+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	1/16/73	6.1000+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.1000+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.1000+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	5	2/21/73	0.0000+ 0	3.5000+ 0	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	5	1/12/73	0.0000+ 0	3.5000+ 0	2.0000+ 1
N,XG	CROSS SECTION	5	1/12/73	0.0000+ 0	2.1700+ 0	2.0000+ 1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.1700+ 0	2.0000+ 1
N,XG	CROSS SECTION	3	1/12/73	0.0000+ 0	2.5900+ 0	2.0000+ 1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.5900+ 0	2.0000+ 1
N,XG	CROSS SECTION	8	1/12/73	0.0000+ 0	1.5000+ 0	2.0000+ 1
N,XG	G ANGULAR DIST.	2	1/12/73	0.0000+ 0	1.5000+ 0	2.0000+ 1
N,XG	CROSS SECTION	5	1/12/73	0.0000+ 0	3.3000+ 0	2.0000+ 1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	3.3000+ 0	2.0000+ 1
N,XG	CROSS SECTION	3	1/12/73	0.0000+ 0	2.5900+ 0	2.0000+ 1
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	2.5900+ 0	2.0000+ 1

PHOTON = 6.6500- 1 MEV
 PHOTON = 6.6500 1 MEV
 PHOTON = 1.0690+ 0 MEV
 PHOTON = 1.0690+ 0 MEV
 PHOTON = 1.4600+ 0 MEV
 PHOTON = 1.4600+ 0 MEV
 PHOTON = 1.7700+ 0 MEV
 PHOTON = 1.7700+ 0 MEV
 PHOTON = 2.5200+ 0 MEV
 PHOTON = 2.5200+ 0 MEV

evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for the continuum inelastic scattering were assumed to be isotropic. The energy distributions for incident neutron energies at 3 MeV and below were chosen so as to reproduce the average and maximum secondary neutron energies for the reaction. The energy distributions above 3 MeV were obtained from temperature model calculations. The energy distributions at 6 MeV and above also contain contributions from preequilibrium processes, which are estimated by following the procedures described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The threshold for the n,2n reaction in A^{40} (the principal isotope of argon) is 10.12 MeV. The n,2n thresholds for the trace isotopes A^{36} and A^{38} are somewhat higher. Thus, in the evaluation for natural argon, an effective n,2n threshold of 10.5 MeV was selected. There are no experimental n,2n data for argon. Hence the evaluated n,2n cross sections (shown in UCRL-50400, Vol. 15, Part B) are based entirely on nuclear systematics.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons produced by the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction in A^{40} is 6.88 MeV. However, the only experimental n,p data for this isotope are three points near 14 MeV (page 2-152 of UCRL-50400, Vol. 9, Rev. 1, Part A). Some n,p data for the trace isotopes A^{36} and A^{38} are given on pages 1-145, 2-146, and 2-149 of this reference. The evaluated n,p cross sections for natural argon, which have an assumed effective threshold of 8 MeV, are shown in UCRL-50400, Vol. 15, Part B; these cross sections were obtained mainly from nuclear systematics.

n, α CROSS SECTION

The threshold for the n, α reaction in A^{40} is 2.55 MeV. The thresholds for A^{38} and A^{36} are lower in energy (the n, α reaction in A^{36} is exoergic). In the evaluation for natural argon,

the n,α threshold was set at 2.5 MeV. Extensive experimental data for the various isotopes of argon are given on pages 2-145, 2-145 to 2-151, and 2-153 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,α cross sections, which were based on the experimental data and on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n,γ CROSS SECTION

A thermal neutron capture cross section data point for natural argon is given on page 2-109 of UCRL-50400, Vol. 7, Part A, Rev. 1; a few data points for A^{40} at neutron energies from 0.136 MeV to 1 MeV are given on page 2-110. The evaluated capture cross sections for natural argon, which are based partly on these data and partly on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the compilation of C. A. Bartholomew *et al.*, *Nucl. Data A3*, 367 (1967). Within that compilation we relied primarily on the data of Lycklama *et al.*; the data of Arnell *et al.* were used to fill in the gaps. The choice of which data were used was arbitrary. This thermal neutron gamma-ray spectrum was assumed to apply at all neutron energies. To

conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

$n,X\gamma$ CROSS SECTION

There are no experimental $n,X\gamma$ data for argon. In the evaluation, the $n,X\gamma$ cross section was assumed to include all photons except those produced in the neutron capture reaction. The evaluated $n,X\gamma$ cross sections include five discrete lines plus a continuum contribution that starts at 3.6 MeV. The discrete lines, which are all attributed to A^{40} (which is 99.6% abundant in natural argon) were evaluated as follows.

1.46 MeV

This gamma ray comes from the deexcitation of the first excited state of A^{40} . For neutron energies ranging from 1.46 MeV to about 2.2 MeV the n,n' cross section only excites the 1.46-MeV level. According to the information of F. Ajzenberg-Selove and T. Lauritsen [*Nucl. Phys. A190*, 1 (1972)], most of the states up to 3.5 MeV also decay primarily through this level. Thus, the cross section for the excitation of this gamma ray was set equal to, or slightly below, the n,n' cross section for neutron energies below 3.5 MeV. At 3.5 MeV, the cross section was obtained from the data of S. C. Mathur and I. L.

Morgan, *Nucl. Phys.* 73, 579 (1965).

At 14 and 20 MeV the cross section was guessed.

0.665 MeV

This gamma ray is produced by the deexcitation of the 2.125-MeV state. The cross section at a neutron energy of 3.5 MeV was taken from the data of Mathur and Morgan cited above. At other energies the cross section was guessed.

1.069 MeV

This gamma ray arises from the transition of the 2.529-MeV level to the 1.46-MeV level. According to Ajzenberg-Selove and Lauritsen, cited above, this decay mode competes with the direct decay to the ground state, with the ratio of the 1.069- and 2.529-MeV gamma rays being 2 to 1. The data of Mathur and Morgan at 3.5 MeV do not reflect this 2 to 1 branching ratio; hence the cross sections for the production of the "2.52" and "1.06" MeV gamma rays in this reference were summed and then distributed in the "correct" 2 to 1 ratio. The cross section at 20 MeV was guessed.

2.529 MeV

See the discussion immediately above.

1.75 MeV

This gamma ray is produced by the decay of the 3.21-MeV level to the 1.46-MeV level. In the evaluation of this gamma-ray line, the data of Mathur and Morgan at 3.5, 4.0, and 4.5 MeV were used, and the cross section at 20 MeV was guessed.

The n,X γ cross sections for the continuum component were obtained from the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. In the evaluation, the continuum was assumed to start at 3.6 MeV, reaching 50% of its calculated value at 10 MeV, and then remaining at this value to 20 MeV. Between 3.6 and 10 MeV, the fraction of the calculated value to be used was obtained by linear interpolation.

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

The angular distribution of the 1.46-MeV photons was taken from the data of Mathur and Morgan at 3.5 MeV, and was assumed to have this shape at all incident neutron energies. The angular distributions of the other photon lines and of the continuum photons were assumed to be isotropic. The energy distributions of the

discrete photons were estimated from the kinematics of the reaction. The energy distributions of the photons from the continuum component

of the reaction were calculated from the nuclear systematics of Perkins, Haight, and Howerton cited above.

Potassium

DATA SUMMARY AND GENERAL COMMENTS

The references for the experimental potassium data are summarized in UCRL-50400, Vol. 3. They are listed in UCRL-50400, Vol. 10. These data include measurements of both natural potassium and the specific isotopes ^{39}K and ^{41}K . The evaluation is for natural potassium (see UCRL-50400, Vol. 15, Part B). R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental total cross sections are shown graphically on pages 2-110 to 2-117 (natural potassium), 2-119 (^{39}K), and 2-120 (^{41}K) of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values for natural potassium are given on page 2-118. The evaluated total cross sections for natural potassium are shown in UCRL-50400, Vol. 15, Part B. These cross sections are based on the following specific ECSIL data sets: ECSIL-228 from thermal energies to about 10 eV; ECSIL-508 from 2 to 150 keV; ECSIL-509 from 150 to 320 keV; ECSIL-2517 from 0.36 to 1.3 MeV; ECSIL-380 from 1.3 to 2.1 MeV; and ECSIL-2517 from 2.1 to 20 MeV. These ECSIL data references are given in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

A few elastic scattering data points for natural potassium are listed on page 2-118 of UCRL-50400, Vol. 7, Part A, Rev. 1. The evaluated elastic scattering cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections. These evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies below 30 keV. Above 30 keV the evaluated elastic angular distributions were based on the experimental data, supplemented at the higher energies by spherical optical model calculations in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Some tabular n,n' data for ^{39}K are given on pages 2-164 and 2-165 of

Potassium

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	389	8/25/72	0.0000+0	1.0000-10	2.0000+1
N,ELASTIC	ANGULAR DIST.	10	8/10/79	0.0000+0	3.0000-10	2.0000+1
N,ELASTIC	TOTAL ENERGY DEP.	29	11/12/74	0.0000+0	1.0000-10	2.0000+1
N,ELASTIC	LOCAL ENERGY DEP.	29	11/12/74	0.0000+0	1.0000-10	2.0000+1
N,N'	CROSS SECTION	47	8/25/72	0.0000+0	1.0000+0	2.0000+1
N,N'	ENERGY-ANGLE DIST.	9	8/25/72	0.0000+0	1.0000+0	2.0000+1
N,N'	TOTAL ENERGY DEP.	13	12/03/76	0.0000+0	1.0000+0	2.0000+1
N,N'	LOCAL ENERGY DEP.	12	12/03/76	0.0000+0	1.0000+0	2.0000+1
N,2N	CROSS SECTION	15	8/19/70	-1.3071+1	1.3410+1	2.0000+1
N,2N	ENERGY-ANGLE DIST.	4	8/19/70	-1.3071+1	1.3410+1	2.0000+1
N,2N	TOTAL ENERGY DEP.	4	12/03/76	-1.3071+1	1.3410+1	2.0000+1
N,2N	LOCAL ENERGY DEP.	4	12/03/76	-1.3071+1	1.3410+1	2.0000+1
N,N'P	CROSS SECTION	26	8/19/70	-6.4240+0	6.6000+0	2.0000+1
N,N'P	ENERGY-ANGLE DIST.	5	8/19/70	-6.4240+0	6.6000+0	2.0000+1
N,N'P	TOTAL ENERGY DEP.	11	5/29/78	-6.4240+0	6.6000+0	2.0000+1
N,N'P	LOCAL ENERGY DEP.	10	5/29/78	-6.4240+0	6.6000+0	2.0000+1
N,N'A	CROSS SECTION	26	8/19/70	-7.3650+0	7.6000+0	2.0000+1
N,N'A	ENERGY-ANGLE DIST.	5	8/19/70	-7.3650+0	7.6000+0	2.0000+1
N,N'A	TOTAL ENERGY DEP.	8	5/29/78	-7.3650+0	7.6000+0	2.0000+1
N,N'A	LOCAL ENERGY DEP.	7	5/29/78	-7.3650+0	7.6000+0	2.0000+1
N,P	CROSS SECTION	177	8/19/70	2.2000-1	7.6000-1	2.0000+1
N,P	TOTAL ENERGY DEP.	2	5/29/78	2.2000-1	7.6000-1	2.0000+1
N,P	LOCAL ENERGY DEP.	2	5/29/78	2.2000-1	7.6000-1	2.0000+1
N,A	CROSS SECTION	98	8/19/70	1.3700+0	1.5000+0	2.0000+1
N,A	TOTAL ENERGY DEP.	2	5/29/78	1.3700+0	1.5000+0	2.0000+1
N,A	LOCAL ENERGY DEP.	2	5/29/78	1.3700+0	1.5000+0	2.0000+1
N,G	CROSS SECTION	242	8/25/72	7.8000+0	1.0000-10	2.0000+1
N,G	ENERGY DIST.	2	11/01/72	7.8000+0	1.0000-10	2.0000+1
N,G	MULTIPLICITY	2	11/01/72	7.8000+0	1.0000-10	2.0000+1
N,G	TOTAL ENERGY DEP.	2	11/21/76	7.8000+0	1.0000-10	2.0000+1
N,G	LOCAL ENERGY DEP.	2	11/21/76	7.8000+0	1.0000-10	2.0000+1
N,XG	CROSS SECTION	5	2/21/73	0.0000+0	2.0000+0	2.0000+1
N,XG	ENERGY-ANGLE DIST.	6	1/16/73	0.0000+0	2.0000+0	2.0000+1
N,XG	CROSS SECTION	9	1/12/73	0.0000+0	1.0030+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	1.0030+0	2.0000+1
N,XG	CROSS SECTION	5	1/12/73	0.0000+0	1.5280+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	1.5280+0	2.0000+1
N,XG	CROSS SECTION	4	1/12/73	0.0000+0	1.3250+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	1.3250+0	2.0000+1
N,XG	CROSS SECTION	7	1/12/73	0.0000+0	1.6000+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	1.6000+0	2.0000+1
N,XG	CROSS SECTION	6	1/12/73	0.0000+0	2.5940+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+0	2.5940+0	2.0000+1
N,XG	CROSS SECTION	4	1/12/73	0.0000+0	2.8920+0	2.0000+1
N,XG	ANGULAR DIST.	2	1/16/73	0.0000+0	2.8920+0	2.0000+1
N,XG	CROSS SECTION	4	1/12/73	0.0000+0	3.6970+0	2.0000+1
N,XG	ANGULAR DIST.	2	1/16/73	0.0000+0	3.6970+0	2.0000+1
N,XG	CROSS SECTION	4	1/12/73	0.0000+0	3.6920+0	2.0000+1
N,XG	ANGULAR DIST.	2	5/26/75	0.0000+0	3.6920+0	2.0000+1

PHOTON = 9.8000+ 1 MEV
 PHOTON = 9.8000- 1 MEV
 PHOTON = 1.2660+ 0 MEV
 PHOTON = 1.2660- 0 MEV
 PHOTON = 1.2940+ 0 MEV
 PHOTON = 1.2940- 0 MEV
 PHOTON = 1.6300+ 0 MEV
 PHOTON = 1.6300- 0 MEV
 PHOTON = 2.5300+ 0 MEV
 PHOTON = 2.5300- 0 MEV
 PHOTON = 2.8200+ 0 MEV
 PHOTON = 2.8200- 0 MEV
 PHOTON = 3.0200+ 0 MEV
 PHOTON = 3.0200- 0 MEV
 PHOTON = 3.6000+ 0 MEV
 PHOTON = 3.6000- 0 MEV

UCRL-50400, Vol. 8, Rev. 1, Part A; graphical and tabular n, n' data for K^{41} are given on pages 2-167 and 2-168. In view of the incompleteness of the experimental data, inelastic scattering was represented in the evaluation by a continuum contribution that starts at 1.01 MeV (the energy of the lowest excited state in K^{41}). The evaluated n, n' cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for the continuum inelastic scattering were assumed to be isotropic. The energy distributions were obtained from temperature model calculations. At incident neutron energies of 8 MeV and above, a preequilibrium contribution was added in, as described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n, 2n$ CROSS SECTION

The $n, 2n$ threshold in K^{39} (the dominant isotope in potassium) is 13.41 MeV. Experimental $n, 2n$ measurements of K^{39} are shown graphically on pages 2-156 and 2-157 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular $n, 2n$ values for K^{39} are given on page 2-165; some tabular $n, 2n$ values for K^{41} are given on page

2-168. The evaluated $n, 2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. These values were based on the experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 2n$ REACTION

The angular distribution of secondary neutrons produced by the $n, 2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

$n, n'p$ CROSS SECTION

The threshold for the $n, n'p$ reaction is 6.54 MeV in K^{39} and 8.00 MeV in K^{41} . In the evaluation for natural potassium, the effective threshold was set at 6.6 MeV. One experimental data point for K^{39} is given on page 2-166 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated $n, n'p$ cross sections, which are obtained almost entirely from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, n'p$ REACTION

The angular distribution of secondary neutrons produced by the

n,n'p reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with the nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n' α CROSS SECTION

The threshold for the n,n' α reaction in K^{39} is 7.40 MeV. Experimental data for this reaction are shown graphically on page 2-158 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,n' α cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n' α REACTION

The angular distribution of secondary neutrons from the n,n' α reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with the nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction in K^{39} is -0.22 MeV, and the threshold in K^{41} is 1.75 MeV. The effective

n,p threshold for natural potassium was set at 0.76 MeV. Experimental n,p cross sections for K^{39} are shown graphically on pages 2-160 to 2-162 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 2-166. Some tabulated experimental n,p cross section values for K^{41} are given on page 2-169. The evaluated n,p cross sections for natural potassium, which are based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

Although the threshold for the n, α reaction in K^{39} is exoergic, the evaluated n, α cross sections were assigned an effective threshold of 1.5 MeV. Experimental values for the n, α cross section in K^{39} are shown graphically on pages 2-163 and 2-164 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 2-167. Tabulated experimental values for K^{41} are given on page 2-169. The evaluated n, α cross sections, which are based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

Two neutron capture cross section data points for natural potassium are given on page 2-118 of UCRL-50400, Vol. 7, Part A, Rev. 1; graphical and tabulated values for K^{41} are given on

pages 2-120 and 2-121. The evaluated capture cross sections for natural potassium, which are based mainly on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the data of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies, since there were no data for incident neutron energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of neutron energy.

$n,X\gamma$ CROSS SECTION

Experimental $n,X\gamma$ data for natural potassium are shown on pages 2-154 and 2-155 of UCRL-50400, Vol. 8, Rev. 1, Part A; $n,X\gamma$ data for K^{39} are shown on pages 2-159, 2-160, and 2-166. In the evaluation, the $n,X\gamma$ cross section was assumed to include all photons except those produced in the neutron capture reaction. The evaluated $n,X\gamma$ cross sections include eight discrete lines plus a continuum that starts at 2 MeV. The discrete lines were evaluated as follows.

0.98 MeV

This gamma ray comes from the transition of the 0.98-MeV level in K^{41} to the ground state. Since this is the lowest level in natural potassium, the n,n' cross section can be used to determine the cross section for producing this gamma ray up to an energy of 1.3 MeV, at which energy another level can be excited. For neutron energies between 1.82 and 3.96 MeV, the data of Nichols and McEllistrem were used [*Phys. Rev.* 166, 1074 (1968)]. At higher energies, the cross section was estimated, using the 6.9% abundance of K^{41} in natural potassium as a guide.

1.266 MeV

This gamma ray arises when A^{39} decays to the ground state. The 1.266-MeV level is excited by the n,p reaction in K^{39} . At 3.42 and 3.96 MeV the data of Nichols and McEllistrem were used. At higher energies the cross section was guessed to be half of the n,p cross section.

1.294 MeV

This gamma ray arises from the decay of the 1.294-MeV level to the ground state in K^{41} . At 1.82 and 2.63 MeV, the data of Nichols and McEllistrem were used. At higher energies, the cross section was guessed.

1.63 MeV

Many gamma rays in K^{41} are produced by transitions from the levels around 1.63 MeV to the ground state. Data on the production cross sections below 3.96 MeV are given by Nichols and McEllistrem. The cross section at higher energies was estimated.

Other discrete gamma rays

Gamma ray lines at 2.53, 2.82, 3.02, and 3.60 MeV arise from transitions to the ground state in K^{39} . For neutron energies up to 3.96 MeV, the cross sections were based on the data of Nichols and McEllistrem cited above, and also on their data in *Can. J. Phys. Sci.* 11, 839 (1966). The cross sections at higher energies were estimated, based on the data at 3.96 MeV.

The gamma rays for the continuum component of the $n, X\gamma$ cross section near its 2-MeV threshold are mainly produced by the $n, p\gamma$ reaction. The $n, X\gamma$ cross sections for the continuum component were calculated from the NKGAMEL code, using the systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of

evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. In the evaluation, the calculated cross section value at 5 MeV was multiplied by 36% (the ratio of the n, p cross section to the total nonelastic cross section), and this same ratio was used at higher energies after the contributions of the discrete lines had been subtracted.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The photons produced by the excitation of the discrete gamma-ray lines at 2.82, 3.02, and 3.60 MeV were assigned angular distributions based on the 3.96-MeV data of Nichols and McEllistrem, *Bull. A. T. S.* 11, 839 (1966). The angular distributions for all other photons were assumed to be isotropic. The energy distributions of the photons from the discrete levels were estimated based on the kinematics of the reaction. The energy distributions of the photons from the continuum component of the reaction were calculated from the nuclear systematics of Perkins, Haight, and Howerton cited above.

Calcium

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural calcium and various separated isotopes are summarized in UCRL-50400, Vol. 3; they are listed in UCRL-50400, Vol. 10. The evaluation is for natural calcium (see UCRL-50400, Vol. 15, Part B). R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for natural calcium are shown graphically on pages 2-121 to 2-132 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on pages 2-133 and 2-134. Total cross sections for separated isotopes of calcium are given on pages 2-135 to 2-140 of that reference. The evaluated total cross sections for natural calcium are shown in UCRL-50400, Vol. 15, Part B. These evaluated cross sections are based on the following specific ECSIL data sets: ECSIL-736 from 10 to 100 keV; ECSIL-747 from 100 to 400 keV; ECSIL-451 from 0.4 to 1.4 MeV; ECSIL-380 from 1.4 to 2.1 MeV; ECSIL-3164 from 2.1 to 6 MeV; ECSIL-1508 from 6 to 10 MeV; ECSIL-787 from 10 to 14 MeV; and ECSIL-2517 from 14 to 20 MeV. These ECSIL data references are given in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural calcium are given on pages 2-133 and 2-134 of UCRL-50400, Vol. 7, Part A, Rev. 1. In general, the evaluated elastic cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections. These evaluated elastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies below 100 keV. Above 100 keV the evaluated elastic angular distributions were based on the experimental data, supplemented at the higher energies by spherical optical model calculations in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Graphical and tabular n,n' data for natural calcium are given on

Calcium

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E MIN.	E MAX.
N,ELASTIC	CROSS SECTION	792	12/13/71	0.0000+0	1.0000-10	2.0000+0
N,ELASTIC	ANGULAR DIST.	15	8/19/70	0.0000+0	1.0000-10	2.0000+0
N,ELASTIC	N TOTAL ENERGY DEP.	33	11/12/74	0.0000+0	1.0000-10	2.0000+0
N,ELASTIC	N LOCAL ENERGY DEP.	33	11/12/74	0.0000+0	1.0000-10	2.0000+0
N,N'	CROSS SECTION	22	7/14/73	0.0000+0	1.0000-10	2.0000+0
N,N'	N ENERGY-ANGLE DIST.	10	8/29/72	0.0000+0	1.0000-10	2.0000+0
N,N'	N TOTAL ENERGY DEP.	9	12/03/76	0.0000+0	1.0000-10	2.0000+0
N,N'	N LOCAL ENERGY DEP.	9	12/03/76	0.0000+0	1.0000-10	2.0000+0
N,2N	CROSS SECTION	17	8/19/70	1.0000+0	1.0282+0	2.0000+0
N,2N	N ENERGY-ANGLE DIST.	5	8/29/72	-1.0000+0	1.0282+0	2.0000+0
N,2N	N TOTAL ENERGY DEP.	5	12/03/76	-1.0000+0	1.0282+0	2.0000+0
N,2N	N LOCAL ENERGY DEP.	5	12/03/76	-1.0000+0	1.0282+0	2.0000+0
N,N'P	CROSS SECTION	22	8/19/70	-8.3400+0	8.5500+0	2.0000+0
N,N'P	N ENERGY-ANGLE DIST.	6	8/29/72	-8.3400+0	8.5500+0	2.0000+0
N,N'P	N TOTAL ENERGY DEP.	8	5/29/78	-8.3400+0	8.5500+0	2.0000+0
N,N'P	N LOCAL ENERGY DEP.	6	5/29/78	-8.3400+0	8.5500+0	2.0000+0
N,N'A	CROSS SECTION	22	8/19/70	-7.0400+0	7.2200+0	2.0000+0
N,N'A	N ENERGY-ANGLE DIST.	6	8/29/72	-7.0400+0	7.2200+0	2.0000+0
N,N'A	N TOTAL ENERGY DEP.	10	5/29/78	-7.0400+0	7.2200+0	2.0000+0
N,N'A	N LOCAL ENERGY DEP.	8	5/29/78	-7.0400+0	7.2200+0	2.0000+0
N,P	CROSS SECTION	130	8/29/72	-5.5000+0	5.7000+0	2.0000+0
N,P	N TOTAL ENERGY DEP.	2	5/29/78	-5.5000+0	5.7000+0	2.0000+0
N,P	N LOCAL ENERGY DEP.	2	5/29/78	-5.5000+0	5.7000+0	2.0000+0
N,A	CROSS SECTION	69	7/14/73	1.8000+0	6.0000+0	2.0000+0
N,A	N TOTAL ENERGY DEP.	2	5/29/78	1.8000+0	6.0000+0	2.0000+0
N,A	N LOCAL ENERGY DEP.	2	5/29/78	1.8000+0	6.0000+0	2.0000+0
N,G	CROSS SECTION	403	4/03/76	8.3600+0	1.0000-10	2.0000+0
N,G	G ENERGY DIST.	2	11/01/72	8.3600+0	1.0000-10	2.0000+0
N,G	G MULTIPLICITY	2	11/01/72	8.3600+0	1.0000-10	2.0000+0
N,G	N TOTAL ENERGY DEP.	2	11/21/76	8.3600+0	1.0000-10	2.0000+0
N,G	N LOCAL ENERGY DEP.	2	11/21/76	8.3600+0	1.0000-10	2.0000+0
N,XG	CROSS SECTION	7	1/22/73	0.0000+0	1.4580+0	2.0000+0
N,XG	G ENERGY-ANGLE DIST.	5	1/22/73	0.0000+0	1.4580+0	2.0000+0
N,XG	CROSS SECTION	7	1/22/73	0.0000+0	3.4360+0	2.0000+0
N,XG	C ANGULAR DIST.	2	5/31/73	0.0000+0	3.4360+0	2.0000+0
N,XG	CROSS SECTION	9	1/22/73	0.0000+0	1.3650+0	2.0000+0
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+0	1.3650+0	2.0000+0
N,XG	CROSS SECTION	9	1/22/73	0.0000+0	1.1840+0	2.0000+0
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+0	1.1840+0	2.0000+0
N,XG	CROSS SECTION	5	1/22/73	0.0000+0	3.8270+0	9.0000+0
N,XG	G ANGULAR DIST.	5	1/22/73	0.0000+0	3.8270+0	9.0000+0
N,XG	CROSS SECTION	5	1/22/73	0.0000+0	4.0010+0	9.0000+0
N,XG	G ANGULAR DIST.	5	1/22/73	0.0000+0	4.0010+0	9.0000+0

PHOTON = 5.1100-1 MEV
 PHOTON = 5.1100-1 MEV
 PHOTON = 7.7000-1 MEV
 PHOTON = 7.7000-1 MEV
 PHOTON = 1.1580+0 MEV
 PHOTON = 1.1580+0 MEV
 PHOTON = 3.7340+0 MEV
 PHOTON = 3.7340+0 MEV
 PHOTON = 3.9030+0 MEV
 PHOTON = 3.9030+0 MEV

pages 2-170 to 2-172 of UCRL-50400, Vol. 8, Rev. 1, Part A. In view of the scarcity of experimental data, inelastic scattering was represented in the evaluation by a continuum contribution that starts at 1.19 MeV, which is an effective threshold for the average of the n,n' contributions from the various calcium isotopes. The evaluated n,n' cross sections are shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for the continuum inelastic scattering were assumed to be isotropic. The energy distributions for incident neutron energies below 5 MeV were chosen so as to reproduce the average and maximum secondary neutron energies for the reaction. The energy distributions at 5 MeV and above were obtained from temperature model calculations. The energy distributions at 11 MeV and above also contain contributions from preequilibrium processes, which are estimated by following the techniques described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n,2n$ CROSS SECTION

The effective threshold for the $n,2n$ reaction in the evaluation was set at 10.28 MeV, which is a weighted average over the various contributing

isotopes. The only $n,2n$ data for calcium are some values for Ca^{48} that are given on page 2-178 of UCRL-50400, Vol. 8, Rev. 1, Part A. Thus, the evaluated $n,2n$ cross sections were determined almost entirely from nuclear systematics. These cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons produced by the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n' CROSS SECTION

The threshold for the evaluated n,n' reaction was set equal to 8.55 MeV, the threshold for the reaction in Ca^{40} . The only experimental data for this reaction, which are for Ca^{40} , are listed on page 2-174 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,n' cross sections, which were based on these data and data derived from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'p$ REACTION

The angular distribution of secondary neutrons produced by the $n,n'p$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

$n,n'\alpha$ CROSS SECTION

The threshold for the $n,n'\alpha$ reaction in Ca^{40} is 7.22 MeV. A single data point for this reaction is listed on page 2-175 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated $n,n'\alpha$ cross sections, which were obtained mainly from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'\alpha$ REACTION

The angular distribution of secondary neutrons produced by the $n,n'\alpha$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction in Ca^{40} is 0.54 MeV; the thresholds for this reaction in the other isotopes are in the range of a few MeV. Thus, an effective threshold of 0.97 MeV for natural calcium was used in the evaluation. Experimental n,p cross sections for the various isotopes of calcium are given on pages 2-175 to 2-177 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,p cross sections for natural calcium, which were based on the above data and data derived from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n,α CROSS SECTION

Although the threshold for the n,α reaction in Ca^{40} is exoergic, the evaluated n,α cross sections were assigned an effective threshold of 0.6 MeV. Experimental values of the n,α cross section are shown on pages 2-173 to 2-175 and on page 2-177 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,α cross sections, which are based directly on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

n,γ CROSS SECTION

Some neutron capture data for natural calcium are given on page 2-134 of UCRL-50400, Vol. 7, Part A,

Rev. 1; single data points for Ca^{40} , Ca^{44} , and Ca^{48} are given on pages 2-137 and 2-140. The evaluated neutron capture cross sections for natural calcium, which are based mainly on nuclear systematics, are shown in UCRL-50400, Vol. 15 Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the capture process at all neutron energies was set equal to the thermal neutron spectrum measured by V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum will be in error at neutron energies above the keV region, but there are no experimental data with which to improve this approximation. To conserve energy, the multiplicity of the gamma rays was chosen to be $M(E) = M_{\text{thermal}} \times (E+Q)/Q$, where E is the incident neutron energy and Q is the energy release in the neutron capture reaction.

$n, X\gamma$ CROSS SECTION

Experimental $n, X\gamma$ data for natural calcium are given on pages 2-172 and 2-173 of UCRL-50400, Vol. 8, Rev. 1, Part A. In the evaluation for calcium, the $n, X\gamma$ cross section was assumed to include all photons except those produced in the neutron capture reaction. The evaluated $n, X\gamma$ cross sections include five discrete lines plus a continuum that starts at

1.458 MeV. The discrete lines were evaluated as follows.

3.734 MeV

This gamma ray arises from the transition of the 3.734-MeV level to the ground state in Ca^{40} . The data of W. E. Tucker, ORO-2791-30 (1969) and ORO-2791-32 (1971), give the cross section for neutron energies up to 5 MeV. At 9 and 11 MeV, this gamma-ray line was included as a part of the complete gamma-ray spectrum. But at 20 MeV it was assumed that it would be included in the continuum component of the reaction.

3.903 MeV

This gamma ray arises from a corresponding level in Ca^{40} . The same procedure was followed in the evaluation of this line as used above for the 3.734-MeV line.

0.770 MeV

This gamma-ray line arises from a transition between the 800-keV level and the 30-keV level in K^{40} . The K^{40} nucleus was formed by the n, p reaction in Ca^{40} . The data of Tucker, cited above, were used to evaluate the cross section for this line at low neutron energies. Since this line lies below the threshold for the continuum component of the reaction, it could not be included in the continuum component at 20 MeV, as discussed above, but

instead was represented as a discrete line at all energies.

1.158 MeV

This gamma ray arises from the transition of the first excited state to the ground state in Ca^{44} . The evaluation procedure for the 0.770 MeV line was repeated here.

0.511 MeV

This gamma-ray line is produced by positron annihilation which occurs after a β^+ is emitted in the decay of the 3.352-MeV level in Ca^{40} . Other decay levels may also contribute to the production of this gamma-ray line. The evaluation procedure for the 0.770 MeV line was repeated here.

The continuum gamma rays were assumed to start at 1.458 MeV, which is the threshold for producing the first unaccounted-for gamma ray from the $^{40}\text{O}(n,p)^{40}\text{K}$ reaction. At 9 and 11 MeV, the measured gamma-ray spectra of D. O. Nellis and P. S. Buchanan were used [Texas Nuclear report DASA01-68-C-0128 (1971)]. The measurements were inserted into the evaluation as points; the shape

of the gamma-ray spectrum below the low-energy experimental cut-off was guessed. From 14 to 20 MeV the $n, X\gamma$ cross sections for the continuum component were calculated from the NXGAMEL code, using the systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The photons produced by the excitation of the discrete gamma-ray lines at 3.734 and 3.903 MeV were assigned angular distributions based on the data of W. E. Tucker cited above. The angular distributions for all other photons were assumed to be isotropic. The energy distributions of the photons from the discrete levels were based on the kinematics of the reaction. The energy distributions of the photons from the continuum component of the reaction were calculated from the nuclear systematics of Perkins, Haight, and Howerton.

Titanium

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural titanium and its various isotopes are summarized in UCRL-50400, Vol. 3; they are listed in UCRL-50400, Vol. 10. C. Philis, R. Howerton, and A. B. Smith did the evaluation. It is described in detail in the Argonne National Laboratory report ANL/NDM-28, June 1977. The evaluated data, which are for natural titanium, are shown in ANL/NDM-28. The present description of the titanium evaluation is taken from that report, but it is put into the same general format that we have used in describing the evaluations for the other isotopes and elements in the ENDL library. The total, elastic, and capture cross sections for neutron energies below 200 keV were obtained from a set of resonance parameters developed by J. Trochon *et al.*, CEA report CEA-R-4883 (1977).

TOTAL CROSS SECTION

Experimental total cross sections for the various isotopes of titanium and for natural titanium are given on pages 3-6 to 3-16 and 3-18 to 3-24 of UCRL-50400, Vol. 7, Part A, Rev. 1. The evaluated total cross sections for natural titanium are shown on pages 20, 21, and 27 of ANL/NDM-28. As mentioned above, the total cross sections below 200 keV were taken

from the work of Trochon *et al.* The total cross sections from 200 keV to 20 MeV were based on comparisons made between a number of different sets of experimental data, as discussed in ANL/NDM-28.

ELASTIC SCATTERING CROSS SECTION

Experimental values of the elastic scattering cross section for natural titanium are given on pages 3-17 and 3-19 of UCRL-50400, Vol. 7, Part A, Rev. 1. The evaluated elastic cross sections are shown on page 31 of ANL/NDM-28. The elastic scattering cross sections below 200 keV were taken from the Trochon resonance parameters. The elastic scattering cross sections above 200 keV were obtained, in part, by taking differences between total cross sections and the sums of non-elastic cross sections, and in part by comparing several sets of experimental data. The evaluation procedures used here are described in detail in ANL/NDM-28.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies

Titanium

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	REACTION	POINTS	DATE	G-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	517	7/25/77	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	ANGULAR DIST.	12	11/03/76	0.0000+ 0	2.5000+ 1	2.0000+ 1	
N,ELASTIC	TOTAL ENERGY DEP.	30	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	LOCAL ENERGY DEP.	30	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	18	7/25/77	0.0000+ 0	2.5000+ 1	2.0000+ 1	
N,N'	ENERGY-ANGLE DIST.	11	7/25/77	0.0000+ 0	2.5000+ 1	2.0000+ 1	
N,N'	TOTAL ENERGY DEP.	15	12/03/76	0.0000+ 0	2.5000+ 1	2.0000+ 1	
N,N'	LOCAL ENERGY DEP.	12	12/03/76	0.0000+ 0	2.5000+ 1	2.0000+ 1	
N,N'	CROSS SECTION	39	8/29/72	0.0000+ 0	1.0000+ 0	2.0000+ 1	LEVEL = 4.8700+ 1 MEV
N,N'	ANGULAR DIST.	2	8/29/72	0.0000+ 0	1.0000+ 0	2.0000+ 1	LEVEL = 9.8700+ 1 MEV
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0000+ 0	2.0000+ 1	LEVEL = 8.8700+ 1 MEV
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0000+ 0	2.0000+ 1	LEVEL = 4.8700+ 1 MEV
N,2N	CROSS SECTION	6	8/29/72	-1.1630+ 1	1.2000+ 1	2.0000+ 1	
N,2N	ENERGY-ANGLE DIST.	6	10/18/72	-1.1630+ 1	1.2000+ 1	2.0000+ 1	
N,2N	TOTAL ENERGY DEP.	5	12/03/76	-1.1630+ 1	1.2000+ 1	2.0000+ 1	
N,2N	LOCAL ENERGY DEP.	5	12/03/76	-1.1630+ 1	1.2000+ 1	2.0000+ 1	
N,P	CROSS SECTION	8	8/29/72	-3.2100+ 0	6.0000+ 0	2.0000+ 1	
N,P	TOTAL ENERGY DEP.	2	5/29/78	-3.2100+ 0	6.0000+ 0	2.0000+ 1	
N,P	LOCAL ENERGY DEP.	2	5/29/78	-3.2100+ 0	6.0000+ 0	2.0000+ 1	
N,A	CROSS SECTION	5	8/29/72	-2.0300+ 0	6.0000+ 0	2.0000+ 1	
N,A	TOTAL ENERGY DEP.	2	5/29/78	-2.0300+ 0	6.0000+ 0	2.0000+ 1	
N,A	LOCAL ENERGY DEP.	2	5/29/78	-2.0300+ 0	6.0000+ 0	2.0000+ 1	
N,G	CROSS SECTION	365	8/29/72	8.2400+ 0	1.0000-10	2.0000+ 1	
N,G	ENERGY DIST.	2	12/01/75	8.2400+ 0	1.0000-10	2.0000+ 1	
N,G	MULTIPLICITY	2	12/01/75	8.2400+ 0	1.0000-10	2.0000+ 1	
N,G	TOTAL ENERGY DEP.	2	11/21/76	8.2400+ 0	1.0000+ 0	2.0000+ 1	
N,G	LOCAL ENERGY DEP.	2	11/21/76	8.2400+ 0	1.0000+ 0	2.0000+ 1	
N,XG	CROSS SECTION	8	1/23/73	0.0000+ 0	3.6000+ 0	2.0000+ 1	
N,XG	ENERGY-ANGLE DIST.	8	1/23/73	0.0000+ 0	3.6000+ 0	2.0000+ 1	
N,XG	CROSS SECTION	9	1/23/73	0.0000+ 0	1.0000+ 0	5.5000+ 0	PHOTON = 9.9000+ 1 MEV
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.0000+ 0	1.0000+ 0	PHOTON = 9.9000+ 1 MEV
N,XG	CROSS SECTION	8	1/23/73	0.0000+ 0	1.4000+ 0	5.0000+ 0	PHOTON = 1.3800+ 0 MEV
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.4000+ 0	2.0000+ 0	PHOTON = 1.3800+ 0 MEV
N,XG	CROSS SECTION	5	1/23/73	0.0000+ 0	1.6000+ 0	5.0000+ 0	PHOTON = 1.5600+ 0 MEV
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.6000+ 0	1.0000+ 0	PHOTON = 1.5600+ 0 MEV

below 0.25 MeV. In the energy region from 0.25 MeV to 14 MeV, the elastic angular distributions were obtained from the experimental data, as discussed in ANL/NDM-28, using a Legendre-function fitting procedure to interpolate and extrapolate from the experimental points. At energies above 14 MeV, spherical optical model calculations were used.

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering cross section data for natural titanium are shown on pages 3-11 to 3-13 and 3-15 of UCRL-50400, Vol. 8, Rev. 1, Part A; data for Ti^{46} and Ti^{48} are shown on pages 3-17 and 3-25, respectively. The evaluated n, n' cross sections include twelve discrete levels plus a continuum contribution that starts at 3.25 MeV. A complete description of the evaluation procedures for these states is given in ANL/NDM-28. The evaluated cross sections for the discrete levels are shown on page 41 of ANL/NDM-28.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

As is discussed in ANL/NDM-28, the angular distributions for most of the discrete levels were assumed to be isotropic. The energy distributions for these discrete levels were based on the kinematics of the reaction. The angular distributions for the

continuum neutrons were also assumed to be isotropic, although experimental evidence indicates considerable forward-peaking of the high-energy preequilibrium neutrons at the higher energies. The reasons for making this assumption are discussed in ANL/NDM-28. The energy distributions for the continuum neutrons were determined by starting with a temperature-model distribution that was fitted to the experimental data, and then superimposing some observed structural components plus a contribution from preequilibrium components, as discussed in ANL/NDM-28.

$n, 2n$ CROSS SECTION

The titanium isotopes Ti^{46} , Ti^{47} , Ti^{48} , Ti^{49} , and Ti^{50} all contribute to the $n, 2n$ reaction. The thresholds for the $n, 2n$ reaction in these isotopes are 13.48, 9.06, 11.87, 8.31, and 11.17 MeV, respectively. Experimental $n, 2n$ data for natural titanium are given on page 3-15 of UCRL-50400, Vol. 8, Rev. 1, Part A; $n, 2n$ data for Ti^{46} are given on pages 3-17, 3-18, and 3-21. In the evaluation for elemental titanium, the contributions of all five isotopes were included. The Ti^{46} contribution was obtained from the experimental data, and the $Ti^{47} - Ti^{50}$ contributions were obtained from systematics and from the over-all constraints imposed by the measurements on natural titanium. The evaluation

procedures are described in ANL/NDM-28, and the evaluated n,2n cross sections are shown on pages 53, 54, and 55 of that reference.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons produced by the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. These energy distributions were first calculated from theoretical models, as described in ANL/NDM-28, and were then "hardened" so as to conform to the spectrum obtained from 14-MeV pulsed sphere measurements at Lawrence Livermore Laboratory.

n,3n CROSS SECTION

Ti⁵⁰, with an n,3n threshold of 19.48 MeV, is the only titanium isotope below 20 MeV that can contribute to this reaction. Since there are no experimental data, the n,3n cross sections for Ti⁵⁰ were based on theoretical calculations, as described in ANL/NDM-28.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons produced by the n,3n reaction was assumed to be isotropic in the laboratory system.

The neutron emission spectrum was represented by a relatively "hard" temperature distribution.

n,n'p CROSS SECTION

The threshold for the n,n'p reaction in Ti⁴⁶ is 10.58 MeV; it is slightly higher for the other titanium isotopes. The evaluation for this reaction, which is discussed in ANL/NDM-28, is based in part on experimental data and in part on theoretical calculations.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n'p REACTION

The angular distribution of secondary neutrons from the n,n'p reaction was assumed to be isotropic in the laboratory system. The energy distributions were represented by rather "hard" temperature distributions, as mentioned in ANL/NDM-28.

n,n'α CROSS SECTION

The threshold for the n,n'α reaction in Ti⁴⁶ is 8.19 MeV; it is slightly higher for the other titanium isotopes. The evaluation of the n,n'α cross sections was obtained almost entirely from theoretical calculations, as mentioned in ANL/NDM-28, with a normalization to one experimental measurement at 15 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'\alpha$ REACTION

The angular distribution of secondary neutrons produced by the $n,n'\alpha$ reaction was assumed to be isotropic in the laboratory system. The energy distributions of the secondary neutrons, which are presented in tabular form, are derived from a "hard" temperature distribution, as described in ANL/NDM-28.

n,p CROSS SECTION

Extensive experimental data for the n,p reaction in the five isotopes of titanium are given on pages 3-16, 3-19 to 3-24, and 3-26 to 3-33 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,p cross sections, which include contributions from Ti^{46} through Ti^{50} , are described in detail in ANL/NDM-28. The evaluated n,p cross sections are shown on pages 62 to 67 of that reference.

n,d CROSS SECTION

The threshold for the n,d reaction in Ti^{46} is 8.30 MeV; it is somewhat higher in the other isotopes. Since there are almost no experimental data for this reaction, the evaluation was based mainly on systematics, as described in ANL/NDM-28. The evaluated n,d cross sections are shown on page 76 of ANL/NDM-28.

n,t CROSS SECTION

The threshold for the n,t reaction in Ti^{47} is 10.97 MeV; it is somewhat higher for the other isotopes. The experimental data are limited to a single value for natural titanium, which is listed on page 3-16 of UCRL-50400, Vol. 8, Rev. 1, Part A. Hence, the evaluation was based on systematics, as described in ANL/NDM-28. The evaluated n,t cross sections are shown on page 76 of ANL/NDM-28.

n,He^3 CROSS SECTION

The threshold for the n,He^3 reaction in Ti^{46} is 9.73 MeV; it is somewhat higher for the other isotopes. Since there are no experimental data for this reaction, the same evaluation procedures were used as described above for the n,d and n,t reactions. The evaluated n,He^3 cross sections are shown on page 76 of ANL/NDM-28.

n,α CROSS SECTION

The threshold for the n,α reaction is at or near zero neutron energy for all titanium isotopes. The few experimental data that are available for this reaction are listed on pages 3-25, 3-30, and 3-33 of UCRL-50400, Vol. 8, Rev. 1, Part A. Hence the evaluation was based mainly on theoretical calculations (see ANL/NDM-28). The evaluated n,α cross sections are shown on page 70 of ANL/NDM-28.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural titanium are given on pages 3-18 and 3-19 of UCRL-50400, Vol. 7, Part A, Rev. 1; some values for Ti^{50} are given on page 3-24. The evaluated neutron capture cross sections for neutron energies below 200 keV were taken from the Trochon resonance parameters, as described above. Above 200 keV, the evaluated capture cross sections were obtained from theoretical calculations combined with the available experimental data, as discussed in ANL/NDM-28. The evaluated, n, γ cross sections are shown on pages 46 to 48 of ANL/NDM-28.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies up to 20 MeV with the photon multiplicity adjusted so as to conserve energy.

n,X γ CROSS SECTION

Experimental, n,X γ cross sections for natural titanium are shown on pages 3-13 and 3-14 of UCRL-50400, Vol. 8, Rev. 1, Part A. Since these are the only available experimental

data, the evaluated n,X γ cross sections were based in large part on theoretical calculations, as described in ANL/NDM-28. For neutron energies up to 5 MeV, the n,X γ cross section was represented by three discrete photon lines (which correspond to the excitations of the lowest lying states in Ti^{46} , Ti^{47} , and Ti^{47}) plus a continuum component with a threshold at 3 MeV. For neutron energies above 5 MeV, the n,X γ cross section was represented entirely by a continuum component, which was calculated with the NXGAMEL code, using the systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

The angular distributions for photon production were assumed to be isotropic. The energy distributions of the photons produced by the excitation of the discrete lines were based on the kinematics of the reaction. The energy distributions of the photons from the continuum component of the reaction were calculated from the nuclear systematics of Perkins, Haight, and Howerton.

Vanadium-51

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural vanadium and for $^{23}\text{V}^{50}$ and $^{23}\text{V}^{51}$ are summarized in UCRL-50400, Vol. 3; they are listed in UCRL-50400, Vol. 10. V^{51} was chosen for the evaluation because it is the dominant isotope in natural vanadium. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B.

P. Guenther, D. Havel, R. Howerton, F. Mann, D. Smith, A. Smith, and J. Whalen did the evaluation. This evaluation is described in the Argonne National Laboratory report ANL/NDM-24, May 1977. The present description of the vanadium evaluation is taken in part from that report, but it has been put into the same general form that we have used in describing the evaluations for the other isotopes and elements in the ENDL library.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for natural vanadium are shown on pages 3-25 to 3-38 of UCRL-50200, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on page 3-41 (the evaluated data shown there are for an earlier evaluation). Experimental total cross sections for V^{50} are shown graphically on pages 3-42 and 3-43 of that

report. The evaluated total cross sections for V^{51} are shown graphically on page 104 of ANL/NDM-24.

The total cross sections used in the vanadium evaluation are discussed in detail in ANL/NDM-24; we summarize the results here. The total cross sections below 100 keV are taken from ENDF/B-IV MAT-1196. The values from 100 to 220 keV are from ECSIL-1552. The values from 220 to 360 keV are from ECSIL-1549 and from J. Whalen, private communication. The values from 360 keV to 20 MeV are from ECSIL-2517. The reasons for these choices are given in ANL/NDM-24.

ELASTIC SCATTERING CROSS SECTION

Values of the elastic scattering cross section for natural vanadium are given on pages 3-39 and 3-41 of UCRL-50400, Vol. 7, Part A, Rev. 1; values for V^{51} are given on page 3-44. The evaluated elastic cross sections shown in UCRL-50400, Vol. 15, Part B represent an earlier evaluation. The evaluated elastic cross sections were based in large part on experimental data of A. B. Smith *et al.* (ANL/NDM-24). In the evaluation, the differences between total elastic and total nonelastic cross sections were used as a guide, with a combination of experimental data and model calculations used at the higher energies.

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	REACTION	POINTS	DATE	Q VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	2000	1/07/77	0.0000+ 0	1.0660-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	40	1/07/77	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	34	1/06/77	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	34	1/06/77	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	56	1/07/77	0.0000+ 0	3.0000+ 0	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	9	1/07/77	0.0000+ 0	3.0000+ 0	2.0000+ 1	
N,N'	N TOTAL ENERGY DEP.	8	1/06/77	0.0000+ 0	3.0000+ 0	2.0000+ 1	
N,N'	N LOCAL ENERGY DEP.	6	1/06/77	0.0000+ 0	3.0000+ 0	2.0000+ 1	
N,N'	CROSS SECTION	29	1/07/77	0.0000+ 0	3.2640- 1	2.0000+ 1	
N,N'	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	3.2640- 1	2.0000+ 1	LEVEL = 3.2010- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	1/06/77	0.0000+ 0	3.2640- 1	2.0000+ 1	LEVEL = 3.2010- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	1/06/77	0.0000+ 0	3.2640- 1	2.0000+ 1	LEVEL = 3.2010- 1 MEV
N,N'	CROSS SECTION	28	1/07/77	0.0000+ 0	9.4720- 1	2.0000+ 1	LEVEL = 9.2900- 1 MEV
N,N'	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	9.4720- 1	2.0000+ 1	LEVEL = 9.2900- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	1/06/77	0.0000+ 0	9.4720- 1	2.0000+ 1	LEVEL = 9.2900- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	1/06/77	0.0000+ 0	9.4720- 1	2.0000+ 1	LEVEL = 9.2900- 1 MEV
N,N'	CROSS SECTION	20	1/07/77	0.0000+ 0	1.6410+ 0	2.0000+ 1	LEVEL = 1.6090+ 0 MEV
N,N'	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	1.6410+ 0	2.0000+ 1	LEVEL = 1.6090+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	2	1/06/77	0.0000+ 0	1.6410+ 0	2.0000+ 1	LEVEL = 1.6090+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	2	1/06/77	0.0000+ 0	1.6410+ 0	2.0000+ 1	LEVEL = 1.6090+ 0 MEV
N,N'	CROSS SECTION	17	1/07/77	0.0000+ 0	1.8490+ 0	2.0000+ 1	LEVEL = 1.8130+ 0 MEV
N,N'	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	1.8490+ 0	2.0000+ 1	LEVEL = 1.8130+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	2	1/06/77	0.0000+ 0	1.8490+ 0	2.0000+ 1	LEVEL = 1.8130+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	2	1/06/77	0.0000+ 0	1.8490+ 0	2.0000+ 1	LEVEL = 1.8130+ 0 MEV
N,N'	CROSS SECTION	11	1/07/77	0.0000+ 0	2.4560+ 0	2.0000+ 1	LEVEL = 2.4090+ 0 MEV
N,N'	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	2.4560+ 0	2.0000+ 1	LEVEL = 2.4090+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	2	1/06/77	0.0000+ 0	2.4560+ 0	2.0000+ 1	LEVEL = 2.4090+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	2	1/06/77	0.0000+ 0	2.4560+ 0	2.0000+ 1	LEVEL = 2.4090+ 0 MEV
N,N'	CROSS SECTION	12	1/07/77	0.0000+ 0	2.7270+ 0	2.0000+ 1	LEVEL = 2.6750+ 0 MEV
N,N'	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	2.7270+ 0	2.0000+ 1	LEVEL = 2.6750+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	2	1/06/77	0.0000+ 0	2.7270+ 0	2.0000+ 1	LEVEL = 2.6750+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	2	1/06/77	0.0000+ 0	2.7270+ 0	2.0000+ 1	LEVEL = 2.6750+ 0 MEV
N,N'	CROSS SECTION	11	1/07/77	0.0000+ 0	3.1400+ 0	2.0000+ 1	LEVEL = 3.0800+ 0 MEV
N,N'	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	3.1400+ 0	2.0000+ 1	LEVEL = 3.0800+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	2	1/06/77	0.0000+ 0	3.1400+ 0	2.0000+ 1	LEVEL = 3.0800+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	2	1/06/77	0.0000+ 0	3.1400+ 0	2.0000+ 1	LEVEL = 3.0800+ 0 MEV
N,2N	CROSS SECTION	13	1/07/77	-1.1052+ 1	1.1270+ 1	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	3	1/07/77	-1.1052+ 1	1.1270+ 1	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	5	1/06/77	-1.1052+ 1	1.1271+ 1	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	5	1/06/77	-1.1052+ 1	1.1271+ 1	2.0000+ 1	
N,N'P	CROSS SECTION	18	1/07/77	-8.0520+ 0	8.2090+ 0	2.0000+ 1	
N,N'P	N ENERGY-ANGLE DIST.	5	1/07/77	-8.0520+ 0	8.2090+ 0	2.0000+ 1	
N,N'P	N TOTAL ENERGY DEP.	10	1/06/77	-8.0520+ 0	8.2114+ 0	2.0000+ 1	
N,N'P	N LOCAL ENERGY DEP.	10	1/06/77	-8.0520+ 0	8.2114+ 0	2.0000+ 1	
N,N'A	CROSS SECTION	7	1/07/77	-1.0293+ 1	1.0490+ 1	2.0000+ 1	
N,N'A	N ENERGY-ANGLE DIST.	3	1/07/77	-1.0293+ 1	1.0490+ 1	2.0000+ 1	
N,N'A	N TOTAL ENERGY DEP.	5	1/06/77	-1.0293+ 1	1.0497+ 1	2.0000+ 1	
N,N'A	N LOCAL ENERGY DEP.	5	1/06/77	-1.0293+ 1	1.0497+ 1	2.0000+ 1	
N,P	CROSS SECTION	41	1/07/77	-1.6700+ 0	1.7015+ 0	2.0000+ 1	
N,P	N TOTAL ENERGY DEP.	2	1/06/77	-1.6700+ 0	1.7015+ 0	2.0000+ 1	
N,P	N LOCAL ENERGY DEP.	2	1/06/77	-1.6700+ 0	1.7015+ 0	2.0000+ 1	

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06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,D	CROSS SECTION	22	1/07/77	-5.8270+ 0	5.9410+ 0	2.0000+ 1	
N,D	TOTAL ENERGY DEP.	2	1/06/77	-5.8270+ 0	5.9410+ 0	2.0000+ 1	
N,D	LOCAL ENERGY DEP.	2	1/06/77	-5.8270+ 0	5.9410+ 0	2.0000+ 1	
N,T	CROSS SECTION	11	1/07/77	-1.0518+ 1	1.0720+ 1	2.0000+ 1	
N,T	TOTAL ENERGY DEP.	2	1/06/77	-1.0518+ 1	1.0720+ 1	2.0000+ 1	
N,T	LOCAL ENERGY DEP.	2	1/06/77	-1.0518+ 1	1.0720+ 1	2.0000+ 1	
N,A	CROSS SECTION	34	1/07/77	-2.0500+ 0	2.1004+ 0	2.0000+ 1	
N,A	TOTAL ENERGY DEP.	2	1/06/77	-2.0500+ 0	2.1004+ 0	2.0000+ 1	
N,A	LOCAL ENERGY DEP.	2	1/06/77	-2.0500+ 0	2.1004+ 0	2.0000+ 1	
N,G	CROSS SECTION	270	1/07/77	7.3040+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	2/23/78	7.3040+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	2/23/78	7.3040+ 0	1.0000-10	2.0000+ 1	
N,G	TOTAL ENERGY DEP.	2	1/06/77	7.3040+ 0	1.0000-10	2.0000+ 1	
N,G	LOCAL ENERGY DEP.	2	1/06/77	7.3040+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	12	2/23/78	0.0000+ 0	3.0000+ 0	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	12	2/23/78	0.0000+ 0	3.0000+ 0	2.0000+ 1	
N,XG	CROSS SECTION	29	1/07/77	0.0000+ 0	3.2640- 1	2.0000+ 1	PHOTON = 3.2010- 1 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	3.2640- 1	2.0000+ 1	PHOTON = 3.2010- 1 MEV
N,XG	CROSS SECTION	24	1/07/77	0.0000+ 0	9.4720- 1	2.0000+ 1	PHOTON = 6.0900- 1 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	9.4720- 1	2.0000+ 1	PHOTON = 6.0900- 1 MEV
N,XG	CROSS SECTION	27	1/07/77	0.0000+ 0	9.4720- 1	2.0000+ 1	PHOTON = 9.2900- 1 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	9.4720- 1	2.0000+ 1	PHOTON = 9.2900- 1 MEV
N,XG	CROSS SECTION	17	1/07/77	0.0000+ 0	1.6490+ 0	2.0000+ 1	PHOTON = 1.4930+ 0 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	1.6490+ 0	2.0000+ 1	PHOTON = 1.4930+ 0 MEV
N,XG	CROSS SECTION	20	1/07/77	0.0000+ 0	1.6410+ 0	2.0000+ 1	PHOTON = 1.6090+ 0 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	1.6410+ 0	2.0000+ 1	PHOTON = 1.6090+ 0 MEV
N,XG	CROSS SECTION	17	1/07/77	0.0000+ 0	1.6490+ 0	2.0000+ 1	PHOTON = 1.6130+ 0 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	1.6490+ 0	2.0000+ 1	PHOTON = 1.6130+ 0 MEV
N,XG	CROSS SECTION	11	1/07/77	0.0000+ 0	2.4560+ 0	2.0000+ 1	PHOTON = 2.0990+ 0 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	2.4560+ 0	2.0000+ 1	PHOTON = 2.0990+ 0 MEV
N,XG	CROSS SECTION	12	1/07/77	0.0000+ 0	2.7270+ 0	2.0000+ 1	PHOTON = 2.6750+ 0 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	2.7270+ 0	2.0000+ 1	PHOTON = 2.6750+ 0 MEV
N,XG	CROSS SECTION	11	1/07/77	0.0000+ 0	3.1400+ 0	2.0000+ 1	PHOTON = 3.0800+ 0 MEV
N,XG	N ANGULAR DIST.	2	1/07/77	0.0000+ 0	3.1400+ 0	2.0000+ 1	PHOTON = 3.0800+ 0 MEV

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies below 1 keV. In the energy region up to a few MeV, the evaluated angular distributions were based on the experimental data. A Legendre function-fitting procedure was used to provide an interpolation between the experimental data points. At the higher energies, spherical optical model calculations were used.

INELASTIC SCATTERING CROSS SECTION

Extensive inelastic scattering cross section data for natural vanadium are given on pages 3-35 to 3-53 of UCRL-50400, Vol. 8, Rev. 1, Part A; data for V^{51} are given on pages 3-55 to 3-58 and 3-61. The evaluated inelastic scattering cross sections include contributions from seven discrete levels plus a continuum contribution that starts at 3 MeV. A complete description of the evaluation procedures for these states is given in ANL/NDM-24. The evaluated n, n' cross sections are shown on pages 102 and 106 of NAL/NDM-24.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for all inelastically scattered neutrons were assumed to be isotropic. The energy distributions for the discrete levels were based on the kinematics of the reaction. The energy distributions for the continuum neutrons were obtained from temperature model calculations fitted to experimental data; pre-equilibrium components were added at the higher energies. The procedures used here are described in detail in ANL/NDM-24.

$n, 2n$ CROSS SECTION

The threshold for the $n, 2n$ reaction is 11.27 MeV. The only directly measured $n, 2n$ cross section for vanadium is a 14-MeV point that is listed on page 3-61 of UCRL-50400, Vol. 8, Rev. 1, Part A. However, as described in ANL-NDM-24, there is a ratio between some cross section vanadium measurements and the fission cross section in U^{238} , so further vanadium cross sections can be indirectly determined for the evaluation. The evaluation procedures for the $n, 2n$ cross section are described in considerable detail in ANL/NDM-24. The evaluated $n, 2n$ cross sections are shown on page 108 of that report.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distributions of secondary neutrons from the $n,2n$ reaction were assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24), and with the results of 14-MeV neutron emission measurements (ANL/NDM-24).

$n,n'p$ CROSS SECTION

The threshold for the $n,n'p$ reaction is 8.21 MeV. Since there are no experimental data for this reaction, the evaluation was obtained from nuclear systematics (ANL/NDM-24). The evaluated $n,n'p$ cross sections are shown on page 111 of ANL/NDM-24.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'\alpha$ REACTION

The angular distribution of secondary neutrons from the $n,n'p$ reaction was assumed to be isotropic in the laboratory system. The energy distributions were obtained from temperature model calculations (ANL/NDM-24).

$n,n'\alpha$ CROSS SECTION

The threshold for the $n,n'\alpha$ reaction is 10.49 MeV. Experimental and

evaluated values for this cross section are shown graphically on page 3-58 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated experimental values are given on page 3-62. The evaluation procedures for this reaction are discussed in ANL/NDM-24, and a graph of the experimental and evaluated values is given on page 112 of that report.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,n'\alpha$ REACTION

The angular distribution of secondary neutrons from the $n,n'\alpha$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The threshold for the n,p reaction in V^{51} is 1.70 MeV. Experimental n,p cross section data are shown on pages 3-59 and 3-62 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated cross sections are shown on page 109 of ANL/NDM-24. As discussed in detail in ANL/NDM-24, the evaluated cross sections above 13 MeV are based on the experimental data, but the cross sections below approximately 13 MeV are based on theoretical considerations.

n,d CROSS SECTION

The threshold for the n,d reaction in V^{51} is 5.94 MeV. Since the n,d reaction leads to a stable isotope, Ti^{50} , this cross section cannot be determined by activation techniques. The information that can be brought to bear on the evaluation of the n,d cross section is discussed in ANL/NDM-24.

n,t CROSS SECTION

The threshold for the n,t reaction in V^{51} is 10.72 MeV. Since there are no experimental data, this evaluation was based on nuclear systematics, as discussed in ANL/NDM-24.

n, α CROSS SECTION

The threshold for the n, α reaction in V^{51} is 2.09 MeV. Experimental values of the n, α cross section are shown on pages 3-60, 3-61, and 3-63 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n, α cross sections are shown on page 110 of ANL/NDM-24. Although the n, α cross section can be measured by activation techniques, the available experimental data are neither complete nor completely consistent. The manner in which these data were used in the evaluation is discussed in ANL/NDM-24.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural vanadium are

shown on pages 3-40 and 3-41 of UCRL-50400, Vol. 7, Part A, Rev. 1; corresponding values for V^{51} are shown on pages 3-45 to 3-47. The evaluated capture cross sections are shown on page 107 of ANL/NDM-24. These evaluated cross sections are based on the experimental data, although considerable analysis of the data was required, as discussed in ANL/NDM-24.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies up to 20 MeV. The photon multiplicity was adjusted so as to conserve energy.

n,X γ CROSS SECTION

There are no experimental n,X γ cross section measurements for vanadium. In the evaluation, the n,X γ cross section was represented by nine discrete lines plus a continuum that starts at 3 MeV. As mentioned above, there are extensive experimental data for the n,n' inelastic scattering to specific levels in V^{51} . To deduce corresponding photon production cross sections from these levels, some of the values for the decay branching ratios had to be estimated. The method of estimation is described in

ANL/NDM-24. The $n, X\gamma$ cross sections for the continuum component were calculated from the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [see *Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The angular distributions for

photon production were assumed to be isotropic. The energy distributions of the photons produced by the excitation of the discrete lines are based on the kinematics of the reaction. The energy distributions of the photons from the continuum component of the reaction were calculated on the basis of the nuclear systematics of Perkins, Haight, and Howerton cited above.

Chromium

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural chromium and its various isotopes are summarized in UCRL-50400, Vol. 3. The evaluation was for natural chromium (UCRL-50400, Vol. 15, Part B). R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for natural chromium are shown graphically on pages 3-47 to 3-56 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on pages 3-60 and 3-61. Total cross sections for Cr⁵⁰ are given on pages 3-62 to 3-64 of that reference; total cross sections for Cr⁵² are given on pages 3-65 and 3-66; total cross sections for Cr⁵³ are given on pages 3-67 to 3-69; and total cross sections for Cr⁵⁴ are given on pages 3-69 and 3-70. The evaluated total cross sections for natural chromium are shown in UCRL-50400, Vol. 15, Part B. The evaluated total cross sections are based on the following specific ECSIL data sets: ECSIL-548 below 1 keV; ECSIL-308 from 3 to 400 keV; ECSIL-455 from 500 keV to 1.2 MeV; and ECSIL-2517 from 1.2 to 20 MeV. These ECSIL data references are given in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural chromium are shown graphically on pages 3-57 and 3-58 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on page 3-61. The evaluated elastic cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections. These evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies below 40 keV. Above 40 keV, the evaluated elastic angular distributions were based on the experimental data, supplemented at the higher energies by spherical optical model calculations in which the best-fit optical model parameters of Becchetti and Greenlees were used [see *Phys. Rev.* 182, 1190 (1969)].

Chromium

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	231	9/04/73	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	39	3/01/74	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	50	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	LOCAL ENERGY DEP.	50	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	17	9/04/73	0.0000+ 0	3.2000+ 0	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	8	9/04/73	0.0000+ 0	3.2000+ 0	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	7	12/03/76	0.0000+ 0	3.2000+ 0	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	7	12/03/76	0.0000+ 0	3.2000+ 0	2.0000+ 1
N,N'	CROSS SECTION	63	9/04/73	0.0000+ 0	5.7700- 1	3.2050+ 0
N,N'	ANGULAR DIST.	2	9/04/73	0.0000+ 0	5.7700- 1	3.2050+ 0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	5.7700- 1	3.2050+ 0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	5.7700- 1	3.2050+ 0
N,N'	CROSS SECTION	47	9/04/73	0.0000+ 0	8.0600- 1	3.2050+ 0
N,N'	ANGULAR DIST.	2	9/04/73	0.0000+ 0	8.0600- 1	3.2050+ 0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	8.0600- 1	3.2050+ 0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	8.0600- 1	3.2050+ 0
N,N'	CROSS SECTION	38	9/04/73	0.0000+ 0	1.0150+ 0	3.2050+ 0
N,N'	ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.0150+ 0	3.2050+ 0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0150+ 0	3.2050+ 0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0150+ 0	3.2050+ 0
N,N'	CROSS SECTION	20	9/04/73	0.0000+ 0	1.4500+ 0	3.2050+ 0
N,N'	ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.4500+ 0	3.2050+ 0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.4500+ 0	3.2050+ 0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.4500+ 0	3.2050+ 0
N,N'	CROSS SECTION	16	9/04/73	0.0000+ 0	2.0000+ 0	3.2050+ 0
N,N'	ANGULAR DIST.	2	9/04/73	0.0000+ 0	2.0000+ 0	3.2050+ 0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.0000+ 0	3.2050+ 0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.0000+ 0	3.2050+ 0
N,N'	CROSS SECTION	10	9/04/73	0.0000+ 0	2.4000+ 0	3.2050+ 0
N,N'	ANGULAR DIST.	2	9/04/73	0.0000+ 0	2.4000+ 0	3.2050+ 0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.4000+ 0	3.2050+ 0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.4000+ 0	3.2050+ 0
N,N'	CROSS SECTION	6	9/04/73	0.0000+ 0	2.7000+ 0	3.2050+ 0
N,N'	ANGULAR DIST.	2	9/04/73	0.0000+ 0	2.7000+ 0	3.2050+ 0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.7000+ 0	3.2050+ 0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.7000+ 0	3.2050+ 0
N,N'	CROSS SECTION	4	9/04/73	0.0000+ 0	3.0000+ 0	3.2050+ 0
N,N'	ANGULAR DIST.	2	9/04/73	0.0000+ 0	3.0000+ 0	3.2050+ 0
N,N'	TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	3.0000+ 0	3.2050+ 0
N,N'	LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	3.0000+ 0	3.2050+ 0
N,2N	CROSS SECTION	9	9/04/73	-7.9405- 0	8.5000+ 0	0.0000+ 1
N,2N	ENERGY-ANGLE DIST.	7	9/04/73	-7.9405- 0	8.5000+ 0	0.0000+ 1
N,2N	TOTAL ENERGY DEP.	10	12/03/76	-7.9405+ 0	8.5000+ 0	0.0000+ 1
N,2N	LOCAL ENERGY DEP.	5	12/03/76	-7.9405+ 0	8.5000+ 0	0.0000+ 1
N,P	CROSS SECTION	24	9/04/73	-2.5660- 1	4.0000+ 0	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	5/29/78	-2.5660- 1	4.0000+ 0	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	5/29/78	-2.5660- 1	4.0000+ 0	2.0000+ 1
N,G	CROSS SECTION	191	9/04/73	9.2500+ 0	1.0000-10	2.0000+ 1
N,G	ENERGY DIST.	2	2/23/78	9.2500+ 0	1.0000-10	2.0000+ 1
N,G	MULTIPLICITY	2	2/23/78	9.2500+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/78	9.2500+ 0	1.0000-10	2.0000+ 1

Chromium (Cont.)

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,G	LOCAL ENERGY DEP.	2	11/21/76	9.2500+ 0	1.0000-10	2.0000+ 1
N,X6	CROSS SECTION	14	2/23/78	0.0000+ 0	5.7700- 1	2.0000+ 1
N,X6	G ENERGY-ANGLE DIST.	14	2/23/78	0.0000+ 0	5.7700- 1	2.0000+ 1

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering cross section data for natural chromium are given on pages 3-64 to 3-68 of UCRL-50400, Vol. 8, Rev. 1, Part A; data for Cr^{50} are given on pages 3-70 and 3-71; data for Cr^{52} are given on pages 3-73 to 3-81 and on pages 3-83 and 3-84; and data for Cr^{54} are given on pages 3-91 and 3-92. The evaluated n, n' cross sections include contributions from eight discrete levels plus a continuum that starts at 3.2 MeV. The evaluated n, n' cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated n, n' cross sections were obtained mainly from the very extensive experimental data, supplemented where necessary by systematics.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for all n, n' secondary neutrons were assumed to be isotropic. The energy distributions for the discrete levels were based on the kinematics of the reaction. The energy distributions for the continuum neutrons were obtained from temperature model calculations; at incident neutron energies of 8 MeV and above a preequilibrium contribution was added in, as described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n, 2n$ CROSS SECTION

The $n, 2n$ threshold for the various isotopes of chromium range from 8.09 MeV for Cr^{53} to 13.2 MeV for Cr^{50} . In the evaluation, an effective $n, 2n$ threshold of 8.5 MeV was used. Experimental $n, 2n$ cross sections for Cr^{50} are given on pages 3-71 and 3-72 of UCRL-50400, Vol. 8, Rev. 1, Part A; $n, 2n$ cross sections for Cr^{52} are given on pages 3-82 and 3-84; and $n, 2n$ cross sections for Cr^{54} are given on page 3-93. The evaluated $n, 2n$ cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated cross sections were based on the experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 2n$ REACTION

The angular distribution of secondary neutrons from the $n, 2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n, p CROSS SECTION

Thresholds for the n, p reaction in the various isotopes of chromium are excited at neutron energies as low as

thermal. The effective threshold for the evaluated n,p cross sections in natural chromium was estimated to be 4 MeV. A single n,p data point for Cr⁵⁰ is given on page 3-72 of UCRL-50400, Vol. 8, Rev. 1, Part A; n,p data for Cr⁵² are given on pages 3-83 and 3-84; and two n,p data points for Cr⁵³ are given on page 3-91. The evaluated n,p data are shown graphically in UCRL-50400, Vol. 15, Part B. The evaluation was based partly on the experimental data and partly on data derived from systematics.

n,γ CROSS SECTION

Neutron capture data for natural chromium are given on pages 3-59 to 3-61 of UCRL-50400, Vol. 7, Part A, Rev. 1; data for Cr⁵⁰ are given on page 3-68. The evaluated neutron capture data are shown graphically in UCRL-50400, Vol. 15, Part B. The evaluation was based mainly on the experimental data.

PHOTON PRODUCTION FROM n,γ REACTIONS

The neutron capture gamma ray spectrum at thermal neutron energies was taken from the measurements of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies up to 20 MeV, since there

are no data for incident neutron energies higher than thermal. To conserve the total energy of the reaction, the gamma ray multiplicity was assumed to vary as a linear function of energy.

n,Xγ CROSS SECTION

Experimental n,Xγ cross sections are given on pages 3-67 and 3-68 of UCRL-50400, Vol. 8, Rev. 1, Part A. Since these are the only available data, the evaluated n,Xγ cross sections were represented by a continuum gamma ray spectrum with a neutron threshold of 0.58 MeV. The n,Xγ cross sections for this continuum spectrum were calculated from the NXGAMEL code, using the systematics of Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n,Xγ PROCESS

The angular distributions of the continuum gamma rays were assumed to be isotropic. The energy distributions of these photons were calculated from the nuclear systematics of Perkins, Haight, and Howerton cited above.

Manganese-55

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ^{55}Mn are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental and evaluated total cross sections for Mn^{55} are shown graphically on pages 3-70 to 3-79 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated experimental values are given on page 3-83. The evaluated total cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated total cross sections are based on the following specific ECSIL data sets: ECSIL-1823 from thermal energies to 10 keV; ECSIL-814 from 10 keV to 600 keV; and ECSIL-2517 from 600 keV to 20 MeV. The ECSIL experimental data references are given in UCRL-50400, Vol. 2.

ELASTIC SCATTERING CROSS SECTION

Experimental and evaluated elastic cross sections for Mn^{55} are shown graphically on page 3-79 of UCRL-50400, Vol. 7, Part A, Rev. 1; a single tabulated experimental data point is shown on page 3-84. The evaluated elastic scattering cross sections, which were obtained by

taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies up to 100 keV. Above 100 keV the evaluated elastic scattering angular distributions were based on the experimental data, supplemented at the higher energies by spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering data for Mn^{55} are shown graphically on pages 3-93 to 3-96 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 3-102. In the evaluation, the inelastic scattering was represented by a continuum cross section that starts at 0.15 MeV. The evaluated continuum cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

Manganese-55

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	282	8/31/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	14	1/03/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	28	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	LOCAL ENERGY DEP.	28	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	21	8/31/72	0.0000+ 0	1.5000- 1	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	12	8/31/72	0.0000+ 0	1.5000- 1	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	15	12/03/76	0.0000+ 0	1.5000- 1	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	1.5000- 1	2.0000+ 1
N,2N	CROSS SECTION	11	8/31/72	-1.0230+ 1	1.0420+ 1	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	6	8/31/72	-1.0230+ 1	1.0420+ 1	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	5	12/03/76	-1.0230+ 1	1.0420+ 1	2.0000+ 1
N,2N	LOCAL ENERGY DEP.	4	12/03/76	-1.0230+ 1	1.0420+ 1	2.0000+ 1
N,P	CROSS SECTION	6	8/31/72	-1.8100+ 0	5.0000+ 0	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	5/29/78	-1.8100+ 0	5.0000+ 0	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	5/29/78	-1.8100+ 0	5.0000+ 0	2.0000+ 1
N,A	CROSS SECTION	7	8/31/72	-6.3000- 1	5.0000+ 0	2.0000+ 1
N,A	TOTAL ENERGY DEP.	2	5/29/78	-6.3000- 1	5.0000+ 0	2.0000+ 1
N,A	LOCAL ENERGY DEP.	2	5/29/78	-6.3000- 1	5.0000+ 0	2.0000+ 1
N,G	CROSS SECTION	110	12/13/71	7.2700+ 0	1.0000-10	2.0000+ 1
N,G	ENERGY DIST.	2	12/01/75	7.2700+ 0	1.0000-10	2.0000+ 1
N,G	MULTIPLICITY	2	12/01/75	7.2700+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	7.2700+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	7.2700+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	7	1/22/73	0.0000+ 0	2.0000+ 0	2.0000+ 1
N,XG	ENERGY-ANGLE DIST.	7	1/22/73	0.0000+ 0	2.0000+ 0	2.0000+ 1
N,XG	CROSS SECTION	8	1/22/73	0.0000+ 0	1.3000- 1	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.3000- 1	2.0000+ 1
N,XG	CROSS SECTION	5	1/22/73	0.0000+ 0	1.3200+ 0	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.3200+ 0	2.0000+ 1
N,XG	CROSS SECTION	7	1/22/73	0.0000+ 0	1.0020+ 0	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.0020+ 0	2.0000+ 1
N,XG	CROSS SECTION	7	1/22/73	0.0000+ 0	1.0020+ 0	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.0020+ 0	2.0000+ 1
N,XG	CROSS SECTION	5	1/22/73	0.0000+ 0	1.3200+ 0	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.3200+ 0	2.0000+ 1
N,XG	CROSS SECTION	4	1/22/73	0.0000+ 0	1.5600+ 0	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.5600+ 0	2.0000+ 1
N,XG	CROSS SECTION	3	1/22/73	0.0000+ 0	1.9200+ 0	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.9200+ 0	2.0000+ 1
N,XG	CROSS SECTION	3	1/22/73	0.0000+ 0	1.9200+ 0	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.9200+ 0	2.0000+ 1
N,XG	CROSS SECTION	2	5/31/73	0.0000+ 0	1.9200+ 0	4.0000+ 0
N,XG	ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.9200+ 0	2.0000+ 1

PHOTON = 1.2600+ 1 MEV
 PHOTON = 1.2600+ 1 MEV
 PHOTON = 3.0800+ 1 MEV
 PHOTON = 3.0800+ 1 MEV
 PHOTON = 8.5800+ 1 MEV
 PHOTON = 8.5800+ 1 MEV
 PHOTON = 9.8400+ 1 MEV
 PHOTON = 9.8400+ 1 MEV
 PHOTON = 1.1670+ 0 MEV
 PHOTON = 1.1670+ 0 MEV
 PHOTON = 1.5290+ 0 MEV
 PHOTON = 1.5290+ 0 MEV
 PHOTON = 1.7570+ 0 MEV
 PHOTON = 1.7570+ 0 MEV
 PHOTON = 1.8830+ 0 MEV
 PHOTON = 1.8830+ 0 MEV

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for the n, n' secondary neutrons were assumed to be isotropic. The energy distributions were obtained from temperature model calculations. At incident neutron energies of 7 MeV and above, a preequilibrium contribution was added in, as described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n, 2n$ CROSS SECTION

The $n, 2n$ threshold for Mn^{55} is 10.41 MeV. Experimental values for $n, 2n$ cross sections are shown graphically on pages 3-97 and 3-98 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 3-102. The evaluated $n, 2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. These cross sections were based on the experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 2n$ REACTION

The angular distributions of secondary neutrons produced by the $n, 2n$ reaction were assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n, p CROSS SECTION

The threshold for the n, p reaction is 1.84 MeV. Since the only experimental data points come from three measurements near 14 MeV, the evaluation was based mainly on systematics. The evaluated n, p cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. In this evaluation, an effective threshold of 5 MeV was used.

n, α CROSS SECTION

The threshold for the n, α reaction is 0.64 MeV. Experimental and evaluated n, α cross sections are shown graphically on pages 3-100 and 3-101 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated experimental values are given on page 3-104. The evaluated cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. In the evaluation, an effective threshold of 5 MeV was used; the cross sections at lower energies were based on systematics, and the cross sections at higher energies were based on the experimental data.

n, γ CROSS SECTION

Neutron capture cross section data are shown graphically on pages 3-80 to 3-83 of UCRL-50400, together with the corresponding evaluated data; some tabulated experimental cross sections are given on page 3-84. The evaluated capture cross sections are

shown in UCRL-50400, Vol. 15, Part B. Since the experimental data extend over the entire range of interest, the evaluation was based on these experimental data.

PHOTON PRODUCTION FROM n,γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the data of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies, since there are no data for incident neutron energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of energy.

$n,X\gamma$ CROSS SECTION

Experimental $n,X\gamma$ cross sections are given on pages 3-99 and 3-100 of UCRL-50400, Vol. 8, Rev. 1, Part A in graphical form, and some tabulated values are given on page 3-103. The evaluated $n,X\gamma$ cross sections include contributions from eight discrete lines plus a continuum contribution that starts at 2 MeV. In the evaluation, the $n,X\gamma$ cross sections for the excitation of discrete photon lines at 0.126, 0.858, 1.167, 1.529, and 1.757 MeV over the incident neutron energy range from threshold up to 2 MeV were taken directly from

experimental measurements. The cross sections for the excitation of photon lines at 0.308, 0.984, and 1.883 MeV over this same incident neutron energy range were developed from the above cross sections and from the transition probabilities of R. L. Auble and J. Rapaport, *Nuclear Data B*, 1 (1970). All of these cross sections above 2 MeV were then linearly extrapolated to zero at a neutron energy of 4 MeV as a method of joining smoothly onto the continuum portion of the $n,X\gamma$ cross section.

The $N,X\gamma$ cross sections for the continuum component were calculated from the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. In the evaluation, the calculated values were multiplied by a factor F , where $F = 0$ at 2 MeV and rises linearly to $F = 1$ at 11 MeV and above. This procedure permits a smooth transition between discrete and continuum components, but it does not conserve energy in the range between 2 and 11 MeV.

SPECTRA OF PHOTONS FROM THE $n,X\gamma$ PROCESS

The photon angular distributions

were assumed to be isotropic. The energy distributions of the photons from the discrete levels were calculated from the kinematics of the reaction. The energy distributions

of the photons from the continuum component of the reaction were calculated from the systematics of Perkins, Haight, and Howerton cited above.

Iron

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural iron and for its various isotopes are summarized in UCRL-50400, Vol. 3.

The results of the evaluation data, which only apply to natural iron, are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton and Luisa Hansen did the evaluation.

TOTAL CROSS SECTION

Extensive measurements of the total cross sections for natural iron are shown graphically on pages 3-83 to 3-107 of UCRL-50400, Vol. 7, Part A, Rev. 1, together with the corresponding evaluated total cross sections; some tabulated total cross sections for natural iron are given on page 3-112. Total cross sections for Fe^{54} are given on page 3-114 of that reference; total cross sections for Fe^{56} are given on pages 3-115 and 3-116; and total cross sections for Fe^{57} are given on pages 3-117 to 3-119. The evaluated total cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated total cross sections are based on the following specific ECSIL data sets: ECSIL-2505 at thermal energies; ECSIL-814 from 4 to 200 keV; ECSIL-2516 from 0.5 to 9 MeV; and ECSIL-2620 from 9 to 15 MeV. The

ECSIL experimental data references are given in UCRL-50400, Vol. 2, Rev. 2.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural iron are shown graphically on pages 3-108 and 3-109 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 3-113. Some elastic scattering data for Fe^{54} and Fe^{56} are given on pages 3-115 to 3-117. The evaluated elastic scattering cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated elastic cross sections were obtained by taking the differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for all neutron energies up to 100 keV. Above 100 keV, the evaluated elastic angular distributions were based on the experimental data, supplemented at the higher energies by spherical optical model calculations in which the best-fit

Iron

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	2609	6/08/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	17	5/24/72	0.0000+ 0	1.0000- 1	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	33	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	33	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	37	10/02/72	0.0000+ 0	1.7500+ 0	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	10	5/27/72	0.0000+ 0	1.7500+ 0	2.0000+ 1	
N,N'	N TOTAL ENERGY DEP.	14	12/03/76	0.0000+ 0	1.7500+ 0	2.0000+ 1	
N,N'	N LOCAL ENERGY DEP.	11	12/03/76	0.0000+ 0	1.7500+ 0	2.0000+ 1	
N,N'	CROSS SECTION	47	5/17/72	0.0000+ 0	8.6026- 1	2.0000+ 1	LEVEL = 8.4500- 1 MEV
N,N'	N ANGULAR DIST.	4	5/27/72	0.0000+ 0	8.6026- 1	2.0000+ 1	LEVEL = 8.4500- 1 MEV
N,N'	N TOTAL ENERGY DEP.	6	12/03/76	0.0000+ 0	8.6026- 1	2.0000+ 1	LEVEL = 8.4500- 1 MEV
N,N'	N LOCAL ENERGY DEP.	6	12/03/76	0.0000+ 0	8.6026- 1	2.0000+ 1	LEVEL = 8.4500- 1 MEV
N,2N	CROSS SECTION	11	5/17/72	-1.1200+ 1	1.1500+ 1	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	5	5/27/72	-1.1200+ 1	1.1500+ 1	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1200+ 1	1.1500+ 1	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	4	12/03/76	-1.1200+ 1	1.1500+ 1	2.0000+ 1	
N,P	CROSS SECTION	37	5/17/72	-1.9100+ 0	1.9500+ 0	2.0000+ 1	
N,P	N TOTAL ENERGY DEP.	2	5/29/78	-1.9100+ 0	1.9500+ 0	2.0000+ 1	
N,P	N LOCAL ENERGY DEP.	2	5/29/78	-1.9100+ 0	1.9500+ 0	2.0000+ 1	
N,A	CROSS SECTION	27	5/17/72	3.2000- 1	3.7500+ 0	2.0000+ 1	
N,A	N TOTAL ENERGY DEP.	2	5/29/78	3.2000- 1	3.7500+ 0	2.0000+ 1	
N,A	N LOCAL ENERGY DEP.	2	5/29/78	3.2000- 1	3.7500+ 0	2.0000+ 1	
N,G	CROSS SECTION	125	4/03/76	7.8450+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	11/01/72	7.8450+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	11/01/72	7.8450+ 0	1.0000-10	2.0000+ 1	
N,G	N TOTAL ENERGY DEP.	2	11/21/76	7.8450+ 0	1.0000-10	2.0000+ 1	
N,G	N LOCAL ENERGY DEP.	2	11/21/76	7.8450+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	13	2/08/73	0.0000+ 0	1.0000- 1	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	10	2/08/73	0.0000+ 0	1.0000- 1	2.0000+ 1	
N,XG	CROSS SECTION	302	2/07/73	0.0000+ 0	3.6100- 1	2.0000+ 1	PHOTON = 8.4600- 1 MEV
N,XG	G ANGULAR DIST.	7	2/08/73	0.0000+ 0	3.6100- 1	2.0000+ 1	PHOTON = 8.4600- 1 MEV
N,XG	CROSS SECTION	8	2/08/73	0.0000+ 0	2.1220+ 0	2.0000+ 1	PHOTON = 1.2380+ 0 MEV
N,XG	G ANGULAR DIST.	5	2/08/73	0.0000+ 0	2.1220+ 0	2.0000+ 1	PHOTON = 1.2380+ 0 MEV
N,XG	CROSS SECTION	6	2/08/73	0.0000+ 0	1.4350+ 0	2.0000+ 1	PHOTON = 1.4090+ 0 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.4350+ 0	2.0000+ 1	PHOTON = 1.4090+ 0 MEV

optical model parameters of Becchetti and Segrè¹ were used [1, p. 118, 119, 120, 121].

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering cross section for natural iron are shown graphically on pages 3-135 to 3-139 of UCRL-50400, Vol. 8, Rev. 1, Part A; the calculated values are given on pages 3-140 and 3-141. Inelastic scattering data for Fe^{54} are shown graphically on pages 3-145 to 3-148 of that reference, with tabular values given on pages 3-152 and 3-153. Inelastic scattering data for Fe^{56} are shown graphically on pages 3-149 to 3-155, with tabular values given on pages 3-161 and 3-162. The evaluated n,n' cross sections include contributions from a discrete level at 0.845 MeV plus a continuum contribution that starts at 1.75 MeV. The evaluated n,n' cross sections, which were derived from the extensive experimental data, are shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distribution of neutrons inelastically scattered from the 0.845-MeV level was assumed to be isotropic for incident neutron energies up to 8 MeV. Above 8 MeV, the angular distribution was assumed to vary as a linear function of a

measured angular distribution at 1 MeV, and the same angular distribution was assumed to apply between 10 and 20 MeV. The angular distribution of the neutrons from the continuum contribution was assumed to be isotropic in the laboratory system. The energy distribution of the neutrons from the discrete level were based on the kinematics of the reaction. The energy distribution for the inelastically scattered continuum neutrons was derived by Luisa Hansen on the basis of experimental pulsed-sphere data, and they reflect the fact that these neutrons have a pre-equilibrium spectrum that is shifted towards higher neutron energies.

$n,2n$ CROSS SECTION

An effective $n,2n$ threshold of 11.5 MeV was used in the evaluation. This energy represents the average contribution of the various isotopes of iron to the $n,2n$ cross section. Two $n,2n$ data points for natural iron are given on page 3-132 of UCRL-50400, Vol. 8, Rev. 1, Part A. Experimental $n,2n$ data for the two principal isotopes of iron, Fe^{54} and Fe^{56} , are given on pages 3-139 and 3-143 and on pages 3-156 and 3-163, respectively, of that reference. The evaluated $n,2n$ cross sections, which were derived from a combination of

experimental data and nuclear systematics, are shown graphically in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons produced by the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

An effective threshold for the n,p reaction in natural iron of 1.95 MeV was chosen for this evaluation. This represents an average over the various contributing isotopes. A single experimental n,p data point for natural iron is listed on page 3-134 of UCRL-50400, Vol. 8, Rev. 1, Part A. The n,p data for Fe^{54} are listed on pages 3-139 to 3-141 and 3-144 of that reference; data for Fe^{56} are listed on pages 3-158 to 3-161 and on pages 3-163 and 3-164; data for Fe^{57} are listed on page 3-165; and data for Fe^{58} are listed on page 3-166. The evaluated n,p cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These

evaluated data were based mainly on the extensive experimental measurements of the n,p cross section.

n,α CROSS SECTION

The n,α reaction for most of the isotopes of iron is exoergic. However, in the evaluation an effective threshold of 3.75 MeV was used to account for the coulomb barrier. Experimental n,α cross section data for Fe^{54} are given on pages 3-142 and 3-145 of UCRL-50400, Vol. 8, Rev. 1, Part A; data for Fe^{56} are given on page 3-164; and data for Fe^{58} are given on page 3-166. The evaluated n,α cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated cross sections were based partly on the experimental data and partly on systematics.

n,γ CROSS SECTION

Neutron capture data for natural iron are given on pages 3-110, 3-111, and 3-113 of UCRL-50400, Vol. 7, Part A, Rev. 1; a single data point for Fe^{56} is given on page 3-117; data for Fe^{57} are given on page 3-119; and data for Fe^{58} are given on pages 3-119 and 3-120. The evaluated neutron capture data are shown graphically in UCRL-50400, Vol. 15, Part B. These data were based partly on the experimental data and partly on nuclear systematics.

PHOTON PRODUCTION FROM n,γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the data of V. L. Orphan, W. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10748 (1970). It was assumed that this spectrum could be applied at all neutron energies, since there were no data for incident neutron energies higher than thermal. To conserve the total energy of the reaction, the gamma-ray multiplicity was assumed to vary as a linear function of energy.

n,γ CROSS SECTION

Extensive n,γ measurements for natural iron are shown graphically on pages 3-121 to 3-129 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on pages 3-133 and 3-134; n,γ measurements for Fe^{56} are given on pages 3-157, 3-158, and 3-163. In the evaluation, the n,γ cross section was represented by three discrete lines plus a continuum that starts at 0.1 MeV. The discrete lines were evaluated as follows:

0.846 MeV

This gamma ray comes from the transition of the 0.846-MeV level in Fe^{56} to the ground state. Numerous measurements have been made of the cross section and angular distribution for this decay. In the evaluation,

the data of F. Voss et al.* were used for neutron energies up to 4.5 MeV. These data agree with the data of J. E. Dickens et al., ORNL-4798 and *Neutron Phys.* 50, 311 (1973), and of V. L. Orphan and C. G. Hoot, Gulf Radiation Technology Rept. Gulf-RT-A10743 (DNA 2736F) (1971), but have a somewhat higher resolution. From 4.5 to 20 MeV, the data of Dickens et al. were used.

1.238 MeV

This gamma ray comes from the transition of the 2.084-MeV level to the 0.846-MeV level in Fe^{56} . In the evaluation, the data of Dickens and of Orphan, cited above, were used.

1.409 MeV

This gamma ray comes from the transition of 1.409-MeV level in Fe^{54} to the ground state. In the evaluation, the data of Dickens were used, with a correction applied for the isotopic abundance of Fe^{54} in natural iron.

The gamma rays contributed by the continuum component of the n,γ cross section were obtained from the experimental data. In particular, the

*"Proceedings of the Third Neutron Cross Section and Technology Conference," Knoxville, CONF-710301, Vol. 1, p. 218 (1971).

data of Dickens at eight neutron energies between 2 and 15 MeV were used, with an extrapolation of these data above 15 MeV.

SPECTRA OF PHOTONS FROM THE n, X_1 PROCESS

Angular distributions for the 0.846-MeV gamma ray were taken from the measurements of D. M. Drake *et al.*, *Rev. Mod. Phys.* 40, 294 (1970). The measurements are in good agreement with the data of Hosoe and Suzuki, *J. Phys. Soc. Jpn.* 14, 699 (1959), at 2.91 MeV, and with the data of Day and Walt, *Phys. Rev.* 117, 1330 (1960), at 2.56 MeV. The

angular distributions above 7 MeV had to be guessed. Angular distributions for the 1.238-MeV gamma ray were obtained from the measurements of L. L. Morgan *et al.*, Texas Nuclear Corporation Rept. (1964); angular distributions above 4 MeV had to be guessed. The angular distributions for the 1.409-MeV gamma ray and for the continuum gamma rays were assumed to be isotropic. The energy distributions of the discrete gamma rays were based on the kinematics of the reaction. The energy distributions of the continuum gamma rays were taken from the measurements of Dickens, cited above.

Cobalt-59

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ^{59}Co are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was done by R. J. Howerton of Lawrence Livermore Laboratory and P. T. Guenther, P. A. Moldauer, A. B. Smith, D. L. Smith, and J. F. Whalen of Argonne National Laboratory. It is based, in part, on experimental data taken by the Argonne group. The Argonne experimental data and the Co^{59} evaluation are described in Argonne report ANL/NDM-1 (July 1973), although some updating changes in the evaluated data were made by R. J. Howerton when this evaluation was inserted into the Livermore ENDL Library.

TOTAL CROSS SECTION

Extensive total cross section measurements for Co^{59} are shown graphically on pages 3-120 to 3-130 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on pages 3-132 and 3-133. The evaluated total cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated total cross sections are based mainly on the following ECSIL data sets: ECSIL-814 (from 0.6 keV to 0.22 MeV) and ECSIL-

2017 (from 0.36 MeV to 20 MeV). The ECSIL experimental data references are given in UCRL-50400, Vol. 2, Rev. 2.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering data for cobalt are shown graphically on page 3-131 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 3-133. The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated total cross sections were obtained by taking the differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections; nuclear model calculations were also used to some extent (see ANL/NDM-1).

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. The evaluated elastic angular distributions were based, in part, on the experimental data of the Argonne group. In the evaluation, the angular distributions were assumed to be isotropic for neutron energies up to 1 keV. At higher energies, Legendre polynomials were fit to the experimental data, and an extensive analysis was made of the various data sets, as

REACTION		POINTS	DATE	TIME	FILE	NAME
N,ELASTIC	CROSS SECTION	2808	3-01-74	0.0000	1	
N,ELASTIC	ANGULAR DIST.	57	3-01-74	0.0000	1	
N,ELASTIC	TOTAL ENERGY DEP.	45	11-12-74	0.0000	1	
N,ELASTIC	LOCAL ENERGY DEP.	45	11-12-74	0.0000	1	
N,N'	CROSS SECTION	27	3-01-74	0.0000	1	
N,N'	ENERGY-ANGLE DIST.	14	3-04-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	12	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	10	12-03-76	0.0000	1	
N,N'	CROSS SECTION	15	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	14	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	CROSS SECTION	13	3-01-74	0.0000	1	
N,N'	ANGULAR DIST.	2	3-01-74	0.0000	1	
N,N'	TOTAL ENERGY DEP.	2	12-03-76	0.0000	1	
N,N'	LOCAL ENERGY DEP.	2</				

Cobalt-59 (Cont.)

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,O	CROSS SECTION	4	3/01/74	-5.1450+0	5.2320+1	5.2320+1
N,O	TOTAL ENERGY DEP.	2	5/29/78	-5.1450+0	5.2320+1	5.2320+1
N,O	LOCAL ENERGY DEP.	2	5/29/78	-5.1450+0	5.2320+1	5.2320+1
N,T	CROSS SECTION	4	3/01/74	-8.9300+0	9.0810+1	9.0810+1
N,T	TOTAL ENERGY DEP.	2	5/29/78	-8.9300+0	9.0810+1	9.0810+1
N,T	LOCAL ENERGY DEP.	2	5/29/78	-8.9300+0	9.0810+1	9.0810+1
N,A	CROSS SECTION	30	3/01/74	3.2008+1	4.9200+1	4.9200+1
N,A	TOTAL ENERGY DEP.	2	5/29/78	3.2008+1	4.9200+1	4.9200+1
N,A	LOCAL ENERGY DEP.	2	5/29/78	3.2008+1	4.9200+1	4.9200+1
N,G	CROSS SECTION	1978	3/01/74	7.4900+0	7.0000+0	7.0000+0
N,G	G ENERGY DIST.	2	2/23/78	7.4900+0	7.0000+0	7.0000+0
N,G	G MULTIPLICITY	2	2/23/78	7.4900+0	7.0000+0	7.0000+0
N,G	TOTAL ENERGY DEP.	2	11/21/76	7.4900+0	7.0000+0	7.0000+0
N,G	LOCAL ENERGY DEP.	2	11/21/76	7.4900+0	7.0000+0	7.0000+0
N,XG	CROSS SECTION	14	2/23/78	0.0000+0	1.180+1	1.180+1
N,XG	G ENERGY-ANGLE DIST.	14	2/23/78	0.0000+0	1.180+1	1.180+1

described in ANL/NDM-1. For neutron energies up to 8 MeV, the evaluated elastic scattering angular distributions were based on the experimental data, with the Legendre fits used to extend the experimental data over the entire angular range. Above 8 MeV, the evaluated angular distributions were obtained almost entirely from model calculations, as described in ANL/NDM-1.

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering data are shown graphically on pages 3-167 to 3-171 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 3-183. The evaluated n, n' cross sections are shown graphically on page 166 of UCRL-50400, Vol. 15, Part B. These evaluated cross sections include contributions from nine discrete levels plus a continuum component that starts at 2.44 MeV. As is discussed in detail in ANL/NDM-1, the evaluated n, n' cross sections are based primarily on the experimental data, with theoretical calculations offering some guidance.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions of the inelastically scattered neutrons were assumed to be isotropic. While this assumption is incorrect for the pre-

equilibrium and direct-interaction portions of this reaction, the alternative of entering anisotropic angular distributions in the evaluation would be equally invalid because the uncertainties in the reaction cross section are so great. For incident neutron energies less than 8 MeV, the energy distributions of the neutrons from the continuum component were obtained from temperature model calculations, as described in ANL/NDM-1. However, instead of the temperature parameter $a = 6.4 \text{ MeV}^{-1}$ (used in ANL/NDM-1), the ENDL evaluation used the value $a = 7.5 \text{ MeV}^{-1}$. This value is based on the experimental data of W. E. Kinney and F. G. Perey, ORNL-4549 (1970), K. Tsukuda *et al.*, *Nucl. Phys.* 78, 369 (1966), U. Facchini and E. Saetta-Manichella, *Energia Nucleare* 15, 54 (1968), and A. Gilbert and A. G. W. Cameron, *Can. Journ. Phys.* 43, 1446 (1965). For incident neutron energies greater than or equal to 8 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a direct interaction and pre-equilibrium component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 10.64 MeV. Experimental n,2n cross section data are shown graphically on pages 3-172 to 3-175 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 3-183. The evaluated n,2n cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. As discussed in ANL/XDM-1, the evaluated n,2n cross sections are based on the extensive experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, using a temperature that is somewhat "softer" than that used for the n,n' process.

n,p CROSS SECTION

The threshold for the n,p reaction is 0.8 MeV. Experimental values for the n,p cross section are shown graphically on page 3-178 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 3-184 and 3-185. The evaluated n,p cross sections are shown in UCRL-

50400, Vol. 15, Part B. The evaluated n,p cross sections are based on a combination of experimental data and nuclear systematics, as described in ANL/XDM-1.

n,d CROSS SECTION

The threshold for the n,d reaction is 5.23 MeV. The only experimental n,d cross section is based on a single point measured at 14.8 MeV. Thus the evaluated n,d cross sections, which are small, were obtained from nuclear systematics, as described in ANL/XDM-1. The evaluated n,d cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

n,t CROSS SECTION

The threshold for the n,t reaction is 9.08 MeV. The only experimental n,t data are two points measured at 14.7 and 14.8 MeV (page 3-185 of UCRL-50400, Vol. 8, Rev. 1, Part A). Thus the evaluation for this reaction was based mainly on nuclear systematics. The evaluated n,t cross sections are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The threshold for the n, α reaction is -0.32 MeV. However, for the evaluation, an effective threshold of 5 MeV was selected, since the n, α cross section is known to have a very

small value below this energy (see ANL/NDM-1). Experimental n, ϵ cross sections are shown graphically on pages 3-179 to 3-181 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 3-185. The evaluated n, ϵ cross sections, which were based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

Neutron capture data are shown graphically on page 3-132 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on pages 3-133 and 3-134. The evaluated capture cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated cross sections were obtained after an extensive analysis of the experimental data, as described in ANL/NDM-1.

PHOTON PRODUCTION FROM n, γ REACTIONS

The neutron capture gamma-ray spectrum at thermal neutron energies was taken from the data of V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neu-

tron energies up to 20 MeV. To conserve the total energy of the reaction, the gamma ray multiplicity was assumed to vary as a linear function of energy.

n, X_i CROSS SECTION

The n, X_i cross section measurements for cobalt are shown graphically on pages 3-176 and 3-177 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 3-184. The evaluated n, X_i cross sections, which extend from 1.12 MeV to 20 MeV, were obtained from a combination of experimental data and theoretical calculations. The theoretical calculations were obtained from the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n, X_i PROCESS

The photon angular distributions were assumed to be isotropic. The energy distributions were calculated from the systematics of Perkins, Haight, and Howerton, cited above.

Nickel

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural nickel and its various isotopes are summarized in UCRL-50400, Vol. 3. The evaluated data for natural nickel are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was done by R. J. Howerton of Lawrence Livermore Laboratory and P. Guenther, A. Smith, D. Smith, and J. Whalen of Argonne National Laboratory. It is based, in part, on experimental data taken by the Argonne group. The Argonne experimental data and the nickel evaluation are described in Argonne report ANL/NDM-11 (July 1975). Some changes in the evaluated data were made by R. J. Howerton when this evaluation was inserted into the Livermore ENDL evaluated library.

TOTAL CROSS SECTION

Extensive total cross section measurements for natural nickel are shown graphically on pages 3-134 to 3-148 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 3-154. Total cross section data for separated isotopes of nickel are given on pages 3-155 to 3-166 of this reference. The evaluated total cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated total cross

sections are based, in part, on the Argonne group's data; a detailed description of the experimental data and of the evaluation procedures is given in ANL/NDM-11.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering data for natural nickel are shown graphically on page 3-149 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 3-154; elastic scattering data for Ni^{58} , Ni^{60} , and Ni^{62} are given on pages 3-157, 3-160, and 3-164, respectively. The evaluated elastic cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated elastic cross sections are based, in part, on experimental measurements made by the Argonne group; the evaluation procedures are described in detail in ANL/NDM-11.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. The evaluated angular distributions are based, in part, on Argonne measurements; the evaluation procedures are discussed in ANL/NDM-11. In the evaluation, the angular distributions were assumed to be isotropic for

Nickel

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		REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,N'		CROSS SECTION	1930	2/27/76	0.0000+0	1.0000-10	2.0000+1	
N,N'	N	ANGULAR DIST.	61	6/05/75	0.0000+0	1.0000-10	2.0000+1	
N,N'	N	TOTAL ENERGY DEP.	56	6/05/75	0.0000+0	1.0000-10	2.0000+1	
N,N'	N	LOCAL ENERGY DEP.	56	6/05/75	0.0000+0	1.0000-10	2.0000+1	
N,N'	N	CROSS SECTION	11	6/05/75	0.0000+0	3.7630+0	2.0000+1	
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	3.7630+0	2.0000+1	
N,N'	N	ENERGY-ANGLE LIST	11	6/05/75	0.0000+0	3.7630+0	2.0000+1	
N,N'	N	TOTAL ENERGY DEP.	9	12/03/76	0.0000+0	3.7630+0	2.0000+1	
N,N'	N	LOCAL ENERGY DEP.	7	12/03/76	0.0000+0	3.7630+0	2.0000+1	
N,N'	N	CROSS SECTION	11	6/05/75	0.0000+0	1.1920+0	2.0000+1	LEVEL = 1.1720+0 MEV
N,N'	N	ANGULAR DIST.	5	6/05/75	0.0000+0	1.1920+0	2.0000+1	LEVEL = 1.1720+0 MEV
N,N'	N	TOTAL ENERGY DEP.	5	12/03/76	0.0000+0	1.1920+0	2.0000+1	LEVEL = 1.1720+0 MEV
N,N'	N	LOCAL ENERGY DEP.	5	12/03/76	0.0000+0	1.1920+0	2.0000+1	LEVEL = 1.1720+0 MEV
N,N'	N	CROSS SECTION	25	6/05/75	0.0000+0	1.3550+0	2.0000+1	LEVEL = 1.3350+0 MEV
N,N'	N	ANGULAR DIST.	5	6/05/75	0.0000+0	1.3550+0	2.0000+1	LEVEL = 1.3350+0 MEV
N,N'	N	TOTAL ENERGY DEP.	5	12/03/76	0.0000+0	1.3550+0	2.0000+1	LEVEL = 1.3350+0 MEV
N,N'	N	LOCAL ENERGY DEP.	5	12/03/76	0.0000+0	1.3550+0	2.0000+1	LEVEL = 1.3350+0 MEV
N,N'	N	CROSS SECTION	25	6/05/75	0.0000+0	1.4790+0	2.0000+1	LEVEL = 1.4590+0 MEV
N,N'	N	ANGULAR DIST.	5	6/05/75	0.0000+0	1.4790+0	2.0000+1	LEVEL = 1.4590+0 MEV
N,N'	N	TOTAL ENERGY DEP.	5	12/03/76	0.0000+0	1.4790+0	2.0000+1	LEVEL = 1.4590+0 MEV
N,N'	N	LOCAL ENERGY DEP.	5	12/03/76	0.0000+0	1.4790+0	2.0000+1	LEVEL = 1.4590+0 MEV
N,N'	N	CROSS SECTION	12	6/05/75	0.0000+0	2.1950+0	2.0000+1	LEVEL = 2.1580+0 MEV
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	2.1950+0	2.0000+1	LEVEL = 2.1580+0 MEV
N,N'	N	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	2.1950+0	2.0000+1	LEVEL = 2.1580+0 MEV
N,N'	N	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	2.1950+0	2.0000+1	LEVEL = 2.1580+0 MEV
N,N'	N	CROSS SECTION	13	6/05/75	0.0000+0	2.3240+0	2.0000+1	LEVEL = 2.2860+0 MEV
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	2.3240+0	2.0000+1	LEVEL = 2.2860+0 MEV
N,N'	N	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	2.3240+0	2.0000+1	LEVEL = 2.2860+0 MEV
N,N'	N	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	2.3240+0	2.0000+1	LEVEL = 2.2860+0 MEV
N,N'	N	CROSS SECTION	15	6/05/75	0.0000+0	2.5000+0	2.0000+1	LEVEL = 2.4590+0 MEV
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	2.5000+0	2.0000+1	LEVEL = 2.4590+0 MEV
N,N'	N	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	2.5000+0	2.0000+1	LEVEL = 2.4590+0 MEV
N,N'	N	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	2.5000+0	2.0000+1	LEVEL = 2.4590+0 MEV
N,N'	N	CROSS SECTION	15	6/05/75	0.0000+0	2.5480+0	2.0000+1	LEVEL = 2.5060+0 MEV
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	2.5480+0	2.0000+1	LEVEL = 2.5060+0 MEV
N,N'	N	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	2.5480+0	2.0000+1	LEVEL = 2.5060+0 MEV
N,N'	N	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	2.5480+0	2.0000+1	LEVEL = 2.5060+0 MEV
N,N'	N	CROSS SECTION	11	6/05/75	0.0000+0	2.6700+0	2.0000+1	LEVEL = 2.6250+0 MEV
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	2.6700+0	2.0000+1	LEVEL = 2.6250+0 MEV
N,N'	N	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	2.6700+0	2.0000+1	LEVEL = 2.6250+0 MEV
N,N'	N	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	2.6700+0	2.0000+1	LEVEL = 2.6250+0 MEV
N,N'	N	CROSS SECTION	12	6/05/75	0.0000+0	2.8220+0	2.0000+1	LEVEL = 2.7750+0 MEV
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	2.8220+0	2.0000+1	LEVEL = 2.7750+0 MEV
N,N'	N	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	2.8220+0	2.0000+1	LEVEL = 2.7750+0 MEV
N,N'	N	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	2.8220+0	2.0000+1	LEVEL = 2.7750+0 MEV
N,N'	N	CROSS SECTION	12	6/05/75	0.0000+0	3.0100+0	2.0000+1	LEVEL = 2.9600+0 MEV
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	3.0100+0	2.0000+1	LEVEL = 2.9600+0 MEV
N,N'	N	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	3.0100+0	2.0000+1	LEVEL = 2.9600+0 MEV
N,N'	N	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	3.0100+0	2.0000+1	LEVEL = 2.9600+0 MEV
N,N'	N	CROSS SECTION	12	6/05/75	0.0000+0	3.3250+0	2.0000+1	LEVEL = 3.2700+0 MEV
N,N'	N	ANGULAR DIST.	2	6/05/75	0.0000+0	3.3250+0	2.0000+1	LEVEL = 3.2700+0 MEV

Nickel (Cont.)

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REACTION	POL:ITS	DATE	Q-VALUE	Z-MIN	E-MAX	LEVEL
N N TOTAL ENERGY DEP.	2	12/13/76	0.0000+ 0	3.3250+ 0	2.0000+ 1	LEVEL = 3.2700+ 0 MEV
N N LOCAL ENERGY DEP.	2	12/13/76	0.0000+ 0	3.3250+ 0	2.0000+ 1	LEVEL = 3.2700+ 0 MEV
N N CROSS SECTION	11	6/05/75	0.0000+ 0	2.6890+ 0	2.0000+ 1	LEVEL = 3.6280+ 0 MEV
N N ANGULAR DIST.	2	6/05/75	0.0000+ 0	2.6890+ 0	2.0000+ 1	LEVEL = 3.6280+ 0 MEV
N N TOTAL ENERGY DEP.	2	12/13/76	0.0000+ 0	3.6890+ 0	2.0000+ 1	LEVEL = 3.6280+ 0 MEV
N N LOCAL ENERGY DEP.	2	12/13/76	0.0000+ 0	3.6890+ 0	2.0000+ 1	LEVEL = 3.6280+ 0 MEV
N N CROSS SECTION	12	6/05/75	-7.8195+ 0	2.1950+ 0	2.0000+ 1	
N N ANGULAR DIST.	2	6/05/75	-7.8195+ 0	2.1950+ 0	2.0000+ 1	
N N ENERGY-ANGLE DIST.	6	6/05/75	-7.8195+ 0	2.1950+ 0	2.0000+ 1	
N N TOTAL ENERGY DEP.	14	12/13/76	-7.8195+ 0	2.1950+ 0	2.0000+ 1	
N N LOCAL ENERGY DEP.	10	12/13/76	-7.8195+ 0	2.1950+ 0	2.0000+ 1	
N N CROSS SECTION	8	6/05/75	-8.1772+ 0	2.3190+ 0	2.0000+ 1	
N N ANGULAR DIST.	2	6/05/75	-8.1772+ 0	2.3190+ 0	2.0000+ 1	
N N ENERGY-ANGLE DIST.	4	6/05/75	-8.1772+ 0	2.3190+ 0	2.0000+ 1	
N N TOTAL ENERGY DEP.	12	12/13/76	-8.1772+ 0	2.3190+ 0	2.0000+ 1	
N N LOCAL ENERGY DEP.	12	12/13/76	-8.1772+ 0	2.3190+ 0	2.0000+ 1	
N N CROSS SECTION	8	6/05/75	-6.2850+ 0	2.4010+ 0	2.0000+ 1	
N N ANGULAR DIST.	2	6/05/75	-6.2850+ 0	2.4010+ 0	2.0000+ 1	
N N ENERGY-ANGLE DIST.	4	6/05/75	-6.2850+ 0	2.4010+ 0	2.0000+ 1	
N N TOTAL ENERGY DEP.	15	12/13/76	-6.2850+ 0	2.4010+ 0	2.0000+ 1	
N N LOCAL ENERGY DEP.	15	12/13/76	-6.2850+ 0	2.4010+ 0	2.0000+ 1	
N N CROSS SECTION	78	12/13/76	-3.9470+ 1	2.4032+ 0	2.0000+ 1	
N N TOTAL ENERGY DEP.	2	12/13/76	3.9470+ 1	1.0000+ 0	2.0000+ 1	
N N LOCAL ENERGY DEP.	2	12/13/76	3.9470+ 1	1.0000+ 0	2.0000+ 1	
N N CROSS SECTION	3	12/13/76	-5.9520+ 0	1.0000+ 0	2.0000+ 1	
N N TOTAL ENERGY DEP.	2	12/13/76	-5.9520+ 0	6.0560+ 0	2.0000+ 1	
N N LOCAL ENERGY DEP.	2	12/13/76	-5.9520+ 0	6.0560+ 0	2.0000+ 1	
N N CROSS SECTION	23	6/05/75	2.8902+ 0	1.0000+ 0	2.0000+ 1	
N N TOTAL ENERGY DEP.	2	12/13/76	2.8902+ 0	1.0000+ 0	2.0000+ 1	
N N LOCAL ENERGY DEP.	2	12/13/76	2.8902+ 0	1.0000+ 0	2.0000+ 1	
N N CROSS SECTION	382	6/05/75	8.6000+ 0	1.0000+ 0	2.0000+ 1	
N N ENERGY DIST.	2	6/01/75	8.6000+ 0	1.0000+ 0	2.0000+ 1	
N N MULTIPLICITY	2	6/01/75	8.6000+ 0	1.0000+ 0	2.0000+ 1	
N N TOTAL ENERGY DEP.	2	11/21/76	8.6000+ 0	1.0000+ 0	2.0000+ 1	
N N LOCAL ENERGY DEP.	2	11/21/76	8.6000+ 0	1.0000+ 0	2.0000+ 1	
N N CROSS SECTION	6	6/14/75	0.0000+ 0	4.0000+ 0	2.0000+ 1	
N N ENERGY DIST.	6	6/14/75	0.0000+ 0	4.0000+ 0	2.0000+ 1	
N N CROSS SECTION	6	6/05/75	0.0000+ 0	2.6700+ 0	2.0000+ 0	PHOTON = 4.6700- 1 MEV
N N ANGULAR DIST.	2	6/05/75	0.0000+ 0	2.6700+ 0	2.0000+ 0	PHOTON = 4.6700- 1 MEV
N N CROSS SECTION	9	6/05/75	0.0000+ 0	2.1950+ 0	2.0000+ 0	PHOTON = 8.2500- 1 MEV
N N ANGULAR DIST.	2	6/05/75	0.0000+ 0	2.1950+ 0	2.0000+ 0	PHOTON = 8.2500- 1 MEV
N N CROSS SECTION	8	6/05/75	0.0000+ 0	2.3240+ 0	2.0000+ 0	PHOTON = 9.5300- 1 MEV
N N ANGULAR DIST.	2	6/05/75	0.0000+ 0	2.3240+ 0	2.0000+ 0	PHOTON = 9.5300- 1 MEV
N N CROSS SECTION	9	6/05/75	0.0000+ 0	2.5000+ 0	2.0000+ 0	PHOTON = 1.0050+ 0 MEV
N N ANGULAR DIST.	2	6/05/75	0.0000+ 0	2.5000+ 0	2.0000+ 0	PHOTON = 1.0050+ 0 MEV
N N CROSS SECTION	4	6/05/75	0.0000+ 0	3.6890+ 0	2.0000+ 0	PHOTON = 1.1690+ 0 MEV
N N ANGULAR DIST.	2	6/05/75	0.0000+ 0	3.6890+ 0	2.0000+ 0	PHOTON = 1.1690+ 0 MEV
N N CROSS SECTION	7	6/05/75	0.0000+ 0	1.1920+ 0	2.0000+ 0	PHOTON = 1.1720+ 0 MEV
N N ANGULAR DIST.	2	6/05/75	0.0000+ 0	1.1920+ 0	2.0000+ 0	PHOTON = 1.1720+ 0 MEV
N N CROSS SECTION	9	6/05/75	0.0000+ 0	2.5480+ 0	2.0000+ 0	PHOTON = 1.1730+ 0 MEV
N N ANGULAR DIST.	2	6/05/75	0.0000+ 0	2.5480+ 0	2.0000+ 0	PHOTON = 1.1730+ 0 MEV
N N CROSS SECTION	6	6/05/75	0.0000+ 0	2.6700+ 0	2.0000+ 0	PHOTON = 1.2920+ 0 MEV

Nickel (Cont.)

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	2.6700+0	4.0000+0	PHOTON = 1.2920+0 MEV
N,XG	CROSS SECTION	8	6/05/75	0.0000+0	2.8220+0	4.0000+0	PHOTON = 1.3210+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	2.8220+0	4.0000+0	PHOTON = 1.3210+0 MEV
N,XG	CROSS SECTION	21	6/05/75	0.0000+0	1.3550+0	4.0000+0	PHOTON = 1.3330+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	1.3550+0	4.0000+0	PHOTON = 1.3330+0 MEV
N,XG	CROSS SECTION	22	6/05/75	0.0000+0	1.4790+0	4.0000+0	PHOTON = 1.4540+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	1.4790+0	4.0000+0	PHOTON = 1.4540+0 MEV
N,XG	CROSS SECTION	7	6/05/75	0.0000+0	3.0100+0	4.0000+0	PHOTON = 1.5060+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	3.0100+0	4.0000+0	PHOTON = 1.5060+0 MEV
N,XG	CROSS SECTION	23	6/05/75	0.0000+0	3.3250+0	4.0000+0	PHOTON = 1.8160+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	3.3250+0	4.0000+0	PHOTON = 1.8160+0 MEV
N,XG	CROSS SECTION	24	6/05/75	0.0000+0	2.1950+0	4.0000+0	PHOTON = 2.1580+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	2.1950+0	4.0000+0	PHOTON = 2.1580+0 MEV
N,XG	CROSS SECTION	74	6/05/75	0.0000+0	3.6890+0	4.0000+0	PHOTON = 2.1740+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	3.6890+0	4.0000+0	PHOTON = 2.1740+0 MEV
N,XG	CROSS SECTION	8	6/05/75	0.0000+0	2.8220+0	4.0000+0	PHOTON = 2.7750+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	2.8220+0	4.0000+0	PHOTON = 2.7750+0 MEV
N,XG	CROSS SECTION	7	6/05/75	0.0000+0	3.0100+0	4.0000+0	PHOTON = 2.9600+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	3.0100+0	4.0000+0	PHOTON = 2.9600+0 MEV
N,XG	CROSS SECTION	5	6/05/75	0.0000+0	3.3250+0	4.0000+0	PHOTON = 3.2700+0 MEV
N,XG	G ANGULAR DIST.	2	6/05/75	0.0000+0	3.3250+0	4.0000+0	PHOTON = 3.2700+0 MEV

neutron energies up to 25 keV. At higher energies, the evaluated elastic angular distributions were obtained by fitting Legendre polynomials to the experimental data. Interpolation and extrapolation were required in the energy regions between 8 and 14 MeV and above 14 MeV because there were no experimental data for those regions.

INELASTIC SCATTERING CROSS SECTION

Extensive inelastic scattering data for natural nickel are shown graphically on pages 3-188 to 3-195 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on page 3-202. Inelastic data for Ni^{58} are given on pages 3-204 to 3-207 (graphical) and 3-221 (tabular); data for Ni^{60} are given on pages 3-226 to 3-233 (graphical) and 3-235 (tabular); and data for Ni^{62} are given on pages 3-238 and 3-239. The evaluated n, n' cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated cross sections include contributions from twelve discrete levels plus a continuum component that starts at 3.763 MeV. The evaluation procedures for obtaining the n, n' cross sections are discussed in detail in ANL/NDM-11. The evaluated n, n' cross sections were based mainly from experimental data, with some guidance from theoretical calculations.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

Anisotropic angular distributions were inserted into the evaluation for neutrons inelastically scattered from the first three discrete levels; these anisotropic distributions were based on experimental data, as described in ANL/NDM-11. The neutrons that were inelastically scattered from the nine higher-energy discrete levels were assumed to be isotropic, as were the neutrons corresponding to continuum inelastic scattering. The energy distributions of the neutrons scattered from discrete levels were based on the kinematics of the reaction. The energy distributions for the continuum neutrons were obtained by using a two-component model — a temperature component plus a direct interaction and preequilibrium component. The evaluation procedures are described in detail in ANL/NDM-11. The procedure of assigning isotropic angular distributions to the continuum neutrons is incorrect, since the pre-equilibrium and direct-interaction components peak at forward angles for the higher neutron energies. But the uncertainties in the reaction cross sections are so large that entering anisotropic angular distributions for the continuum neutrons would not be a physically significant procedure.

n,2n CROSS SECTION

The threshold for the n,2n cross section in the present evaluation was set equal to 7.954 MeV, which is the n,2n threshold in Ni⁶¹ and the lowest n,2n threshold for any of the principle isotopes of nickel. Experimental n,2n data for natural nickel are shown graphically on page 3-196 of UCRL-50400, Vol. 8, Rev. 1, Part A; a data point is given in tabular form on page 3-202. Data for Ni⁵⁸ are given on pages 3-208 to 3-212 (graphical) and 3-222 of that reference. The evaluated n,2n cross sections are shown in UCRL-50400, Vol. 15, Part B. The procedures used to obtain these evaluated cross sections are described in detail in ANL/NDM-11; these procedures are based on a combination of experimental data and nuclear systematics.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations (ANL/NDM-11).

n,n'p CROSS SECTION

The procedure for evaluating the n,n'p cross section is described in

ANL/NDM-11. In this evaluation, only the contributions from the isotopes Ni⁵⁸ and Ni⁶⁰ were considered. The threshold for this reaction was set equal to 8.319 MeV, which is the threshold in Ni⁵⁸. Experimental n,n'p data for the various isotopes of nickel are given on pages 3-202, 3-213, 3-222, 3-237, 3-239, and 3-240 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,n'p cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. These cross sections were based on a combination of experimental data and nuclear systematics.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n'p CROSS SECTION

The angular distribution of secondary neutrons from the n,n'p reaction was assumed to be isotropic in the laboratory system. The energy distributions were represented by rather "soft" (n,2n-type) temperature distributions, as described in ANL/NDM-11.

n,n'α CROSS SECTION

The threshold for the n,n'α cross section was set equal to 6.4 MeV, which is the threshold for Ni⁶⁰. A single data point for Ni⁵⁸ is listed on page 3-222 of UCRL-50400, Vol. 8, Rev. 1, Part A. Thus the evaluated n,n'α cross sections were obtained

almost entirely from nuclear systematics. These evaluated cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, n'\alpha$ REACTION

The angular distribution of the secondary neutrons from the $n, n'\alpha$ reaction was assumed to be isotropic in the laboratory system. The energy distributions were represented by rather "soft" temperature distributions of the form used for the $n, 2n$ process.

n, p CROSS SECTION

The n, p reaction in nickel is exoergic. Experimental data for the n, p reaction in natural nickel and its various isotopes are given on pages 3-203, 3-214 to 3-220, 3-223, 3-225, 3-234, 3-236, 3-237, 3-239, and 3-241 of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluation for this reaction, which is described in detail in ANL/NDM-11, is based on contributions from the isotopes Ni^{58} , Ni^{60} , and Ni^{61} . The isotopes Ni^{62} and Ni^{64} also contribute to this reaction, but they have not been included in the evaluation because of their small isotopic abundances and the lack of experimental data. The evaluated n, p cross sections are shown in UCRL-50400, Vol. 15, Part B.

n, d CROSS SECTION

The threshold for the evaluated n, d cross section was set equal to the 6.06-MeV threshold in Ni^{58} . The only n, d cross section listed in the ECSIL compilation is a single data point for Ni^{58} on page 3-224 of UCRL-50400, Vol. 8, Rev. 1, Part A. However, $n, n'p$ data (see the write-up above) can also be used as a guide in estimating this cross section. The evaluated n, d cross sections (ANL/NDM-11), which are based mainly on systematics, are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The n, α reaction in nickel is exoergic. Experimental n, α data are given on pages 3-224, 3-226, 3-236 to 3-239, and 3-241 of UCRL-50400, Vol. 8, Rev. 1, Part A. Because these data are fragmentary, the evaluation (ANL/NDM-11) only included contributions from Ni^{58} and Ni^{60} . The evaluated n, α cross sections, which are shown in UCRL-50400, Vol. 15, Part B, were obtained in large part from nuclear systematics.

n, γ CROSS SECTION

Experimental neutron capture data for natural nickel are given on pages 3-150 to 3-153 (graphical) and 3-153 (tabular) of UCRL-50400, Vol. 7, Part A, Rev. 1; capture cross sections

for the isotopes Ni^{64} and Ni^{65} are given on pages 3-165 and 3-166. The evaluated capture cross sections (which are shown in UCRL-50400, Vol. 15, Part B) are based on the rather sparse experimental data, and are discussed in ANL/NDM-11.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,γ CROSS SECTION

Experimental n,γ cross sections for natural nickel are given on pages 3-197 to 3-201 (graphical) and on page

3-203 (tabular) of UCRL-50400, Vol. 8, Rev. 1, Part A; some graphical values for Ni^{58} are given on page 3-214. For neutron energies up to 4 MeV, the n,γ cross section was represented by contributions from eighteen discrete gamma-ray lines, which arise from the n,n' levels described above. For neutron energies between 4 and 20 MeV, the n,γ cross section was obtained from the experimental measurements of J. Dickens *et al.*, Oak Ridge National Laboratory Rept. ORNL-TM-4379 (1973). A description of the n,γ evaluation procedures is given in ANL/NDM-11.

SPECTRA OF PHOTONS FROM THE n,γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from experimental measurements, as outlined above and in ANL/NDM-11.

Copper

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural copper and its isotopes ^{63}Cu and ^{65}Cu are listed in UCRL-50400, Vol. 3. The evaluated data for natural copper are shown in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental total cross section data for natural copper are given in graphical form on pages 3-166 to 3-180 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on pages 3-183 and 3-184. Total cross sections for Cu^{63} are given on pages 3-185 and 3-187 of that reference, and total cross sections for Cu^{65} are given on pages 3-188, 3-189, and 3-191. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural copper are shown graphically on page 3-181 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 3-184. Elastic scattering cross sections for Cu^{63} and Cu^{65} are given on pages 3-188 and 3-191, respectively, of that volume. The evaluated elastic

cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the angular distributions were assumed to be isotropic for incident neutron energies below 100 keV. The evaluated elastic angular distributions were obtained from experimental data, supplemented at the higher energies by spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used *Phys. Rev.* 182, 1190 (1969) .

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering data for natural copper are given on page 3-247 of UCRL-50400, Vol. 8, Rev. 1, Part A; inelastic scattering data for Cu^{63} are given on pages 3-250 to 3-252 (graphical) and on page 3-262 (tabular); inelastic scattering data for Ni^{65} are given on page 3-265 (graphical) and on pages 3-271 and

Copper

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REACTION	POINT#	DATE	Q-VALUE	E-MIN	E-MAX
N ELASTIC	96	8/31/72	0.0000+ 0	1.0000-10	2.0000+ 1
N ANGULAR DIST.	21	2/20/76	0.0000- 0	5.0000- 2	2.0000+ 1
N ELASTIC	35	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N ELASTIC	35	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N CROSS SECTION	19	8/31/72	0.0000+ 0	6.8000- 1	2.0000+ 1
N ENERGY-ANGLE DIST.	13	7/13/77	0.0000+ 0	6.8000- 1	2.0000+ 1
N TOTAL ENERGY DEP.	20	12/03/76	0.0000+ 0	6.8000- 1	2.0000+ 1
N LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	6.8000- 1	2.0000+ 1
N CROSS SECTION	17	7/13/77	-9.9100+ 0	1.0063+ 1	2.0000+ 1
N ENERGY-ANGLE DIST.	8	7/13/77	-9.9100+ 0	1.0063+ 1	2.0000+ 1
N TOTAL ENERGY DEP.	5	12/03/76	-9.9100+ 0	1.0063+ 1	2.0000+ 1
N LOCAL ENERGY DEP.	4	12/03/76	-9.9100+ 0	1.0063+ 1	2.0000+ 1
N CROSS SECTION	18	7/13/77	-6.1200+ 0	7.7500+ 0	2.0000+ 1
N ENERGY-ANGLE DIST.	6	8/31/72	-6.1200+ 0	6.2200+ 0	2.0000+ 1
N TOTAL ENERGY DEP.	6	5/29/78	-6.1200+ 0	7.7500+ 0	2.0000+ 1
N LOCAL ENERGY DEP.	4	5/29/78	-6.1200+ 0	7.7500+ 0	2.0000+ 1
N CROSS SECTION	11	7/13/77	-5.7700+ 0	1.2000+ 1	2.0000+ 1
N ENERGY-ANGLE DIST.	7	7/13/77	-5.7700+ 0	1.2000+ 1	2.0000+ 1
N TOTAL ENERGY DEP.	5	5/29/78	-5.7700+ 0	1.2000+ 1	2.0000+ 1
N LOCAL ENERGY DEP.	3	5/29/78	-5.7700+ 0	1.2000+ 1	2.0000+ 1
N CROSS SECTION	17	7/13/77	7.2000- 1	1.0000+ 0	2.0000+ 1
N TOTAL ENERGY DEP.	2	5/29/78	7.2000- 1	1.0000+ 0	2.0000+ 1
N LOCAL ENERGY DEP.	2	5/29/78	7.2000- 1	1.0000+ 0	2.0000+ 1
N CROSS SECTION	10	7/13/77	1.7200+ 0	5.0000+ 0	2.0000+ 1
N TOTAL ENERGY DEP.	2	5/29/78	1.7200+ 0	5.0000+ 0	2.0000+ 1
N LOCAL ENERGY DEP.	2	5/29/78	1.7200+ 0	5.0000+ 0	2.0000+ 1
N CROSS SECTION	139	4/03/76	7.7500+ 0	1.0000-10	2.0000+ 1
N ENERGY DIST.	2	2/23/78	7.7500+ 0	1.0000-10	2.0000+ 1
N MULTIPLICITY	2	2/23/78	7.7500+ 0	1.0000-10	2.0000+ 1
N TOTAL ENERGY DEP.	2	11/21/76	7.7500+ 0	1.0000-10	2.0000+ 1
N LOCAL ENERGY DEP.	2	11/21/76	7.7500+ 0	1.0000-10	2.0000+ 1
N CROSS SECTION	14	2/23/78	0.0000+ 0	6.8000- 1	2.0000+ 1
N ENERGY-ANGLE DIST.	14	2/23/78	0.0000+ 0	6.8000- 1	2.0000+ 1

3-272 (tabular). The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions in the evaluation would be equally invalid because the uncertainties in the reaction cross section are so great. For energies below the onset of the preequilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 7 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The n,2n threshold in Cu⁶³ is

11.02 MeV, and the n,2n threshold in Cu⁶⁵ is 10.06 MeV. In the n,2n evaluation for natural copper, the threshold was set equal to 10.06 MeV. Experimental n,2n data for natural copper are given on page 3-247 of UCRL-50400, Vol. 8, Rev. 1, Part A; data for Cu⁶³ are given on pages 3-253 to 3-258 in graphical form; data for Cu⁶⁵ are given on pages 3-266 to 3-268 (graphical) and on page 3-272 (tabular). The n,2n evaluation was based primarily on the experimental data. Evaluated n,2n cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with nuclear systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,n'p CROSS SECTION

The thresholds for the n,n'p reaction in Cu⁶³ and Cu⁶⁵ are 6.22 MeV and 7.56 MeV, respectively. The threshold for the n,n'p reaction in natural copper was set equal to 6.22

MeV. Experimental n,n'p data for natural copper, for Cu⁶³, and for Cu⁶⁵, are given on pages 3-247, 3-263, and 3-273, respectively, of UCRL-50400, Vol. 8, Rev. 1, Part A. The evaluated n,n'p cross sections are based primarily on these experimental data. Evaluated n,n'p cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n'p CROSS SECTION

The angular distribution of secondary neutrons from the n,n'p reaction was assumed to be isotropic in the laboratory system. The energy distributions were obtained from temperature model calculations, using a rather "soft" (n,2n-type) temperature.

n,n'α CROSS SECTION

The only n,n'α experimental data for Cu⁶⁵ are listed on page 3-269 of UCRL-50400, Vol. 8, Rev. 1, Part A. In the evaluation, an effective n,n'α threshold of 12 MeV was used. The evaluated n,n'α cross sections, which were based primarily on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n'α REACTION

The angular distribution of the secondary neutrons from the n,n'α reaction was assumed to be isotropic

in the laboratory system. The energy distributions were obtained from temperature model calculations, in a manner similar to that used for the n,n'p cross sections.

n,p CROSS SECTION

The n,p cross section in natural copper is exoergic. In the evaluation, an effective n,p threshold of 1 MeV was used. Experimental n,p cross sections for natural copper are given on page 3-263 of UCRL-50400, Vol. 8, Rev. 1, Part A, and cross sections for Cu⁶⁵ are given on page 3-271 in graphical form and on pages 3-273 and 3-274 in tabular form. The evaluated n,p cross sections, which are based in part on the experimental data and in part on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n,α CROSS SECTION

The n,α cross section in copper is exoergic. In the evaluation, an effective n,α threshold of 5 MeV was used. Experimental n,α data for natural copper are given on page 3-264 of UCRL-50400, Vol. 8, Rev. 1, Part A, in tabular form; data for Cu⁶³ are given on pages 3-260 and 3-261 in graphical form; and data for Cu⁶⁵ are given on page 3-274 in tabular form. The evaluated n,α cross sections, which were based on a combination of the experimental data

and data derived from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural copper are given on pages 3-182 (graphical) and 3-184 (tabular) of UCRL-50400, Vol. 7, Part A, Rev. 1; values for Cu⁶³ are given on pages 3-186 and 3-187 (graphical) and 3-188 (tabular); values for Cu⁶⁵ are given on pages 3-190 and 3-191 (graphical) and 3-192 (tabular). The evaluated capture cross sections, which are based mainly on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 keV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,X γ CROSS SECTION

Experimental n,X γ cross sections for natural copper are given on pages 3-245 and 3-246 (graphical) and 3-248 (tabular) of UCRL-50400, Vol. 8, Rev. 1, Part A; cross sections for Cu⁶³ are given on pages 3-259 and 3-260 (graphical) and 3-263 (tabular); and cross sections for Cu⁶⁵ are given on pages 3-270 (graphical) and 3-273 (tabular). In the evaluation, these data were combined with calculations of the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated n,X γ cross section is represented as a continuum that has a threshold at 0.68 MeV.

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Gallium

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural gallium and for the isotopes $^{69}_{31}\text{Ga}$ and $^{71}_{31}\text{Ga}$ are listed in UCRL-50400, Vol. 3. The evaluated data for natural gallium are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental total cross section data for natural gallium are shown graphically on pages 4-1 and 4-2 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 4-4. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

There are no total elastic scattering cross sections for gallium. Thus, the evaluated elastic cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections. The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

A single elastic scattering cross section measurement, at 3.2 MeV, is

shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for neutron energies below 100 keV. At higher neutron energies, the angular distributions were obtained from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering data for gallium are limited to two sets of n, n' angular distributions, one for ^{69}Ga and one for ^{71}Ga . Information about n, n' cross sections can be extracted from these distributions. The n, n' angular distributions are shown graphically in UCRL-50400, Vol. 19. The evaluated inelastic scattering cross sections, which consist entirely of a continuum component, are shown graphically in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction

Gallium

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	49	9/04/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	9	1/03/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	29	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	29	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	18	9/04/72	0.0000+ 0	4.0000- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	12	9/04/72	0.0000+ 0	4.0000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	23	12/03/76	0.0000+ 0	4.0000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	18	12/03/76	0.0000+ 0	4.0000- 1	2.0000+ 1
N,2N	CROSS SECTION	9	9/04/72	-9.3000+ 0	9.4400+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	6	9/04/72	-9.3000+ 0	9.4400+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	8	12/03/76	-9.3000+ 0	9.4400+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	8	12/03/76	-9.3000+ 0	9.4400+ 0	2.0000+ 1
N,P	CROSS SECTION	5	9/04/72	-1.3000- 1	5.0000+ 0	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	5/29/78	-1.3000- 1	5.0000+ 0	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	5/29/78	-1.3000- 1	5.0000+ 0	2.0000+ 1
N,A	CROSS SECTION	7	9/04/72	2.5800+ 0	2.0000+ 0	2.0000+ 1
N,A	TOTAL ENERGY DEP.	2	5/29/78	2.5800+ 0	2.0000+ 0	2.0000+ 1
N,A	LOCAL ENERGY DEP.	2	5/29/78	2.5800+ 0	2.0000+ 0	2.0000+ 1
N,G	CROSS SECTION	371	9/04/72	6.9700+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	6.9700+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	6.9700+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.9700+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.9700+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	14	2/23/78	0.0000+ 0	4.0000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	14	2/23/78	0.0000+ 0	4.0000- 1	2.0000+ 1

portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 8 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 8 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model -- a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The n,2n threshold in Ga^{69} is 10.46 MeV, and the n,2n threshold in Ga^{71} is 9.44 MeV. In the n,2n evaluation for natural gallium, the threshold was set equal to 9.44 MeV. Experimental n,2n cross sections for natural gallium are shown graphically on pages 4-1 and 4-2 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular n,2n values for Ga^{69} are given on page 4-3; and graphical and tabular n,2n values for Ga^{71} are given on

pages 4-4 and 4-6, respectively. The evaluated n,2n cross sections for natural gallium, which were largely based on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,p CROSS SECTION

The n,p mass difference thresholds for Ga^{69} and Ga^{71} are 0.13 MeV and 2.05 MeV, respectively. In the n,p evaluation, an effective n,p threshold of 5 MeV was used. Experimental n,p cross sections for Ga^{69} are shown graphically on page 4-2 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabular values are given on pages 4-3 and 4-4. Experimental n,p cross sections for Ga^{71} are shown graphically on page 4-5 of that reference, and tabular values are given on page 4-6. The evaluated n,p cross sections, which are based primarily on the experimental data,

are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The n, α cross section in gallium is exoergic. In the evaluation, an effective n, α threshold of 2 MeV was assumed. Experimental n, α cross sections for Ga^{69} are shown in tabular form on page 4-4 of UCRL-50400, Vol. 8, Rev. 1, Part A; experimental n, α cross sections for Ga^{71} are shown graphically on page 4-5, and a single tabular value is given on page 4-7. The evaluated n, α cross sections, which were based both on the experimental data and on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural gallium are given on pages 4-3 (graphical) and 4-4 (tabular) of UCRL-50400, Vol. 7, Part A, Rev. 1; values for Ga^{69} are given on pages 4-4 and 4-5 (graphical) and 4-5 (tabular); values for Ga^{71} are given on page 4-6 (graphical and tabular). The evaluated capture cross sections for gallium, which are based mainly on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

$n, X\gamma$ CROSS SECTION

There are no experimental $n, X\gamma$ data for gallium. The evaluated $n, X\gamma$ cross sections were calculated with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated $n, X\gamma$ cross section is represented as a continuum that has a threshold at 0.4 MeV.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton, cited above.

Zirconium

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural zirconium and its various isotopes are listed in UCRL-50400, Vol. 3. The evaluated data for natural zirconium are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental total cross sections for natural zirconium are shown graphically on pages 4-63 to 4-71 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 4-75. Total cross sections for ^{90}Zr are shown on pages 4-76 and 4-77; total cross sections for ^{92}Zr are shown on pages 4-79 and 4-80; and total cross sections for ^{94}Zr are shown on page 4-81. The evaluated total cross sections, which are based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

A few elastic cross section data points for natural Zr are shown graphically on page 4-72 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 4-75. Single elastic data points for Zr^{90} , Zr^{92} , and Zr^{94} are listed on pages 4-78, 4-80, and 4-82,

respectively. The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B. In view of the scarcity of the experimental data, the evaluated elastic cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

An extensive series of elastic scattering differential cross section measurements for neutron energies up to 5 MeV and at 14 MeV are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for neutron energies below 10 keV. Between 10 keV and 5 MeV the evaluated elastic angular distributions were based on the experimental data. Above 5 MeV the elastic angular distributions were taken from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

The experimental n, n' data for natural zirconium are limited to a single point listed on page 5-37 of

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Zirconium

REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	916	9/04/73	0.0000+ 0	1.0000-10	2.0000+ 1	LEVEL = 9.1980- 1 MEV
ANGULAR DIST.	20	3/01/74	0.0000+ 0	1.0000- 2	2.0000+ 1	LEVEL = 9.1980- 1 MEV
TOTAL ENERGY DEP.	36	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	LEVEL = 9.1980- 1 MEV
LOCAL ENERGY DEP.	36	11/12/74	0.0000+ 0	1.0000-10	2.0000+ 1	LEVEL = 1.2100+ 0 MEV
CROSS SECTION	14	9/04/73	0.0000+ 0	2.0000+ 0	2.0000+ 1	LEVEL = 1.2100+ 0 MEV
ENERGY-ANGLE DIST.	9	9/04/73	0.0000+ 0	2.0000+ 0	2.0000+ 1	LEVEL = 1.2100+ 0 MEV
TOTAL ENERGY DEP.	9	15/03/76	0.0000+ 0	2.0000+ 0	2.0000+ 1	LEVEL = 1.2100+ 0 MEV
LOCAL ENERGY DEP.	9	15/03/76	0.0000+ 0	2.0000+ 0	2.0000+ 1	LEVEL = 1.2100+ 0 MEV
CROSS SECTION	27	9/04/73	0.0000+ 0	2.0000+ 0	2.0000+ 1	LEVEL = 1.3000+ 0 MEV
ANGULAR DIST.	2	9/04/73	0.0000+ 0	9.3000- 1	2.0001+ 0	LEVEL = 1.3000+ 0 MEV
TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	9.3000- 1	2.0001+ 0	LEVEL = 1.3000+ 0 MEV
LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	9.3000- 1	2.0001+ 0	LEVEL = 1.3000+ 0 MEV
CROSS SECTION	10	9/04/73	0.0000+ 0	1.2300+ 0	2.0001+ 0	LEVEL = 1.2100+ 0 MEV
ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.2300+ 0	2.0001+ 0	LEVEL = 1.2100+ 0 MEV
TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.2300+ 0	2.0001+ 0	LEVEL = 1.2100+ 0 MEV
LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.2300+ 0	2.0001+ 0	LEVEL = 1.2100+ 0 MEV
CROSS SECTION	12	9/04/73	0.0000+ 0	1.3200+ 0	2.0001+ 0	LEVEL = 1.3000+ 0 MEV
ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.3200+ 0	2.0001+ 0	LEVEL = 1.3000+ 0 MEV
TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.3200+ 0	2.0001+ 0	LEVEL = 1.3000+ 0 MEV
LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.3200+ 0	2.0001+ 0	LEVEL = 1.3000+ 0 MEV
CROSS SECTION	12	9/04/73	0.0000+ 0	1.4000+ 0	2.0001+ 0	LEVEL = 1.3800+ 0 MEV
ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.4000+ 0	2.0001+ 0	LEVEL = 1.3800+ 0 MEV
TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.4000+ 0	2.0001+ 0	LEVEL = 1.3800+ 0 MEV
LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.4000+ 0	2.0001+ 0	LEVEL = 1.3800+ 0 MEV
CROSS SECTION	10	9/04/73	0.0000+ 0	1.5000+ 0	2.0001+ 0	LEVEL = 1.4800+ 0 MEV
ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.5000+ 0	2.0001+ 0	LEVEL = 1.4800+ 0 MEV
TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.5000+ 0	2.0001+ 0	LEVEL = 1.4800+ 0 MEV
LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.5000+ 0	2.0001+ 0	LEVEL = 1.4800+ 0 MEV
CROSS SECTION	7	9/04/73	0.0000+ 0	1.5800+ 0	2.0001+ 0	LEVEL = 1.5600+ 0 MEV
ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.5800+ 0	2.0001+ 0	LEVEL = 1.5600+ 0 MEV
TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.5800+ 0	2.0001+ 0	LEVEL = 1.5600+ 0 MEV
LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.5800+ 0	2.0001+ 0	LEVEL = 1.5600+ 0 MEV
CROSS SECTION	6	9/04/73	0.0000+ 0	1.7700+ 0	2.0001+ 0	LEVEL = 1.7500+ 0 MEV
ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.7700+ 0	2.0001+ 0	LEVEL = 1.7500+ 0 MEV
TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.7700+ 0	2.0001+ 0	LEVEL = 1.7500+ 0 MEV
LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.7700+ 0	2.0001+ 0	LEVEL = 1.7500+ 0 MEV
CROSS SECTION	4	9/04/73	0.0000+ 0	1.8600+ 0	2.0001+ 0	LEVEL = 1.8534+ 0 MEV
ANGULAR DIST.	2	9/04/73	0.0000+ 0	1.8600+ 0	2.0001+ 0	LEVEL = 1.8534+ 0 MEV
TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.8600+ 0	2.0001+ 0	LEVEL = 1.8534+ 0 MEV
LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.8600+ 0	2.0001+ 0	LEVEL = 1.8534+ 0 MEV
CROSS SECTION	11	9/04/73	0.0000+ 0	7.5000+ 0	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
ANGULAR DIST.	11	9/04/73	0.0000+ 0	7.5000+ 0	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
TOTAL ENERGY DEP.	16	12/03/76	-7.5000+ 0	7.5000+ 0	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
LOCAL ENERGY DEP.	16	12/03/76	-7.5000+ 0	7.5000+ 0	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
CROSS SECTION	3	9/04/73	-1.4950+ 1	1.5110+ 1	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
ANGULAR DIST.	3	9/04/73	-1.4950+ 1	1.5110+ 1	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
TOTAL ENERGY DEP.	3	12/03/76	-1.4950+ 1	1.5115+ 1	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
LOCAL ENERGY DEP.	3	12/03/76	-1.4950+ 1	1.5115+ 1	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
CROSS SECTION	12	5/59/78	-7.6300- 1	1.7000+ 0	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
ANGULAR DIST.	12	5/59/78	-7.6300- 1	1.7000+ 0	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
TOTAL ENERGY DEP.	2	5/59/78	-7.6300- 1	1.7000+ 0	2.0000+ 1	LEVEL = 1.8534+ 0 MEV
LOCAL ENERGY DEP.	2	5/59/78	-7.6300- 1	1.7000+ 0	2.0000+ 1	LEVEL = 1.8534+ 0 MEV

Zirconium (Cont.)

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N.G	CROSS SECTION	1184	4/03/76	8.6800+ 0	1.0000-10	2.0000+ 1
N.G	G ENERGY DIST.	2	2/23/78	8.6800+ 0	1.0000-10	2.0000+ 1
N.G	G MULTIPLICITY	2	2/23/78	8.6800+ 0	1.0000-10	2.0000+ 1
N.G	TOTAL ENERGY DEP.	2	11/21/76	8.6800+ 0	1.0000-10	2.0000+ 1
N.G	LOCAL ENERGY DEP.	2	11/21/76	8.6800+ 0	1.0000-10	2.0000+ 1
N.XG	CROSS SECTION	14	2/23/78	0.0000+ 0	9.3000- 1	2.0000+ 1
N.XG	G ENERGY-ANGLE DIST.	14	2/23/78	0.0000+ 0	9.3000- 1	2.0000+ 1

UCRL-50400, Vol. 8, Rev. 1, Part B; however, extensive data exist for the separated isotopes of zirconium: n,n' data for Zr^{90} are shown on pages 5-39 to 5-44 (graphical) and on page 5-52 (tabular); n,n' data for Zr^{91} are shown on pages 5-55 to 5-60 (graphical) and on page 5-62 (tabular); n,n' data for Zr^{92} are shown on pages 5-63 to 5-76 (graphical) and on pages 5-80 and 5-81 (tabular); and n,n' data for Zr^{94} are shown on pages 5-82 to 5-89 (graphical) and on page 5-93 (tabular). The evaluated inelastic scattering cross sections for natural zirconium, which include contributions from eight discrete levels plus a continuum contribution, are shown graphically in UCRL-50400, Vol. 15, Part B. These evaluated inelastic cross sections are based on the very comprehensive experimental data.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For

energies below the onset of the pre-equilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 7 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n,2n$ CROSS SECTION

The evaluated $n,2n$ threshold was set equal to the 7.27-MeV $n,2n$ threshold for Zr^{91} . The other principle isotopes of Zr have somewhat higher $n,2n$ thresholds. The experimental $n,2n$ data for natural Zr are limited to two data points that are listed on page 5-37 of UCRL-50400, Vol. 8, Rev. 1, Part B; however, extensive $n,2n$ data for Zr^{90} are given on pages 5-45 to 5-47 (graphical) and on pages 5-52 and 5-53 (tabular), and a single $n,2n$ data point for Zr^{96} is given on page 5-95. The evaluated $n,2n$ data, which are based mainly on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

The evaluated n,3n threshold was set equal to the 15.11-MeV n,3n threshold for Zr^{94} . The other principle isotopes of Zr all have somewhat higher n,3n thresholds. Since there were no experimental data for the n,3n reaction in Zr, the evaluation was based on nuclear systematics. The evaluated n,3n cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures were used for the n,3n reaction as for the n,2n reaction described above.

n,p CROSS SECTION

An effective threshold for the n,p reaction in natural Zr was set equal to 1.7 MeV. Experimental n,p data for natural Zr are given on page 5-38

of UCRL-50400, Vol. 8, Rev. 1, Part B; n,p data for Zr^{90} are given on pages 5-50 and 5-51 (graphical) and on pages 5-53 and 5-54 (tabular); data for Zr^{91} are given on page 5-62 (graphical) and on page 5-63 (tabular); data for Zr^{92} are given on pages 5-81 and 5-82 (tabular); data for Zr^{94} are given on page 5-94 (tabular); and a single datum for Zr^{96} is given on page 5-95. The evaluated n,p cross sections, which are based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

n,γ CROSS SECTION

Experimental neutron capture cross sections for natural Zr are given on pages 4-73 and 4-74 (graphical) and on page 4-75 (tabular) of UCRL-50400, Vol. 7, Part A, Rev. 1. Neutron capture data for Zr^{90} are given on page 4-78; capture data for Zr^{91} are given on page 4-79; capture data for Zr^{92} are given on page 4-81; capture data for Zr^{94} are given on page 4-82; and capture data for Zr^{96} are given on page 4-83. The evaluated neutron capture cross sections for natural Zr, which were largely based on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the

measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,X γ CROSS SECTION

Experimental n,X γ data for Zr⁹⁰ are given on pages 5-48 to 5-50 (graphical) and on page 5-53 (tabular) of UCRL-50400, Vol. 8, Rev. 1, Part B. Data for Zr⁹¹ are given on page 5-61 (graphical) and on page 5-63 (tabular); data for Zr⁹² are given on pages 5-77 to 5-79 (graphical) and on page 5-81 (tabular); and data for Zr⁹⁴ are given on pages 5-90 to 5-92 (graphical) and on page 5-94 (tabular). The evaluated n,X γ cross sections

were obtained in part from these experimental data and in part from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated n,X γ cross section is represented as a continuum that has a threshold at 0.93 MeV.

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton, cited above.

Niobium-93

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{93}_{41}\text{Nb}$ are summarized in UCRL-50400, Vol. 3. The evaluated niobium data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was done by R. J. Howerton of Lawrence Livermore Laboratory and A. Smith, P. Guenther, and J. Whalen of Argonne National Laboratory. The evaluation is described in Argonne Rept. ANL/NDM-6. Some changes in the evaluated data were made by R. J. Howerton when this evaluation was inserted into the Livermore ENDL evaluated library.

TOTAL CROSS SECTION

Total cross section measurements for Nb^{93} are shown graphically on pages 5-1 to 5-10 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-15. Total cross section measurements for Nb^{94} are shown on page 5-16. The evaluated total cross sections are based on experimental data, supplemented at the highest neutron energies by model calculations. The evaluation procedures are described in detail in ANL/NDM-6.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering data for niobium are shown graphically on page 5-11 of

UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-15. The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B. Since the experimental elastic scattering cross sections do not cover the entire range of neutron energies, the evaluated elastic cross sections, in addition to using experimental data, were based partly on model calculations and partly on differences between evaluated total cross sections and the sums of evaluated nonelastic cross sections. The evaluation procedures are described in ANL/NDM-6.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Measurements of the elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering was assumed to be isotropic for neutron energies below 10 keV. At higher neutron energies, evaluated elastic angular distributions were obtained by fitting Legendre functions to the existing experimental data, and then using these fits as the basis for interpolating and extrapolating the available data. The procedures are described in ANL/NDM-6.

Niobium-93

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REACTION	POINTS	DATE	O-VALUE	E-MIN	E-MAX
N ELASTIC	1753	7/11/77	0.0000-0	1.0000-0	2.0000+1
N ELASTIC	32	5/25/74	0.0000-0	1.0000-2	2.0000+1
N ELASTIC	33	5/25/74	0.0000-0	1.0000-10	2.0000+1
N ELASTIC	33	5/25/74	0.0000+0	1.0000-10	2.0000+1
N ELASTIC	26	7/11/77	0.0000+0	2.5495+0	2.0000+1
N ELASTIC	13	7/05/77	0.0000+0	2.5495+0	2.0000+1
N ELASTIC	9	12/03/76	0.0000+0	2.5495+0	2.0000+1
N ELASTIC	21	5/25/74	0.0000+0	2.5495+0	2.0000+1
N ELASTIC	2	12/03/76	0.0000+0	2.9310-2	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	2.9310-2	6.0000+0
N ELASTIC	22	5/25/74	0.0000+0	7.4792-1	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	7.4792-1	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	7.4792-1	6.0000+0
N ELASTIC	22	5/25/74	0.0000+0	8.1867-1	6.0000+0
N ELASTIC	22	5/25/74	0.0000+0	8.1867-1	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	8.1867-1	6.0000+0
N ELASTIC	20	5/25/74	0.0000+0	9.6928-1	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	9.6928-1	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	9.6928-1	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.0815+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.0815+0	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	1.0815+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.0815+0	6.0000+0
N ELASTIC	17	5/25/74	0.0000+0	1.3292+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.3292+0	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	1.3292+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.3292+0	6.0000+0
N ELASTIC	15	5/25/74	0.0000+0	1.5039+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.5039+0	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	1.5039+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.5039+0	6.0000+0
N ELASTIC	16	5/25/74	0.0000+0	1.6919+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.6919+0	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	1.6919+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.6919+0	6.0000+0
N ELASTIC	16	5/25/74	0.0000+0	1.9678+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.9678+0	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	1.9678+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	1.9678+0	6.0000+0
N ELASTIC	15	5/25/74	0.0000+0	2.1821+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	2.1821+0	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	2.1821+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	2.1821+0	6.0000+0
N ELASTIC	12	5/25/74	0.0000+0	2.3595+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	2.3595+0	6.0000+0
N ELASTIC	2	5/25/74	0.0000+0	2.3595+0	6.0000+0
N ELASTIC	2	12/03/76	0.0000+0	2.3595+0	6.0000+0

Niobium-93 (Cont.)

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REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	LEVEL =	
N N' LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.3589+ 0	6.0000+ 0	2.3350+ 0 MEV	
N N' CROSS SECTION	2	5/25/74	0.0000+ 0	2.5495+ 0	6.0000+ 0	2.5190+ 0 MEV	
N N' ANGLE DIST.	2	5/25/74	0.0000+ 0	2.5495+ 0	6.0000+ 0	2.5190+ 0 MEV	
N N' TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.5495+ 0	6.0000+ 0	2.5190+ 0 MEV	
N N' LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.5495+ 0	6.0000+ 0	2.5190+ 0 MEV	
N N' CROSS SECTION	16	7/05/77	-8.8260+ 0	8.9218+ 0	2.0000+ 1		
N N' ENERGY-ANGLE DIST.	9	7/11/77	-8.8260+ 0	8.9218+ 0	2.0000+ 1		
N N' TOTAL ENERGY DEP.	10	12/03/76	-8.8260+ 0	8.9218+ 0	2.0000+ 1		
N N' LOCAL ENERGY DEP.	9	12/03/76	-8.8260+ 0	8.9218+ 0	2.0000+ 1		
N N' CROSS SECTION	5	7/05/77	-1.6718+ 1	1.6900+ 1	2.0000+ 1		
N N' ENERGY-ANGLE DIST.	3	12/03/76	-1.6718+ 1	1.6900+ 1	2.0000+ 1		
N N' LOCAL ENERGY DEP.	3	12/03/76	-1.6718+ 1	1.6900+ 1	2.0000+ 1		
N N' CROSS SECTION	6	5/25/74	-1.9460+ 0	1.9671+ 0	2.0000+ 1		
N N' A ENERGY-ANGLE DIST.	8	5/25/74	-1.9460+ 0	1.9671+ 0	2.0000+ 1		
N N' A TOTAL ENERGY DEP.	15	12/03/76	-1.9460+ 0	1.9671+ 0	2.0000+ 1		
N N' A LOCAL ENERGY DEP.	11	5/25/74	-1.9460+ 0	1.9671+ 0	2.0000+ 1		
N N' P CROSS SECTION	2	12/03/76	7.1900- 1	3.5000+ 0	2.0000+ 1		
N N' P TOTAL ENERGY DEP.	2	12/03/76	7.1900- 1	3.5000+ 0	2.0000+ 1		
N N' A CROSS SECTION	2	12/03/76	7.1900- 1	3.5000+ 0	2.0000+ 1		
N N' A TOTAL ENERGY DEP.	16	5/25/74	4.9140+ 0	4.5000+ 0	2.0000+ 1		
N N' G LOCAL ENERGY DEP.	2	12/03/76	4.9140+ 0	4.5000+ 0	2.0000+ 1		
N N' G CROSS SECTION	5174	5/25/74	7.2300+ 0	1.0000-10	2.0000+ 1		
N N' G ENERGY DIST.	2	2/23/78	7.2300+ 0	1.0000-10	2.0000+ 1		
N N' G MULTIPLICITY	2	2/23/78	7.2300+ 0	1.0000-10	2.0000+ 1		
N N' G TOTAL ENERGY DEP.	2	11/21/76	7.2300+ 0	1.0000-10	2.0000+ 1		
N N' G LOCAL ENERGY DEP.	2	11/21/76	7.2300+ 0	1.0000-10	2.0000+ 1		
N N' G CROSS SECTION	15	2/23/78	0.0000+ 0	2.9310- 2	2.0000+ 1		
N N' XG ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	2.9310- 2	2.0000+ 1		

INELASTIC SCATTERING CROSS SECTION

Inelastic scattering data for Nb⁹³ are given in graphical form on pages 6-2 to 6-15 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on pages 6-28 and 6-29. The evaluated n,n' cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated cross sections include contributions from twelve discrete levels plus a continuum component that starts at 2.55 MeV. The evaluation was based in large part on the experimental data; the evaluation procedures are discussed in ANL/NDM-6. Model calculations were used for certain portions of the inelastic region, such as in the determination of the shapes of the cross sections near threshold.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for the inelastically scattered neutrons were assumed to be isotropic. The energy distributions of the neutrons scattered from discrete levels were based on the kinematics of the reaction. The energy distributions for the continuum neutrons were obtained with a two-component model - a temperature component plus a direct-interaction and preequilibrium component. The evaluation procedures are discussed in ANL/NDM-6. The procedure

of assigning isotropic angular distributions to the continuum neutrons is incorrect, since the preequilibrium and direct-interaction components peak at forward angles for the higher neutron energies. But the uncertainties in the reaction cross sections are so large that the alternative of entering anisotropic angular distributions for the continuum neutrons into the evaluation would also be incorrect.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is 8.92 MeV. Experimental $n,2n$ data are shown graphically on pages 6-16 to 6-18 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 6-29. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The evaluated cross sections are based mainly on the experimental data. The evaluation procedures are described in ANL/NDM-6.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned

temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

The threshold for the n,3n reaction is 16.9 MeV. A single experimental n,3n data point is listed on page 6-29 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n,3n cross sections are shown in UCRL-50400, Vol. 15, Part B. This evaluation was based almost entirely on nuclear systematics, as described in ANL/NDM-6.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction was assumed to be isotropic in the laboratory system. The tabular energy distributions of secondary neutrons from this reaction were obtained by following the methods described for the n,2n reaction, taking into account the neutron multiplicity and the average neutron energy.

n,n' α CROSS SECTION

The threshold for this reaction is 1.96 MeV. Two experimental n,n' α data points are listed on page 6-30 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n,n' α cross sections are shown in UCRL-50400, Vol. 15,

Part B. These evaluated cross sections were based mainly on systematics, as described in ANL/NDM-6.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,n' α REACTION

The angular distribution of the neutrons from the n,n' α reaction was assumed to be isotropic in the laboratory system. The energy distributions were obtained from temperature model calculations, with an assumed energy-independent secondary neutron "temperature" of 0.5 MeV.

n,p CROSS SECTION

There are almost no measurements of the n,p reaction in niobium. Thus the n,p cross section was based on nuclear systematics, as described in ANL/NDM-6. The evaluated n,p cross sections are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The n, α cross section in niobium is exoergic. Experimental n, α data are shown on pages 6-26 and 6-27 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n, α cross sections are shown in UCRL-50400, Vol. 15, Part B. As discussed in ANL/NDM-6, these evaluated cross sections are based on the experimental data.

n, γ CROSS SECTION

Experimental neutron capture data for niobium are shown graphically on

pages 5-12 to 5-14 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-15. The evaluated neutron capture cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated cross sections are based on the experimental data. The evaluation procedures are discussed in ANL/NDM-6.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction. Above 20 MeV, photons from the capture reaction were subsumed into the total n,γ cross section.

n,γ CROSS SECTION

Experimental n,γ cross sections for niobium are shown graphically on

pages 6-18 to 6-26 of UCRL-50400, Vol. 8, Rev. 1, Part B; some graphical values are given on pages 6-30 and 6-31. Unfortunately, these measurements are not over a broad enough range and are not comprehensive enough to serve as the basis for the evaluation. Thus the evaluated n,γ cross sections were obtained from calculations of the NXCAMEL code, using the systematics developed by Perkins, Haight, and Howerton *Nucl. Sci. Eng.* 57, 1 (1975). The evaluated n,γ cross sections were represented as a continuum with a threshold at 29.3 keV. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n,γ PROCESS

The photon spectra associated with total photon production above 29.3 keV were calculated by using the NXCAMEL code mentioned above. The photon angular distributions were assumed to be isotropic.

Molybdenum

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural molybdenum and its various isotopes are listed in UCRL-50400, Vol. 3. The evaluated data for natural molybdenum are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental total cross sections for natural molybdenum are shown graphically on pages 5-17 to 5-27 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 5-32. Total cross sections for ^{92}Mo are shown on page 5-34; total cross sections for ^{94}Mo are shown on pages 5-35 and 5-36; total cross sections for ^{95}Mo are shown on page 5-37; total cross sections for ^{96}Mo are shown on pages 5-38 and 5-39; total cross sections for ^{98}Mo are shown on pages 5-41 and 5-42; and total cross sections for ^{100}Mo are shown on page 5-45. The evaluated total cross sections, which are based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural Mo are shown graphically on page 5-28 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values

are given on pages 5-32 and 5-33. Elastic cross sections for ^{92}Mo are shown on page 5-35; elastic cross sections for ^{94}Mo are given on pages 5-36 and 5-37; elastic cross sections for ^{96}Mo are given on pages 5-39 and 5-40; elastic cross sections for ^{98}Mo are shown on page 5-43; and elastic cross sections for ^{100}Mo are given on pages 5-46 and 5-48. The evaluated elastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated elastic cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections, with the experimental elastic scattering data used as a guide.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Elastic scattering differential cross section measurements for neutron energies up to 8 MeV and at 14 MeV are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for neutron energies up to 50 keV. Between 50 keV and 8 MeV the angular distributions were based on the experimental data. Above 8 MeV the elastic scattering angular distributions were taken from spherical optical model

Molybdenum

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	119	9/05/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	12	1/03/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	30	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	30	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	19	9/22/72	0.0000+ 0	2.5000- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	12	9/22/72	0.0000+ 0	2.5000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	16	12/03/76	0.0000+ 0	2.5000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	11	12/03/76	0.0000+ 0	2.5000- 1	2.0000+ 1
N,2N	CROSS SECTION	16	9/22/72	-7.8000+ 0	8.0000+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	9/22/72	-7.8000+ 0	8.0000+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	13	12/03/76	-7.8000+ 0	8.0000+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	8	12/03/76	-7.8000+ 0	8.0000+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	9/22/72	-1.4800+ 1	1.5000+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	4	9/22/72	-1.4800+ 1	1.5000+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	3	12/03/76	-1.4800+ 1	1.5000+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	3	12/03/76	-1.4800+ 1	1.5000+ 1	2.0000+ 1
N,G	CROSS SECTION	400	9/05/72	8.7500+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	8.7500+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	8.7500+ 0	1.0000-10	2.0000+ 1
N,G	G TOTAL ENERGY DEP.	2	11/21/76	8.7500+ 0	1.0000-10	2.0000+ 1
N,G	G LOCAL ENERGY DEP.	2	11/21/76	8.7500+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	2.5000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	2.5000- 1	2.0000+ 1

calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

The experimental n, n' data for natural molybdenum are shown graphically on pages 6-34 to 6-39 of UCRL-50400, Vol. 8, Rev. 1, Part A; some tabulated values are given on page 6-41. A single n, n' data point for Mo^{92} is given on page 6-47; n, n' data for Mo^{94} are given on pages 6-49 and 6-50; n, n' data for Mo^{96} are given on page 6-51; n, n' data for Mo^{98} are given on page 6-53; and n, n' data for Mo^{100} are given on pages 6-54 and 6-55. The evaluated inelastic scattering cross section for natural Mo is represented by a continuum contribution that has a threshold at 0.25 MeV, which is just above the energy of the first excited state in Mo^{95} . The evaluated inelastic continuum cross section, which is based on a combination of the experimental data and nuclear systematics, is shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this

assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation is also incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 8 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 8 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n, 2n$ CROSS SECTION

The dominant even-A isotopes in Mo have $n, 2n$ thresholds that are somewhat above 8 MeV, and the trace odd-A isotopes in Mo have thresholds that are generally below 8 MeV. Thus, 8 MeV was selected as an effective $n, 2n$ threshold for natural Mo. A single $n, 2n$ data point for natural Mo is given on page 6-41 of UCRL-50400, Vol. 8, Rev. 1, Part B; $n, 2n$ data for Mo^{92} are shown graphically on pages

6-43 to 6-55. Some tabular values are given on page 6-48; n,2n data for Mo⁹⁵ are given on page 6-56. The evaluated n,2n cross sections are shown in UCRL-50400, Vol. 15, Part B. Because of the scarcity of experimental data, these evaluated n,2n cross sections were determined, in part, from nuclear systematics.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

The Mo isotopes with $A \leq 98$ have n,3n thresholds above 15 MeV; the Mo isotopes with $A \geq 99$ have n,3n thresholds below 15 MeV. Thus, 15 MeV was selected as an effective n,3n threshold. Since there are no experimental n,3n data for Mo, the evaluated n,3n cross sections were determined entirely from nuclear systematics. The evaluated n,3n cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures were used for the n,3n reaction as for the n,2n reaction described above.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural Mo are given on pages 5-29 to 5-31 (graphical) and on page 5-33 (tabular) of UCRL-50400, Vol. 7, Part A, Rev. 1; neutron capture data for Mo⁹⁵ are given on page 5-38; neutron capture data for Mo⁹⁶ and Mo⁹⁷ are given on page 5-40; neutron capture data for Mo⁹⁸ are given on pages 5-43 to 5-45; and capture data for Mo¹⁰⁰ are given on pages 5-46 to 5-48. The evaluated neutron capture cross sections for natural Mo, which were largely based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,X γ CROSS SECTION

Experimental n,X γ data for natural Mo are given on page 6-40 (graphical) and on page 6-42 (tabular) of UCRL-50400, Vol. 8, Rev. 1, Part B. Since these are the only available n,X γ cross sections for Mo, the evaluated n,X γ cross sections were based, in part, on these experimental data and in part on calculations with the NKGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of

evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated n,X γ cross section is represented as a continuum that has a threshold at 0.25 MeV.

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Silver-107

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural silver and for $_{47}\text{Ag}^{107}$ are summarized in UCRL-50400, Vol. 3. The evaluated Ag^{107} data are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

In the evaluation for this isotope, values derived from ENDF/B MAT-1138 were used, although the elastic scattering and capture cross sections up to 1 keV were modified to some extent.

TOTAL CROSS SECTION

Total cross sections for natural silver are shown graphically on pages 5-74 to 5-83 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-90; tabular total cross section values for Ag^{107} are given on page 5-94. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural silver are given in graphical form on page 5-84 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-90. There are no measured elastic cross sections for Ag^{107} . The evaluated elastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B. As stated above, values of the elastic

scattering cross section for energies below 1 keV were derived from ENDF/B MAT-1138. Values for the evaluated elastic cross section above 1 keV were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections. At the highest energies, elastic scattering values were obtained from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Elastic scattering differential cross section measurements for neutron energies up to 6.7 MeV and at 14 MeV are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for neutron energies less than 10 keV. Above 10 keV, the elastic angular distributions were obtained from the experimental data and from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees, as described above.

INELASTIC SCATTERING CROSS SECTION

Experimental n, n' data for Ag^{107} are shown graphically on page 6-83 of

	REACTION	POINTS	DATE	D-VALUE	E-MIN	E-MAX
N. ELASTIC	CROSS SECTION	699	9/14/73	0.0000+0	1.0000-10	2.0000+1
N. ELASTIC	ANGULAR DIST.	18	3/13/74	0.0000+0	1.0000-10	2.0000+1
N. ELASTIC	TOTAL ENERGY DEP.	38	11/14/74	0.0000+0	1.0000-10	2.0000+1
N. ELASTIC	LOCAL ENERGY DEP.	38	11/14/74	0.0000+0	1.0000-10	2.0000+1
N. ELASTIC	CROSS SECTION	20	9/14/73	0.0000+0	9.4500-1	2.0000+1
N. ELASTIC	ENERGY-ANGLE DIST.	10	9/14/73	0.0000+0	9.4500-1	2.0000+1
N. ELASTIC	TOTAL ENERGY DEP.	12	12/03/76	0.0000+0	9.4500-1	2.0000+1
N. ELASTIC	LOCAL ENERGY DEP.	10	12/03/76	0.0000+0	9.4500-1	2.0000+1
N. ELASTIC	CROSS SECTION	27	9/14/73	0.0000+0	9.4000-2	8.5000+0
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	9.4000-2	8.5000+0
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	9.4000-2	8.5000+0
N. ELASTIC	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	9.4000-2	8.5000+0
N. ELASTIC	CROSS SECTION	29	9/14/73	0.0000+0	1.2100-1	8.5000+0
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	1.2100-1	8.5000+0
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.2100-1	8.5000+0
N. ELASTIC	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.2100-1	8.5000+0
N. ELASTIC	CROSS SECTION	28	9/14/73	0.0000+0	3.2500-1	MEV
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	3.2500-1	MEV
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	3.2500-1	MEV
N. ELASTIC	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	3.2500-1	MEV
N. ELASTIC	CROSS SECTION	22	9/14/73	0.0000+0	4.2300-1	MEV
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	4.2300-1	MEV
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	4.2300-1	MEV
N. ELASTIC	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	4.2300-1	MEV
N. ELASTIC	CROSS SECTION	19	9/14/73	0.0000+0	7.7000-1	MEV
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	7.7000-1	MEV
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	7.7000-1	MEV
N. ELASTIC	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	7.7000-1	MEV
N. ELASTIC	CROSS SECTION	16	9/14/73	0.0000+0	9.3100-1	MEV
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	9.3100-1	MEV
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	9.3100-1	MEV
N. ELASTIC	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	9.3100-1	MEV
N. ELASTIC	CROSS SECTION	12	9/14/73	0.0000+0	8.5000+0	LEVEL = 9.2200-1
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	8.5000+0	LEVEL = 9.2200-1
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	8.5000+0	LEVEL = 9.2200-1
N. ELASTIC	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	8.5000+0	LEVEL = 9.2200-1
N. ELASTIC	CROSS SECTION	6	9/14/73	0.0000+0	9.6209+0	2.0000+1
N. ELASTIC	ANGULAR DIST.	6	9/14/73	0.0000+0	9.6209+0	2.0000+1
N. ELASTIC	TOTAL ENERGY DEP.	6	12/03/76	0.0000+0	9.6209+0	2.0000+1
N. ELASTIC	LOCAL ENERGY DEP.	6	12/03/76	0.0000+0	9.6209+0	2.0000+1
N. ELASTIC	CROSS SECTION	7	12/03/76	0.0000+0	9.6209+0	2.0000+1
N. ELASTIC	ANGULAR DIST.	7	12/03/76	0.0000+0	9.6209+0	2.0000+1
N. ELASTIC	TOTAL ENERGY DEP.	7	12/03/76	0.0000+0	9.6209+0	2.0000+1
N. ELASTIC	LOCAL ENERGY DEP.	7	12/03/76	0.0000+0	9.6209+0	2.0000+1
N. ELASTIC	CROSS SECTION	2	9/14/73	0.0000+0	1.7650+1	2.0000+1
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	1.7650+1	2.0000+1
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.7650+1	2.0000+1
N. ELASTIC	LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.7650+1	2.0000+1
N. ELASTIC	CROSS SECTION	20	9/14/73	0.0000+0	4.5000+0	2.0000+1
N. ELASTIC	ANGULAR DIST.	2	9/14/73	0.0000+0	4.5000+0	2.0000+1
N. ELASTIC	TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	4.5000+0	2.0000+1

Silver-107 (Cont.)

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N.A	LOCAL ENERGY DEP.	2	5/29/78	4.1820+ 0	5.5000+ 0	2.0000+ 1
N.G	CROSS SECTION	870	4/03/76	7.2690+ 0	1.0000-10	2.0000+ 1
N.G	G ENERGY DIST.	2	2/23/78	7.2690+ 0	1.0000-10	2.0000+ 1
N.S	G MULTIPLICITY	2	2/23/78	7.2690+ 0	1.0000-10	2.0000+ 1
N.G	TOTAL ENERGY DEP.	2	11/21/76	7.2690+ 0	1.0000-10	2.0000+ 1
N.G	LOCAL ENERGY DEP.	2	11/21/76	7.2690+ 0	1.0000-10	2.0000+ 1
N.XG	CROSS SECTION	15	2/23/78	0.0000+ 0	9.4000- 2	2.0000+ 1
N.XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	9.4000- 2	2.0000+ 1

UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated inelastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B. These include six discrete levels plus a continuum contribution that starts at 0.945 MeV. The evaluated n, n' cross sections were obtained partly from the experimental data and partly from nuclear systematics.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 8 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "pre-equilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the

inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n, 2n$ CROSS SECTION

The threshold for the $n, 2n$ reaction in Ag^{107} is 9.63 MeV. Experimental $n, 2n$ data for Ag^{107} are shown graphically on pages 6-84 to 6-87 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabulated values are given on page 6-89. The evaluated $n, 2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated cross sections were based on the experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 2n$ REACTION

The angular distribution of secondary neutrons from the $n, 2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, page 24).

$n, 3n$ CROSS SECTION

The threshold for the $n, 3n$ reaction in Ag^{107} is 17.63 MeV. Experimental $n, 3n$ data for Ag^{107} are shown on page 6-88 of UCRL-50400, Vol. 8,

Rev. 1, Part B. The evaluated $n,3n$ cross sections, which are based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The same evaluation procedures were used for the $n,3n$ reactions as for the $n,2n$ reaction described above.

n,p CROSS SECTION

The n,p reaction in Ag^{107} is exo-ergic. There are no experimental data for this reaction. In the evaluation, an effective n,p threshold of 4.5 MeV was chosen. The evaluated n,p cross sections are shown in UCRL-50400, Vol. 15, Part B.

n,D CROSS SECTION

The threshold for the n,D reaction in Ag^{107} is 3.60 MeV. There are no experimental data for this reaction. In the evaluation, an effective threshold of 7.5 MeV was chosen. The evaluated n,D cross sections, which were based on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n,T CROSS SECTION

The threshold for the n,T reaction in Ag^{107} is 6.93 MeV. There are no experimental data for this reaction. In the evaluation, an effective threshold of 11.5 MeV was chosen.

The evaluated n,T cross sections, which were based on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n,α CROSS SECTION

The n,α reaction in Ag^{107} is exo-ergic. The experimental n,α data for Ag^{107} are limited to the single data point listed on page 6-89 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n,α cross sections, which were obtained from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n,γ CROSS SECTION

Experimental neutron capture cross sections for natural silver are shown graphically on pages 5-85 to 5-89 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabulated values are given on page 5-90. Graphical values of capture cross sections for Ag^{107} are shown on pages 5-91 to 5-93; some tabulated values are given on page 5-94. In the evaluation, the capture cross sections below 1 keV were taken from ENDF/B MAT-1138, as described above. Above 1 keV, the neutron capture cross sections were obtained from the experimental data and from nuclear systematics. The evaluated neutron capture cross sections for Ag^{107} are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n, γ CROSS SECTION

Experimental n, γ data for natural silver are shown on page 6-81 of UCRL-50400, Vol. 8, Rev. 1, Part B. Since these are the only available n, γ cross sections, the evaluated n, γ cross sections for Ag¹⁰⁷ were

obtained, in part, from these experimental data and in part from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton *Nucl. Sci. Eng.* 57 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated n, γ cross section is represented as a continuum that has a threshold at 0.094 MeV.

SPECTRA OF PHOTONS FROM THE n, γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Silver-109

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural silver and for $^{109}_{47}\text{Ag}$ are summarized in UCRL-50400, Vol. 3. The evaluated ^{109}Ag data are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

In the evaluation for ^{109}Ag , values derived from ENDF/B MAT-1139 were used, although the elastic scattering and capture cross sections up to 1 keV were modified to some extent.

TOTAL CROSS SECTION

Total cross sections for natural silver are shown graphically on pages 5-74 to 5-83 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on page 5-90. Graphical values of total cross sections for ^{109}Ag are shown on pages 5-94 and 5-95, and a single tabular value is given on page 5-98. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural silver are shown graphically on page 5-84 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-90. There are no experimental elastic cross

sections for ^{109}Ag . The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B. As stated above, the values below 1 keV were derived from ENDF/B MAT-1139. Values for the elastic cross section above 1 keV were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections. At the higher energies, elastic scattering cross sections were obtained from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used *Phys. Rev.* 182, 1190 (1969) .

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Elastic scattering differential cross section measurements for natural silver at incident neutron energies up to 6.7 MeV and at 14.6 MeV are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for neutron energies up to 10 keV. Above 10 keV, the elastic scattering angular distributions were derived from the experimental data and from optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees, as described above.

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INELASTIC SCATTERING CROSS SECTION

Experimental n,n' data for Ag^{109} are shown graphically on page 6-90 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated inelastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B. These include five discrete levels plus a continuum component that has a threshold at 0.71 MeV. The evaluated n,n' cross sections were obtained, in part, from the experimental data and in part from nuclear systematics.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at above 6 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model —

a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction in Ag^{109} is 9.27 MeV. Experimental $n,2n$ data for Ag^{109} are shown graphically on pages 6-91 and 6-92 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on pages 6-93 and 6-94. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated $n,2n$ cross sections were based on the experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

The threshold for the n,3n reaction in Ag^{109} is 16.61 MeV. There are no experimental data for this reaction. The evaluated n,3n cross sections, which are shown in UCRL-50400, Vol. 15, Part B, were based on nuclear systematics.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures were used for the n,3n reaction in Ag^{109} as for the n,2n reaction.

n,p CROSS SECTION

The threshold for the n,p reaction in Ag^{109} is 0.34 MeV. In the evaluation, an effective n,p threshold of 3.5 MeV was chosen. Experimental n,p data for Ag^{109} are shown graphically on pages 6-92 and 6-93 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 6-94. The evaluated n,p cross sections, which were based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The n, α reaction in Ag^{109} is exo-ergic. In the evaluation, an effective n, α threshold of 5.5 MeV was chosen. Experimental n, α cross sections for Ag^{109} are limited to the two data points shown on page 6-95 of UCRL-50400, Vol. 8, Rev. 1, Part B.

Thus the evaluated n, α cross sections for Ag^{109} , which are shown in UCRL-50400, Vol. 15, Part B, were obtained mainly from nuclear systematics.

n, γ CROSS SECTION

Experimental neutron capture cross sections for Ag^{109} are shown graphically on pages 5-96 and 5-97 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on pages 5-98 and 5-99. In the evaluation, the capture cross sections below 1 keV were derived from ENDF/B MAT-1159, as described above. Above 1 keV, the neutron capture cross sections were obtained from the experimental data and from nuclear systematics. The evaluated neutron capture cross sections for Ag^{109} are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,X γ CROSS SECTION

Experimental n,X γ data for natural silver are shown on page 6-81 of UCRL-50400, Vol. 8, Rev. 1, Part B. Since these are the only available n,X γ cross sections, the evaluated n,X γ cross sections for Ag¹⁰⁹ were obtained, in part, from these experimental data and in part from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton *Nucl. Sci. Eng.* 57, 1 (1975) . A summary of this method of evaluating photon production

data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated n,X γ cross section is represented as a continuum that has a threshold at 0.089 MeV.

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Cadmium

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural cadmium and its various isotopes are listed in UCRL-50400, Vol. 3. The evaluated data for natural cadmium are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental total cross sections for natural cadmium are shown graphically on pages 5-99 to 5-106 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular experimental values are given on page 5-110. The evaluated total cross sections, which are based on these experimental data, are shown in UCRL-50400, Vol. 5, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural Cd are shown graphically on page 5-107 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-110. The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B. The evaluated elastic cross sections at incident neutron energies up to a few MeV were taken directly from the experimental data. The evaluated elastic cross sections at the higher energies were obtained by taking

differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections, with a few high-energy data points serving as a guide.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Elastic scattering differential cross section measurements for neutron energies up to 8 MeV and at 14 MeV are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for neutron energies up to 50 keV. Between 50 keV and 8 MeV the angular distributions were based on the experimental data. Above 8 MeV the elastic scattering angular distributions were taken from spherical optical model calculations in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

The experimental n,n' data for natural cadmium are shown graphically on pages 6-97 and 6-98 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 6-101. Experimental n,n' data for the various isotopes of cadmium are given on pages 6-106 to 6-110 and 6-113 to 6-123. The evaluated inelastic

Cadmium

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	37	9/25/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	14	5/02/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	32	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	32	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	15	9/25/72	0.0000+ 0	2.5000- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	10	9/25/72	0.0000+ 0	2.5000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	20	12/03/76	0.0000+ 0	2.5000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	14	12/03/76	0.0000+ 0	2.5000- 1	2.0000+ 1
N,2N	CROSS SECTION	15	9/25/72	-8.6200+ 0	8.7500+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	6	9/25/72	-8.6200+ 0	8.7500+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	9	12/03/76	-8.6200+ 0	8.7500+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	5	12/03/76	-8.6200+ 0	8.7500+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	9/25/72	-1.6150+ 1	1.6350+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	3	9/25/72	-1.6150+ 1	1.6350+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	3	12/03/76	-1.6150+ 1	1.6350+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	3	12/03/76	-1.6150+ 1	1.6350+ 1	2.0000+ 1
N,G	CROSS SECTION	1030	9/25/72	9.0400+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	9.0400+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	9.0400+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	9.0400+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	9.0400+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	2.5000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	2.5000- 1	2.0000+ 1

scattering cross section for natural cadmium is represented by a continuum contribution that has a threshold at 0.25 MeV. This evaluated cross section, which is based on a combination of the experimental data and nuclear systematics, is shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 8 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 8 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model -- a "temperature" component plus a "pre-equilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the

inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The n,2n threshold for natural cadmium was set equal to 8.75 MeV, which is the average over the n,2n threshold for the various isotopes of cadmium. Some n,2n data for natural Cd are given on page 6-101 of UCRL-50400, Vol. 8, Rev. 1, Part B; n,2n data for the various isotopes of Cd are given on pages 6-103 to 6-106, 6-110, 6-111, and 6-123 to 6-125. The evaluated n,2n data are shown in UCRL-50400, Vol. 15, Part B. These evaluated data were based on a combination of the experimental data and nuclear systematics.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distributions of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The n,3n threshold for natural Cd was set equal to 16.35 MeV, which is the average of all the n,3n thresholds for the various isotopes of Cd. Since there are no experimental data for this reaction, the evaluation was based on nuclear systematics. The evaluated n,3n cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures were used for the n,3n reaction as for the n,2n reaction described above.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural Cd are shown graphically on pages 5-108 and 5-109 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-110. The evaluated capture cross sections, which were based partly on these experimental data and partly on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248

(1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,X γ CROSS SECTION

Experimental n,X γ cross sections for natural Cd are shown in graphical form on pages 6-99 and 6-100 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 6-102. The evaluated n,X γ cross sections were obtained, in part, from these experimental data and in part from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated n,X γ cross section is represented as a continuum that has a threshold at 0.25 MeV.

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Tin

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural tin and its various isotopes are listed in UCRL-50400, Vol. 3. The evaluated data for natural tin are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental total cross sections for natural tin are shown graphically on pages 5-133 to 5-138 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on pages 5-140 and 5-141. Experimental total cross sections for the various isotopes of tin are given on pages 5-142 to 5-149. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B. These evaluated total cross sections are based on the experimental data, and the resonance peaks in the evaluated data were taken from fits to the data set ECSIL-862.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural Sn are shown graphically on page 5-139 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-141. A single elastic scattering data point for

Sn^{118} is given on page 5-145. The evaluated elastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B. In the region of 1 MeV, the evaluated cross sections were based on the experimental data, but at lower end higher energies the cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Elastic scattering differential cross section measurements for neutron energies up to 7.5 MeV and at 14 MeV are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic scattering angular distributions were assumed to be isotropic for neutron energies up to 80 keV. Between 80 keV and 7.5 MeV the angular distributions were based on the experimental data. Above 7.5 MeV the elastic scattering angular distributions were taken from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

The experimental n, n' data for

Tin

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	84	2/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	14	4/05/76	0.0000+ 0	8.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	36	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	36	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	16	10/02/72	0.0000+ 0	7.5000- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	12	7/11/77	0.0000+ 0	7.5000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	13	12/03/76	0.0000+ 0	7.5000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	9	12/03/76	0.0000+ 0	7.5000- 1	2.0000+ 1
N,2N	CROSS SECTION	14	10/03/72	-9.3000+ 0	9.5000+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	9	7/11/77	-9.3000+ 0	9.5000+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	7	12/03/76	-9.3000+ 0	9.5000+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	5	12/03/76	-9.3000+ 0	9.5000+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	7/11/77	-1.5000+ 1	1.5127+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	10/03/72	-1.5000+ 1	1.5127+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	3	12/03/76	-1.5000+ 1	1.5127+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	3	12/03/76	-1.5000+ 1	1.5127+ 1	2.0000+ 1
N,G	CROSS SECTION	70	10/02/72	9.3500+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	9.3500+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	9.3500+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	9.3500+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	9.3500+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	7.5000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	7.5000- 1	2.0000+ 1

natural tin are limited to two data points listed on page 6-147 of UCRL-50400, Vol. 8, Rev. 1, Part B; however, some n,n' data for isotopes of tin are given on pages 6-151, 6-152, 6-155, 6-158, and 6-159. Due to the scarcity of experimental data, the evaluated n,n' cross sections were represented by a continuum cross section with a threshold at 0.75 MeV. The evaluated n,n' cross sections, which were obtained largely from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. At 10 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature"

component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22. For neutron energies above 10 MeV, the energy distributions for inelastic scattering were only characterized by the preequilibrium and direct-interaction components of the spectrum.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction in tin was set equal to 9.5 MeV, which is the effective average of all thresholds for the various isotopes of tin. The experimental $n,2n$ data for tin are limited to a single data point given on page 6-147 of UCRL-50400, Vol. 8, Rev. 1, Part B; however, rather extensive data for Sn^{112} are given on pages 6-148 to 6-150. Data for other isotopes of tin are given on pages 6-151, 6-155, 6-156, and 6-158 to 6-160. The evaluated $n,2n$ cross sections, which were based on a combination of the experimental data and nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$

reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The $n,3n$ threshold in natural tin was set equal to 15.13 MeV, which is the effective average of all thresholds for the various isotopes of tin. Since there are no experimental data for this reaction, the evaluated $n,3n$ cross sections were obtained from nuclear systematics. The evaluated $n,3n$ cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The same evaluation procedures were used for the $n,3n$ reaction as for the $n,2n$ reaction described above.

n,γ CROSS SECTION

Experimental neutron capture cross sections for natural tin are shown graphically on page 5-140 of UCRL-50400, Vol. 7, Part A, Rev. 1; some tabular values are given on page 5-141. Experimental capture cross sections for the various isotopes of tin are given on pages 5-142 to 5-149, in graphical and tabular forms. The

evaluated neutron capture cross sections, which were based partly on these experimental data and partly on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

$n,X\gamma$ CROSS SECTION

A few experimental $n,X\gamma$ cross sections for natural tin are listed on page 6-147 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated $n,X\gamma$ cross sections were obtained, in part, from these experimental data and, in part, from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated $n,X\gamma$ cross section is represented as a continuum that has a threshold at 0.75 MeV.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$
PROCESS

The photon angular distributions were assumed to be isotropic. The

photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Barium-138

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural Ba and its various isotopes are listed in UCRL-50400, Vol. 3. The evaluated data for Ba¹³⁸ are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Total cross section data for natural Ba are shown graphically on pages 7-1 to 7-3 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 7-4. There are no experimental data for the separate isotopes of barium. The evaluated total cross sections for Ba¹³⁸ are shown in UCRL-50400, Vol. 15, Part B. These evaluated total cross sections were based on the experimental data for natural Ba, in particular on ECSIL data sets ECSIL-498, ECSIL-728, ECSIL-748, and ECSIL-750.

ELASTIC SCATTERING CROSS SECTION

A few elastic scattering data points for natural barium are listed on page 7-4 of UCRL-50400, Vol. 7, Part B, Rev. 1. The evaluated elastic cross sections for Ba¹³⁸ are shown graphically in UCRL-50400, Vol. 15, Part B. In view of the scarcity of experimental data, the evaluated

elastic cross sections for Ba¹³⁸ were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Elastic scattering differential cross section measurements on natural barium for neutron energies up to 5 MeV and at 14 MeV are shown in UCRL-50400, Vol. 19. The evaluated elastic scattering angular distributions were assumed to be isotropic for neutron energies below 100 keV. Above 100 keV, the angular distributions were obtained from the available experimental data and from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Experimental n,n' data for natural barium are listed on page 7-45 of UCRL-50400, Vol. 8, Rev. 1, Part B; data for Ba¹³⁷ and Ba¹³⁸ are given on pages 7-46 and 7-47. In view of the scarcity of the experimental data, the evaluated n,n' cross sections were represented by a continuum cross section with a threshold at 1.44 MeV. These evaluated n,n' cross sections,

Barium-138

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	104	2/27/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST	13	1/03/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	35	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	35	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	20	10/03/72	0.0000+ 0	1.4400+ 0	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	11	10/03/72	0.0000+ 0	1.4400+ 0	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	14	12/03/76	0.0000+ 0	1.4400+ 0	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	13	12/03/76	0.0000+ 0	1.4400+ 0	2.0000+ 1
N,2N	CROSS SECTION	13	10/03/72	-8.5700+ 0	8.6500+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	10/03/72	-8.5700+ 0	8.6500+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	11	12/03/76	-8.5700+ 0	8.6500+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	7	12/03/76	-8.5700+ 0	8.6500+ 0	2.0000+ 1
N,3N	CROSS SECTION	6	10/03/72	-1.5520+ 1	1.5650+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	4	10/03/72	-1.5520+ 1	1.5650+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	3	12/03/76	-1.5520+ 1	1.5650+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	3	12/03/76	-1.5520+ 1	1.5650+ 1	2.0000+ 1
N,P	CROSS SECTION	4	10/03/72	-4.0400+ 0	6.0000+ 0	2.0000+ 1
N,P	TOTAL ENERGY DEP.	2	5/29/78	-4.0400+ 0	6.0000+ 0	2.0000+ 1
N,P	LOCAL ENERGY DEP.	2	5/29/78	-4.0400+ 0	6.0000+ 0	2.0000+ 1
N,A	CROSS SECTION	5	10/03/72	3.8700+ 0	2.2500+ 0	2.0000+ 1
N,A	TOTAL ENERGY DEP.	2	5/29/78	3.8700+ 0	2.2500+ 0	2.0000+ 1
N,A	LOCAL ENERGY DEP.	2	5/29/78	3.8700+ 0	2.2500+ 0	2.0000+ 1
N,G	CROSS SECTION	121	4/03/76	4.7100+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	4.7100+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	4.7100+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	4.7100+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	4.7100+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	1.4400+ 0	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	1.4400+ 0	2.0000+ 1

which were obtained mainly from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct interaction portions of the reaction, the alternative of entering anisotropic angular distributions in the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 7 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model - a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The n,2n threshold for Ba¹³⁸ is

8.65 MeV. Experimental n,2n cross sections for Ba¹³⁸ are given on page 7-48 of UCRL-50400, Vol. 8, Rev. 1, Part B. The n,2n cross sections for Ba¹³², Ba¹³⁴, and Ba¹³⁶ are given on pages 7-45 and 7-46. The evaluated n,2n cross sections, which are based on a combination of experimental data and nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The n,3n threshold in Ba¹³⁸ is 15.65 MeV. There are no experimental data for this reaction. The evaluated n,3n cross sections, which were based on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures were used for the n,3n reaction as for the n,2n reaction described above.

n,p CROSS SECTION

An effective threshold of 6 MeV was chosen for the n,p reaction in Ba¹³⁸. Experimental n,p data for Ba¹³⁸ are listed on page 7-48 of UCRL-50400, Vol. 8, Rev. 1, Part B; some n,p data for Ba¹³⁶ are listed on page 7-46. The evaluated n,p cross sections, which were based on these experimental data and on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n,α CROSS SECTION

The n,α reaction in Ba¹³⁸ is exo-ergic. In the evaluation, an effective n,α threshold of 2.25 MeV was chosen. Experimental n,α data for Ba¹³⁸ are listed on page 7-49 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n,α cross sections, which were based on a combination of experimental data and nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n,γ CROSS SECTION

Experimental neutron capture cross sections for Ba¹³⁸ are shown graphically on page 7-7 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 7-8. Some capture cross sections for natural barium are given on page 7-4. The evaluated neutron capture cross sections, which were based partly on the

experimental data and partly on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,Xγ CROSS SECTION

There are no experimental n,Xγ data for barium. In the evaluation, the n,Xγ cross section was represented by a continuum with a threshold at 1.44 MeV. The evaluated n,Xγ cross sections were obtained from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n,Xγ PROCESS

The photon angular distributions were assumed to be isotropic. The

photon energy distributions were obtained from the systematics of

Perkins, Haight, and Howerton cited above.

Europium

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for natural europium and its various isotopes are listed in UCRL-50400, Vol. 3. The evaluated data for natural Eu are shown graphically in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Total cross section data for natural Eu are shown graphically on pages 8-16 and 8-17 of UCRL-50400, Vol. 7, Part B, Rev. 1; a tabulated data point is given on page 8-20. Total cross sections for Eu^{151} and Eu^{153} are given on pages 8-21 to 8-23, 8-25, and 8-26. The evaluated total cross sections, which were based on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

There are no elastic scattering data for Eu. Thus the evaluated elastic cross sections, which are shown in UCRL-50400, Vol. 15, Part B, were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Since there are no elastic scat-

tering differential cross section measurements for europium, the evaluated elastic scattering angular distributions were obtained from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenless were used [*Phys. Rev.* 182, 1190 (1969)]. In the evaluation, the elastic angular distributions were assumed to be isotropic for neutron energies below 0.5 MeV.

INELASTIC SCATTERING CROSS SECTION

There are no experimental n, n' data for europium. Thus the evaluated n, n' cross sections, which were obtained from nuclear systematics, were represented as a continuum component with a threshold energy of 30 keV. These evaluated n, n' cross sections are shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation

Europium

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REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	38	1/03/75	0.0000+ 0	1.0000-10	2.0000+ 1
CROSS SECTION	8	1/03/72	0.0000+ 0	5.0000- 1	2.0000+ 1
ANGULAR DIST.	26	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	26	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
CROSS SECTION	25	10/03/72	0.0000+ 0	3.0000- 2	2.0000+ 1
LOCAL ENERGY DEP.	12	10/03/72	0.0000+ 0	3.0000- 2	2.0000+ 1
N,N'	22	12/03/76	0.0000+ 0	3.0000- 2	2.0000+ 1
ENERGY-ANGLE DIST.	14	12/03/76	0.0000+ 0	3.0000- 2	2.0000+ 1
N,N'	15	10/03/72	-8.2700+ 0	8.3500- 0	2.0000+ 1
LOCAL ENERGY DEP.	7	10/03/72	-8.2700+ 0	8.3500- 0	2.0000+ 1
CROSS SECTION	11	12/03/76	-8.2700+ 0	8.3500- 0	2.0000+ 1
ANGULAR DIST.	6	12/03/76	-1.4500+ 1	1.5000- 1	2.0000+ 1
N,ELASTIC	5	10/03/72	-1.4500+ 1	1.5000- 1	2.0000+ 1
CROSS SECTION	3	10/03/72	-1.4500+ 1	1.5000- 1	2.0000+ 1
LOCAL ENERGY DEP.	262	10/03/75	5.2600+ 0	1.0000-10	2.0000+ 1
N,N'	2	2/23/78	5.2600+ 0	1.0000-10	2.0000+ 1
ENERGY DIST.	2	2/23/78	5.2600+ 0	1.0000-10	2.0000+ 1
CROSS SECTION	2	11/21/76	5.2600+ 0	1.0000-10	2.0000+ 1
LOCAL ENERGY DEP.	2	11/21/76	5.2600+ 0	1.0000-10	2.0000+ 1
N,N'	15	2/23/78	0.0000+ 0	3.0000- 2	2.0000+ 1
CROSS SECTION	15	2/23/78	0.0000+ 0	3.0000- 2	2.0000+ 1
ENERGY-ANGLE DIST.					

would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 7 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model - a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The threshold for the n,2n reaction in natural Eu was set equal to 8.35 MeV, which is the average threshold value for the isotopes Eu^{151} and Eu^{153} . Experimental n,2n data for these two isotopes are given on pages 8-11 and 8-12 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n,2n cross sections, which were based on a combination of experimental data and nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of

secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The threshold for the n,3n reaction in natural Eu was set equal to 15 MeV, which is a representative value for the various isotopes of Eu. There are no experimental data for this reaction, so the evaluated n,3n cross sections were obtained entirely from nuclear systematics. These evaluated n,3n cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures were used for the n,3n reaction as for the n,2n reaction described above.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural Eu are shown graphically on pages 8-18 and 8-19 of UCRL-50400, Vol. 3, Rev. 2; some tabular values are given on page 8-20. Capture cross sections for Eu^{151} are given on pages 8-23 to 8-25, and

capture cross sections for Eu^{153} are given on page 8-27. The evaluated neutron capture cross sections, which were obtained from experimental data and nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

$n, X\gamma$ CROSS SECTION

There are no experimental $n, X\gamma$

data for europium. In the evaluation, the $n, X\gamma$ cross section was represented by a continuum with a threshold at 30 keV. The evaluated $n, X\gamma$ cross sections were obtained from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Gadolinium

DATA SUMMARY AND GENERAL COMMENTS

References to the experimental data for natural gadolinium and its various isotopes are listed in UCRL-50400, Vol. 3, Rev. 2. The evaluated data for natural Gd are shown in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Total cross section data for natural Gd are shown graphically on pages 8-28 to 8-34 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 8-37. Total cross sections for isotopes of Gd are given on pages 8-39 to 8-42. The evaluated total cross sections, which were based on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering data for natural Gd are shown on page 8-35 of UCRL-50400, Vol. 7, Part B, Rev. 1. In view of the scarcity of experimental data, the evaluated elastic cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental elastic scattering differential cross section measurements for Gd are limited to the energy range between 1 and 3.6 MeV. Thus the evaluated elastic scattering angular distributions were obtained primarily from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)]. In the evaluation, the elastic angular distributions were assumed to be isotropic for neutron energies below 0.5 MeV.

INELASTIC SCATTERING CROSS SECTION

Experimental n, n' data for natural Gd are shown graphically on pages 8-13 and 8-14 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 8-15. Experimental n, n' data for Gd^{160} are shown on pages 8-17 to 8-22. The evaluated n, n' cross sections, which were obtained from experimental data and nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B. These data are represented as a continuum component that has threshold at 30 keV.

Gadolinium

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	178	2/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	8	1/03/72	0.0000+ 0	5.0000- 1	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	26	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	26	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	21	10/03/72	0.0000+ 0	3.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	13	10/03/72	0.0000+ 0	3.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	19	12/03/76	0.0000+ 0	3.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	12	12/03/76	0.0000+ 0	3.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	13	10/03/72	-6.3700+ 0	6.4109+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	8	10/03/72	-6.3700+ 0	6.4109+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	15	12/03/76	-6.3700+ 0	6.4109+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	11	12/03/76	-6.3700+ 0	6.4109+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	10/03/72	-1.3400+ 1	1.3500+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	4	10/03/72	-1.3400+ 1	1.3500+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.3400+ 1	1.3500+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.3400+ 1	1.3500+ 1	2.0000+ 1
N,G	CROSS SECTION	358	4/03/76	8.0400+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	8.0400+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	8.0400+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	8.0400+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	8.0400+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	3.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	3.0000- 2	2.0000+ 1

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 7 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The n,2n threshold for natural Gd was set equal to 6.41 MeV, which is the n,2n threshold for Gd¹⁵⁷. The experimental n,2n data for Gd are

limited to a single data point for Gd¹⁵⁴ (which is listed on page 8-16 of UCRL-50400, Vol. 8, Rev. 1, Part B) and some data points for Gd¹⁶⁰, which are listed on page 8-22. The evaluated n,2n data for natural Gd, which were obtained mainly from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The n,3n threshold for natural Gd was set equal to 13.5 MeV, which is the n,3n threshold in Gd¹⁶⁰. There are no experimental data for this reaction. The evaluated n,3n cross sections, which were based on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures were

used for the $n,3n$ reaction as for the $n,2n$ reaction described above.

n,γ CROSS SECTION

Experimental neutron capture cross sections for natural Gd are shown graphically on page 8-36 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 8-37. Experimental neutron capture cross sections for the various isotopes of Gd are given on pages 8-38 to 8-44 of that reference. The evaluated neutron capture cross sections for natural Gd, which were taken in part from the experimental data and in part from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon

multiplicity was adjusted so as to conserve the total energy of the reaction.

$n,X\gamma$ CROSS SECTION

There are no experimental $n,X\gamma$ data for gadolinium. In the evaluation, the $n,X\gamma$ cross section was represented by a continuum with a threshold at 30 keV. The evaluated $n,X\gamma$ cross sections were obtained from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE $n,X\gamma$ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Holmium-165

DATA SUMMARY AND GENERAL COMMENTS

References to the experimental data for $^{165}_{67}\text{Ho}$ are listed in UCRL-50400, Vol. 3. The evaluated Ho^{165} data are shown in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Total cross section data for Ho^{165} are shown graphically on pages 8-60 to 8-70 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 8-75. The evaluated total cross sections, which were based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering data are shown on page 8-71 of UCRL-50400, Vol. 7, Part B, Rev. 1. The evaluated elastic cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections, with the experimental elastic cross sections used as a guide. The data are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental elastic scattering differential cross sections for Ho^{165}

are limited to the energy range between 0.35 and 1 MeV. Thus the evaluated elastic scattering angular distributions were obtained primarily from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* **182**, 1190 (1969)]. In the evaluation, the elastic angular distributions were assumed to be isotropic for neutron energies below 200 keV.

INELASTIC SCATTERING CROSS SECTION

Experimental n, n' data for Ho^{165} are shown graphically on pages 8-28 to 8-31 of UCRL-50400, Vol. 8, Rev. 1, Part B; a single tabular value is given on page 8-32. The evaluated n, n' data, which were based on a combination of experimental data and nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B. These data are represented as a continuum component that has a threshold at 95 keV.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction

Holmium-165

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	3372	7/02/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	13	1/03/72	0.0000+ 0	2.0000- 1	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	28	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	28	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	20	10/03/72	0.0000+ 0	9.5000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	14	10/03/72	0.0000+ 0	9.5000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	19	12/03/76	0.0000+ 0	9.5000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	13	12/03/76	0.0000+ 0	9.5000- 2	2.0000+ 1
N,2N	CROSS SECTION	16	10/03/72	-7.9900+ 0	8.0400+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	8	10/03/72	-7.9900+ 0	8.0400+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	13	12/03/76	-7.9900+ 0	8.0400+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	9	12/03/76	-7.9900+ 0	8.0400+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	10/03/72	-1.4670+ 1	1.4800+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	10/03/72	-1.4670+ 1	1.4800+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.4670+ 1	1.4800+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.4670+ 1	1.4800+ 1	2.0000+ 1
N,G	CROSS SECTION	4662	7/02/76	6.2400+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	6.2400+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	6.2400+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.2400+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.2400+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	9.5000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	9.5000- 2	2.0000+ 1

portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 7 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The n,2n threshold in Ho^{165} is 8.04 MeV. Experimental n,2n cross section data are given graphically on page 8-32 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 8-33. The evaluated n,2n cross sections, which were based on these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of

secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The threshold for the n,3n reaction in Ho^{165} is 14.8 MeV. There are no experimental data for this reaction. The evaluated n,3n cross sections, which were based entirely on nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures used for the n,2n reaction described above were used for the n,3n reaction.

n, γ CROSS SECTION

Experimental neutron capture cross sections for Ho^{165} are shown graphically on pages 8-72 to 8-74 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on pages 8-75 and 8-76. The evaluated neutron capture cross sections, which were based on the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

$n,X\gamma$ CROSS SECTION

There are no experimental $n,X\gamma$ data for Ho^{165} . In the evaluation, the $n,X\gamma$ cross section was represented by a continuum with a threshold at

95 keV. The evaluated $n,X\gamma$ cross sections were obtained from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE $n,X\gamma$ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Tantalum-181

DATA SUMMARY AND GENERAL COMMENTS

References to the experimental data for tantalum are given in UCRL-50400, Vol. 3. Since natural tantalum consists of 99.99% Ta¹⁸¹, it makes no practical difference whether the experimental and evaluated data for tantalum are quoted as corresponding to the natural element or to the isotope Ta¹⁸¹. The evaluated cross sections for Ta¹⁸¹ are shown in UCRL-50400, Vol. 15, Part B.

This evaluation was done by R. J. Howerton, R. C. Haight, M. H. MacGregor, and S. T. Perkins; it is described in detail in UCRL-51306, Rev. 1 (Feb. 1975). In the energy region below 300 eV, the total, elastic, and capture cross sections were obtained by using a standard set of resolved resonance parameters [BNL-325, Suppl. 2, Vol. IIc (1966)].

TOTAL CROSS SECTION

Total cross section data are shown graphically on pages 9-20 to 9-26 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 9-32. Below 300 eV, the evaluated total cross sections were obtained from resolved resonance parameters, as described above. Above 300 eV, the evaluated total cross sections were obtained from the experimental total cross section data. The evalu-

ated total cross sections for Ta¹⁸¹ are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for Ta are shown graphically on page 9-27 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 9-33. Below 300 eV, the evaluated elastic cross sections were obtained from resolved resonance parameters, as mentioned above. Above 300 eV, the evaluated elastic cross sections were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections. The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental elastic scattering angular distribution measurements in the energy range from 0.06 to 14.6 MeV are given in UCRL-50400, Vol. 19. In the evaluation, the elastic angular distributions were assumed to be isotropic for neutron energies below 0.05 MeV. Between 0.05 MeV and 1 MeV the angular distributions were taken from experiment. Above 1 MeV, the elastic angular distributions were

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REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,N IN TOTAL ENERGY DEP.	4	12/03/76	-1.4220+ 1	1.4300+ 1	2.0000+ 1	PHOTON = 1.0000- 2 MEV
N,N IN CROSS SECTION	4	12/03/76	-1.4220+ 1	1.4300+ 1	2.0000+ 1	PHOTON = 1.0000- 2 MEV
N,P TOTAL ENERGY DEP.	6	1/01/72	-2.3500- 1	2.4000- 1	2.0000+ 1	PHOTON = 5.7400- 2 MEV
N,P TOTAL ENERGY DEP.	2	5/29/78	-2.3500- 1	2.4000- 1	2.0000+ 1	PHOTON = 1.3610- 1 MEV
N,P CROSS SECTION	1873	4/03/76	6.0700+ 0	1.0000-10	2.0000+ 1	PHOTON = 1.3610- 1 MEV
B ENERGY-ANGLE DIST.	2	10/13/75	6.0700+ 0	1.0000-10	3.5000+ 2	PHOTON = 1.3780- 1 MEV
G ENERGY DIST.	3	6/25/73	6.0700+ 0	1.0000-10	3.5000+ 2	PHOTON = 1.3780- 1 MEV
G MULTIPLICITY	4	6/25/73	6.0700+ 0	1.0000-10	3.5000+ 2	PHOTON = 1.3780- 1 MEV
B MULTIPLICITY	3	6/25/73	6.0700+ 0	1.0000-10	3.5000+ 2	PHOTON = 1.3780- 1 MEV
N,G TOTAL ENERGY DEP.	2	11/21/76	6.0700+ 0	1.0000-10	2.0000+ 1	PHOTON = 1.3780- 1 MEV
N,G CROSS SECTION	47	10/13/75	6.0700+ 0	1.0000-10	2.0000+ 1	PHOTON = 1.3780- 1 MEV
G ENERGY-ANGLE DIST.	33	7/22/74	0.0000+ 0	3.4993- 2	2.0000+ 1	PHOTON = 1.3780- 1 MEV
N,G CROSS SECTION	3	7/22/74	0.0000+ 0	1.3680- 1	2.0000+ 1	PHOTON = 1.3780- 1 MEV
G ANGULAR DIST.	36	7/22/74	0.0000+ 0	1.3680- 1	2.0000+ 1	PHOTON = 1.3780- 1 MEV
N,G CROSS SECTION	2	7/22/74	0.0000+ 0	1.3680- 1	2.0000+ 1	PHOTON = 1.3780- 1 MEV
G ANGULAR DIST.	25	7/22/74	0.0000+ 0	1.3680- 1	2.0000+ 1	PHOTON = 1.3780- 1 MEV
N,G CROSS SECTION	12	7/22/74	0.0000+ 0	6.2300- 1	2.0000+ 1	PHOTON = 1.3780- 1 MEV
G ANGULAR DIST.	12	7/22/74	0.0000+ 0	6.2300- 1	2.0000+ 1	PHOTON = 1.3780- 1 MEV
N,G CROSS SECTION	12	7/22/74	0.0000+ 0	1.5950- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	14	7/22/74	0.0000+ 0	3.0320- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	5	7/22/74	0.0000+ 0	3.0320- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	2	7/22/74	0.0000+ 0	3.3940- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	13	7/22/74	0.0000+ 0	4.9800- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	8	7/22/74	0.0000+ 0	4.9800- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	2	7/22/74	0.0000+ 0	7.2400- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	14	7/22/74	0.0000+ 0	3.0320- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	7	7/22/74	0.0000+ 0	9.3000- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	3	7/22/74	0.0000+ 0	9.3000- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	9	7/22/74	0.0000+ 0	3.3940- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	16	7/22/74	0.0000+ 0	4.8500- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	13	7/22/74	0.0000+ 0	4.8500- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	18	7/22/74	0.0000+ 0	4.8500- 1	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	7	7/22/74	0.0000+ 0	1.2000+ 0	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	2	7/22/74	0.0000+ 0	1.2000+ 0	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	5	11/26/73	0.0000+ 0	1.2000+ 0	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	2	7/22/74	0.0000+ 0	1.4500+ 0	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	6	11/26/73	0.0000+ 0	1.4500+ 0	2.0000+ 1	PHOTON = 1.5240- 1 MEV
G ANGULAR DIST.	2	7/22/74	0.0000+ 0	1.3000+ 0	2.0000+ 1	PHOTON = 1.5240- 1 MEV
N,G CROSS SECTION	2	7/22/74	0.0000+ 0	1.3000+ 0	2.0000+ 1	PHOTON = 1.5240- 1 MEV

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Tantalum-181 (Cont.)

REACTION	POINTS	DATE	O-VALUE	E-MIN	E-MAX	
N,XG CROSS SECTION	6	11/26/73	0.0000+0	1.2600-0	2.0000+1	PHOTON = 1.2060+0 MEV
N,XG ANGULAR DIST.	2	7/22/74	0.0000+0	1.3000-0	2.0000+1	PHOTON = 1.2060+0 MEV
N,XG CROSS SECTION	2	11/26/73	0.0000+0	1.3500+0	2.0000+1	PHOTON = 1.2450+0 MEV
N,XG ANGULAR DIST.	5	7/22/74	0.0000+0	1.3000+0	2.0000+1	PHOTON = 1.2450+0 MEV
N,XG CROSS SECTION	2	11/26/73	0.0000+0	1.5000+0	2.0000+1	PHOTON = 1.3080+0 MEV
N,XG ANGULAR DIST.	6	7/22/74	0.0000+0	1.5000+0	2.0000+1	PHOTON = 1.3080+0 MEV
N,XG CROSS SECTION	2	11/26/73	0.0000+0	1.4000+0	2.0000+1	PHOTON = 1.3620+0 MEV
N,XG ANGULAR DIST.	2	7/22/74	0.0000+0	1.4000+0	2.0000+1	PHOTON = 1.3620+0 MEV
N,XG CROSS SECTION	5	11/26/73	0.0000+0	1.4500+0	2.0000+1	PHOTON = 1.4260+0 MEV
N,XG ANGULAR DIST.	2	7/22/74	0.0000+0	1.4500+0	2.0000+1	PHOTON = 1.4260+0 MEV
N,XG CROSS SECTION	47	10/13/75	0.0000+0	3.4899-2	2.0000+1	
N,XB ANGULAR DIST.	20	10/13/75	0.0000+0	3.4899-2	2.0000+1	
N,XB CROSS SECTION	18	7/22/74	0.0000+0	6.2300-3	2.0000+1	PHOTON = 3.1000-3 MEV
N,XB ENERGY-ANGLE DIST.	18	7/22/74	0.0000+0	1.5650-1	2.0000+1	PHOTON = 1.4200-2 MEV
N,XB CROSS SECTION	11	7/22/74	0.0000+0	1.3680-1	2.0000+1	PHOTON = 6.8700-2 MEV
N,XB CROSS SECTION	23	7/22/74	0.0000+0	6.2300-1	2.0000+1	PHOTON = 7.0400-2 MEV
N,XB CROSS SECTION	12	7/22/74	0.0000+0	1.5950-1	2.0000+1	PHOTON = 8.5000-2 MEV
N,XB CROSS SECTION	14	7/22/74	0.0000+0	3.0320-1	2.0000+1	PHOTON = 9.8000-2 MEV
N,XB CROSS SECTION	14	7/22/74	0.0000+0	3.3940-1	2.0000+1	PHOTON = 1.1150-1 MEV
N,XB CROSS SECTION	9	7/22/74	0.0000+0	1.3680-1	2.0000+1	PHOTON = 1.2610-1 MEV
N,XB CROSS SECTION	26	7/22/74	0.0000+0	6.2300-1	2.0000+1	PHOTON = 1.5500-1 MEV
N,XB CROSS SECTION	12	7/22/74	0.0000+0	3.0320-1	2.0000+1	PHOTON = 1.5680-1 MEV
N,XB CROSS SECTION	14	7/22/74	0.0000+0	7.2400-1	2.0000+1	PHOTON = 1.6890-1 MEV
N,XB CROSS SECTION	9	7/22/74	0.0000+0	3.3940-1	2.0000+1	PHOTON = 1.8350-1 MEV
N,XB CROSS SECTION	13	7/22/74	0.0000+0	4.9800-1	2.0000+1	PHOTON = 2.9150-1 MEV
N,XB CROSS SECTION	8	7/22/74	0.0000+0	4.9800-1	2.0000+1	PHOTON = 4.1480-1 MEV
N,XB CROSS SECTION	13	7/22/74	0.0000+0	4.9800-1	2.0000+1	
N,XB CROSS SECTION	8	7/22/74	0.0000+0	4.9800-1	2.0000+1	
N,XB CROSS SECTION	13	7/22/74	0.0000+0	4.9800-1	2.0000+1	
N,XB CROSS SECTION	8	7/22/74	0.0000+0	4.9800-1	2.0000+1	

obtained from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Experimental n, n' data for Ta¹⁸¹ are given on pages 9-11 to 9-20 and on page 9-30 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n, n' cross sections include contributions from nine discrete levels plus a continuum component that starts at 1.2 MeV. The evaluated n, n' cross sections for the excitation of the discrete levels were obtained from the experimental data. The evaluated n, n' cross sections for the continuum component were obtained by taking differences between the evaluated non-elastic cross section and the sums of the evaluated partial nonelastic cross sections. These evaluated inelastic cross sections are shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic for incident neutron energies below 7 MeV. Above 7 MeV, anisotropic angular distributions were used to reflect the production of preequilibrium and direct-interaction neutrons. The methods used to

obtain energy distributions for the inelastically scattered neutrons are described on pages 6 and 7 of UCRL-51306, Rev. 1. These methods involve temperature model calculations that are based on the available energy for producing secondary neutrons.

$n, 2n$ CROSS SECTION

The threshold for the $n, 2n$ reaction in Ta¹⁸¹ is 7.68 MeV. Experimental $n, 2n$ data for Ta¹⁸¹ are shown graphically on pages 9-21 to 9-23 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 9-30. The evaluated $n, 2n$ cross sections were obtained partly from these experimental data and partly from nuclear systematics. The evaluated $n, 2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 2n$ REACTION

The angular distributions of the secondary neutrons from the $n, 2n$ reaction were assumed to be isotropic in the laboratory system. The energy distributions of the secondary neutrons were obtained from detailed nuclear cascade calculations; they are described on pages 7 and 8 of UCRL-51306, Rev. 1.

$n, 3n$ CROSS SECTION

The $n, 3n$ threshold in Ta¹⁸¹ is 14.3 MeV. A single experimental $n, 3n$

data point is given on page 9-30 of UCRL-50400, Vol. 8, Rev. 1, Part B. Thus the evaluated $n,3n$ cross sections were obtained from nuclear systematics. These evaluated $n,3n$ cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distributions of the secondary neutrons from the $n,3n$ reaction were assumed to be isotropic in the laboratory system. The energy distributions of the secondary neutrons were obtained from nuclear cascade calculations, in the same manner as described above for the $n,2n$ reactions.

n,p CROSS SECTION

The threshold for the n,p reaction in Ta^{181} is 0.24 MeV. Experimental n,p cross sections for Ta^{181} are shown graphically on page 9-29 of UCRL-50400, Vol. 8, Rev. 1, Part B; a single tabulated value is given on page 9-31. The evaluated n,p cross sections were obtained from the experimental data. These evaluated n,p cross sections are shown in UCRL-50400, Vol. 15, Part B.

n,γ CROSS SECTION

Neutron capture cross sections for natural tantalum and for Ta^{181} are shown graphically on pages 9-28 to

9-31 and 9-33 to 9-36 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on pages 9-33, 9-37, and 9-38. As mentioned at the beginning of this report, the neutron capture cross sections below 300 eV were obtained from a standard set of resolved resonance parameters. Above 300 eV, the capture cross sections were obtained from the experimental data. The evaluated neutron capture cross sections are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

At thermal neutron energies, the photon production energy spectra were taken from experiment. For neutron energies above thermal, the photon spectra were modified in accordance with the information that could be obtained from the available experimental data and from gamma-ray energy level diagrams. The procedures used here, which are described on pages 17 and 18 of UCRL-51306, Rev. 1, were chosen for the purpose of conserving the total energy of the reaction. Above 35 keV, the photons from the neutron capture process were subsumed into the continuum component of the $n,X\gamma$ reaction.

$n,X\gamma$ CROSS SECTION

Experimental $n,X\gamma$ cross sections for Ta^{181} are shown graphically on pages 9-24 to 9-28 of UCRL-50400, Vol.

8, Rev. 1, Part B; some tabular values are given on page 9-31. The methods used to obtain evaluated n,X γ cross sections for Ta¹⁸¹ are discussed at considerable length on pages 9 to 17 of UCRL-51306, Rev. 1. Photon production cross sections have been accurately measured for Ta. These measurements were used to determine the parameters of the NXGAMEL photon production code. The code was subsequently used for calculating evaluated photon cross sections and energy spectra for many other elements. The NXGAMEL code is described in *Nucl. Sci. Eng.* 57, 1 (1975); a summary of

this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41. The evaluated n,X γ cross sections for Ta¹⁸¹ include contributions from 24 discrete lines plus a continuum component with a threshold at 35 keV.

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Tungsten

DATA SUMMARY AND GENERAL COMMENTS

References to experimental data for natural tungsten and its various isotopes are listed in UCRL-50400, Vol. 3. The evaluated data for natural tungsten are shown in UCRL-50400, Vol. 15, Part B. R. J. Hower-ton did the evaluation.

TOTAL CROSS SECTION

Total cross section data for natural W are shown graphically on pages 9-40 to 9-44 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on pages 9-49 and 9-50. Total cross sections for iso-topes of W are given on pages 9-51, 9-52, 9-55, 9-57, 9-60, and 9-61 of that report. The evaluated total cross sections, which were obtained from the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural W are given on page 9-50 of UCRL-50400, Vol. 7, Part B, Rev. 1; elastic cross sections for iso-topes of W are given on pages 9-53, 9-58, and 9-62. The evaluated elastic cross sections (UCRL-50400, Vol. 15, Part B) were obtained by taking dif-ferences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections,

with the experimental elastic cross section data used as a guide.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental elastic scattering angular distributions for W at inci-dent neutron energies from 0.3 to 7.5 MeV and at 14 MeV are shown in UCRL-50400, Vol. 19. In the evalua-tion, the elastic angular distribu-tions were assumed to be isotropic for neutron energies below 50 keV. Above 50 keV, the elastic angular distributions were obtained from experimental values, supplemented at the higher energies by spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Experimental n,n' data for natural W are shown graphically on pages 9-32 and 9-33 of UCRL-50400, Vol. 8, Rev. 1, Part B; a tabular value is given on page 9-35. The n,n' data for isotopes of W are given on pages 9-36 to 9-42. The evaluated n,n' cross sections, which were represented as a continuum with a threshold at 0.1 MeV, are shown in UCRL-50400, Vol. 15, Part B. These evaluated cross sections were based on a combination

Tungsten

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	1249	11/26/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	11	10/19/71	0.0000+ 0	5.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	29	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	29	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	14	3/13/70	0.0000+ 0	1.0000- 1	1.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	13	10/03/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	20	12/03/76	0.0000+ 0	1.0000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	13	12/03/76	0.0000+ 0	1.0000- 1	2.0000+ 1
N,2N	CROSS SECTION	9	3/13/70	7.4600+ 0	7.5009+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	10/03/72	-7.4600+ 0	7.5009+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	14	12/03/76	-7.4600+ 0	7.5009+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	7	12/03/76	-7.4600+ 0	7.5009+ 0	2.0000+ 1
N,3N	CROSS SECTION	6	10/03/72	-1.3090+ 1	1.3200+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	6	10/03/72	-1.3090+ 1	1.3200+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.3090+ 1	1.3200+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.3090+ 1	1.3200+ 1	2.0000+ 1
N,G	CROSS SECTION	2041	4/03/76	5.8300+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	5.8300+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	5.8300+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.8300+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.8300+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	1.0000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	1.0000- 1	2.0000+ 1

of experimental data and nuclear systematics.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 7 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The threshold chosen for the n,2n evaluation was 7.5 MeV, which is an

effective average over the principle isotopes of W. Experimental n,2n data for natural W are given on pages 9-34 and 9-35 of UCRL-50400, Vol. 8, Rev. 1, Part B; data for isotopes of W are given on pages 9-37, 9-39, and 9-44. The evaluated n,2n cross sections, which were obtained by combining these experimental data with nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

The threshold for the n,3n evaluation was set equal to 13.2 MeV, which is an effective threshold for the principal isotopes of W. Since there are no experimental data for this reaction, the evaluated n,3n cross sections were obtained from nuclear systematics. These evaluated cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 3n$ REACTION

The evaluation procedures used for the $n, 2n$ evaluation described above were also used here.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural W are shown graphically on pages 9-45 to 9-49 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on pages 9-50 and 9-51. Neutron capture data for isotopes of W are given on pages 9-53 to 9-56, 9-58 to 9-60, and 9-62 to 9-66. The evaluated neutron capture cross sections, which were obtained from these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to

apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

$n, X\gamma$ CROSS SECTION

There are no experimental $n, X\gamma$ data for W. In the evaluation, the $n, X\gamma$ cross section for W was represented by a continuum with a threshold at 100 keV. The evaluated $n, X\gamma$ cross sections were obtained from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Rhenium-185

DATA SUMMARY AND GENERAL COMMENTS

References to experimental data for natural Re and for ^{185}Re are given in UCRL-50400, Vol. 3. The evaluated data for ^{185}Re are shown graphically in UCRL-50400, Vol. 15, Part B.

This evaluation is based in large part on the evaluation done by W. B. Henderson and J. W. Zwick in January 1968, which is documented in General Electric Report GEMP-587. Those portions of the evaluation done at LLL include the n,γ cross section for incident neutron energies greater than 0.001 MeV, the inelastic scattering cross section for incident neutron energies less than 1.7 MeV, all secondary neutron energy distributions, and all photon production data.

TOTAL CROSS SECTION

Total cross section data for natural Re are given on pages 9-66 to 9-68 of UCRL-50400, Vol. 7, Part B, Rev. 1; data for ^{185}Re are given on page 9-73. As stated above, the evaluated total cross sections were taken from GEMP-587. These evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

The elastic cross section for the entire energy range was taken from Henderson and Zwick (GEMP-587). The evaluations defined the resolved plus unresolved resonance region as one that extends up to 0.1 MeV. They used the resolved and unresolved resonance parameters of S. J. Friesenhahn *et al.*, as given in GA-8189 (1967). Since there are no measurements of the elastic scattering cross section for this isotope, the evaluators used ABACUS-NEARREX calculations for incident neutron energies above 0.1 MeV. From 0.1 to 5 MeV, the sum of the shape elastic and compound elastic cross sections were used; above 5 MeV the compound elastic cross section is negligible, and only the shape elastic cross section was used. The evaluated elastic cross sections in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Elastic scattering angular distributions were taken from GEMP-587 and are based on ABACUS-NEARREX calculations. The elastic scattering is assumed to be isotropic in the center-of-mass system for incident neutron energies below 0.001 MeV.

Rhenium-185

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	600	6/03/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	38	6/03/74	0.0000+ 0	1.0000- 3	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	38	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	38	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	31	6/03/74	0.0000+ 0	1.2700- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	15	6/03/74	0.0000+ 0	1.2700- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	19	12/03/76	0.0000+ 0	1.2700- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	12	12/03/76	0.0000+ 0	1.2700- 1	2.0000+ 1
N,2N	CROSS SECTION	16	6/03/74	-7.8100+ 0	7.8530+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	9	6/03/74	-7.8100+ 0	7.8530+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	14	12/03/76	-7.8100+ 0	7.8530+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	9	12/03/76	-7.8100+ 0	7.8530+ 0	2.0000+ 1
N,3N	CROSS SECTION	4	6/03/74	-1.4470+ 1	1.4550+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	6/03/74	-1.4470+ 1	1.4550+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.4470+ 1	1.4550+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.4470+ 1	1.4550+ 1	2.0000+ 1
N,G	CROSS SECTION	1063	3/09/73	6.1780+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	6.1780+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	6.1780+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.1780+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.1780+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	1.2700- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	1.2700- 1	2.0000+ 1

INELASTIC SCATTERING CROSS SECTION

For incident neutron energies below 1.7 MeV, the GEMP-587 excitation functions for inelastic scattering from eight levels (as obtained from ABACUS-NEARREX calculations) were replaced by Howerton with a continuum inelastic scattering cross section. The cross section that was substituted was then joined smoothly to the Henderson and Zwick continuum inelastic scattering cross section. The latter is essentially the sum of the eight level excitation functions, at higher neutron energies. Since there is no way of verifying the accuracy of the calculated excitation functions (there are no experimental data for comparison with the calculations), it was felt that the more economical continuum representation supplies as much information as the eight-level representation. Moreover, it has an uncertainty which is considerably less than the uncertainty in any one of the calculated excitation functions. At incident neutron energies above 1.7 MeV, where the GEMP-587 values were adopted, the evaluators obtained the inelastic scattering cross section by differencing the total nonelastic cross section and the sum of all other inelastic cross sections $[(n,\gamma), (n,2n), \text{ and } (n,3n)]$. The low-energy continuum representation of Howerton

was joined smoothly to the higher-energy continuum inelastic cross section. The evaluated inelastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 4 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 4 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The threshold for the n,2n reaction in Re^{185} is 7.85 MeV. Experimental data for this reaction are given on page 9-48 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated data for this reaction, which are shown in UCRL-50400, Vol. 15, Part B, were taken from GEMP-587. The threshold and cross section shape were provided by S. Pearlstein, with a renormalization performed by the evaluators so as to achieve agreement with the experimental values.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

The threshold for the n,3n reaction is 14.55 MeV. The n,3n cross sections contained in the GEMP-587 evaluation were adopted for the present evaluation. The threshold shape was provided by S. Pearlstein, with the cross sections renormalized by

the evaluators, using the same renormalization factor that was used for the n,2n cross sections. The evaluated n,3n cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The evaluation techniques used for the n,2n evaluation described above were also used here.

n, γ CROSS SECTION

Experimental data for the n, γ capture cross section are reported in ECSIL Refs. 68-1990, 63-2646, 65-2299, 57-305, 66-1788, 43-309, 52-342, 60-909, and 67-2300. The Q-value for the n, γ reaction is 6.178 MeV. For incident neutron energies below 0.001 MeV, the cross section was obtained from the GEMP-587 evaluation by expanding the resonance parameter representation. From 0.001 MeV to 0.1 MeV, the evaluation was based on the data of Refs. 68-1990, 65-2299. From 0.1 to 3 MeV the evaluation was done by M. Lindner, and was based on data taken by Lindner, Nagle and Landrum. There are no experimental data above 3 MeV, so the extrapolation to higher energies was based on the trend established at lower energies, with a value of 3 mbarns being assumed at 20 MeV. The evaluated neutron capture cross sections are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,γ CROSS SECTION

There are no experimental n,γ data for Re^{185} . In the evaluation, the n,γ cross section was represented by a continuum with a thresh-

old at 0.127 MeV. The evaluated n,γ cross sections were obtained from calculations with the NKGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n,γ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Rhenium-187

DATA SUMMARY AND GENERAL COMMENTS

References to experimental data for natural Re and for Re¹⁸⁷ are given in UCRL-50400, Vol. 3. The evaluated data for Re¹⁸⁷ are shown graphically in UCRL-50400, Vol. 15, Part B.

This evaluation is based in large part on the evaluation done by W. B. Henderson and J. W. Zwick in January 1968, which is documented in General Electric report GEMP-587. Those portions of the evaluation that were subsequently done at LLL include the n, γ cross section for incident neutron energies greater than 0.001 MeV, the inelastic scattering cross section for incident neutron energies less than 1.5 MeV, all secondary neutron energy distributions, and all photon production data.

TOTAL CROSS SECTION

Total cross section data for natural Re are given on pages 9-66 to 9-68 of UCRL-50400, Vol. 7, Part B, Rev. 1; data for Re¹⁸⁷ are given on page 9-76. As stated above, the evaluated total cross sections were taken from the work of Henderson & Zwick (GEMP-587). These evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

The elastic scattering cross section for the entire energy range was taken from Henderson and Zwick (GEMP-587). The evaluators defined the resolved plus unresolved resonance region as the one extending up to 0.1 MeV, and they use the resolved and unresolved resonance parameters of S. J. Friesenhahn *et al.*, as given in GA-8189 (1967). Since there are no measurements of the elastic scattering cross section for this isotope, the evaluators used ABACUS-NEARREX calculations for incident neutron energies above 0.1 MeV. From 0.1 to 5 MeV, the sum of the shape elastic and compound elastic cross sections were used; above 5 MeV the compound elastic cross section is negligible, and only the shape elastic cross section was used. The evaluated elastic cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Elastic scattering angular distributions were taken from GEMP-587 and are based on ABACUS-NEARREX calculations. The elastic scattering is assumed to be isotropic in the center-of-mass system for incident neutron energies below 0.001 MeV.

Rhenium-187

06/09/78

	REACTION	POINTS	DATE	SCALE	E MIN	E MAX
N,ELASTIC	CROSS SECTION	504	2/27/76	1.0000	1.0000	1.0000
N,ELASTIC	N ANGULAR DIST.	38	6/03/74	0.0000	0.0000	0.0000
N,ELASTIC	N TOTAL ENERGY DEP.	39	11/14/74	0.0000	0.0000	0.0000
N,ELASTIC	N LOCAL ENERGY DEP.	39	11/14/74	0.0000	0.0000	0.0000
N,N'	CROSS SECTION	26	6/03/74	0.0000	0.0000	0.0000
N,N'	N ENERGY-ANGLE DIST.	14	6/03/74	0.0000	0.0000	0.0000
N,N'	N TOTAL ENERGY DEP.	17	12/03/76	0.0000	0.0000	0.0000
N,N'	N LOCAL ENERGY DEP.	13	12/03/76	0.0000	0.0000	0.0000
N,2N	CROSS SECTION	15	6/03/74	3200	3600	3600
N,2N	N ENERGY-ANGLE DIST.	10	6/03/74	3200	3600	3600
N,2N	N TOTAL ENERGY DEP.	15	12/03/76	3200	3600	3600
N,2N	N LOCAL ENERGY DEP.	9	12/03/76	3200	3600	3600
N,3N	CROSS SECTION	5	6/03/74	3560	3600	3600
N,3N	N ENERGY-ANGLE DIST.	5	6/03/74	3560	3600	3600
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	3560	3600	3600
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	3560	3600	3600
N,G	CROSS SECTION	947	4/03/76	5.8730	5.8730	5.8730
N,G	G ENERGY DIST.	2	2/23/78	5.8730	5.8730	5.8730
N,G	G MULTIPLICITY	2	2/23/78	5.8730	5.8730	5.8730
N,G	G TOTAL ENERGY DEP.	2	11/21/76	5.8730	5.8730	5.8730
N,G	G LOCAL ENERGY DEP.	2	11/21/76	5.8730	5.8730	5.8730
N,XG	CROSS SECTION	15	2/23/78	0.0000	0.0000	0.0000
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000	0.0000	0.0000

INELASTIC SCATTERING CROSS SECTION

For incident neutron energies below 1.5 MeV, the GEMP-587 excitation functions for inelastic scattering from eleven levels (as obtained from ABACUS-NEARREX calculations) were replaced by R. J. Howerton with a continuum inelastic scattering cross section. The cross section that was substituted was then joined smoothly to the Henderson and Zwick continuum inelastic scattering cross section. The latter is essentially the sum of the eleven level excitation functions at the higher neutron energies. Since there is no way of verifying the accuracy of the calculated excitation functions (as there are no experimental data for comparison with the calculations), it was felt that this more economical continuum representation supplies as much information as the eleven-level representation. Moreover it has an uncertainty which is considerably less than the uncertainty in any one of the calculated excitation functions. At incident energies above 1.5 MeV (where the GEMP-587 values were adopted) the evaluators obtained the inelastic scattering cross section by taking differences between the evaluated total nonelastic cross sections and the sums of all other inelastic cross sections $[(n,\gamma), (n,2n), \text{ and } (n,3n)]$. The low-energy

continuum representation of Howerton was joined smoothly onto the higher-energy continuum inelastic cross section. The evaluated inelastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 4 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 4 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The threshold for the n,2n reaction in Re¹⁸⁷ is 7.41 MeV. Experimental data for this reaction are given on page 9-48 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated data for this reaction (UCRL-50400, Vol. 15, Part 5) were taken from GEMP-587. The threshold and cross section shape were provided by S. Pearlstein, with a renormalization performed by the evaluators so as to achieve agreement with the experimental values.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (see UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

The threshold for the n,3n reaction is 13.62 MeV. The n,3n cross sections contained in the GEMP-587 evaluation were adopted for the present evaluation. The threshold shape was provided by S. Pearlstein, with the cross sections renormalized

by the evaluators, using the same renormalization factor used for the n,2n cross sections. The evaluated n,3n cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTIONS

The same evaluation techniques used for the n,2n evaluation described above were used here.

n,γ CROSS SECTION

Experimental neutron capture cross sections for Re¹⁸⁷ are shown graphically on pages 9-77 and 9-78 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 9-79. The Q-value for the neutron capture reaction is 5.87 MeV. For incident neutron energies below 0.001 MeV, the cross sections were obtained from the GEMP-587 evaluation by expanding the resonance parameter representation into points. From 0.001 MeV to 0.1 MeV, the evaluation was based on the data of Refs. 68-1990, 65-2299. From 0.1 to 3 MeV the evaluation was done by M. Lindner, and was based on data taken by Lindner, Nagle and Landrum. There are no experimental data above 3 MeV, so the extrapolation to higher energies was based on the trend established at lower energies, with a value of 3 mbarns being assumed to 20 MeV. The evaluated neutron capture cross

SPECTRA OF PHOTONS FROM THE $n, X\gamma$ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

sections are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies

up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

$n, X\gamma$ CROSS SECTION

There are no experimental $n, X\gamma$ data for Re^{187} . In the evaluation, $n, X\gamma$ cross section was represented by a continuum with a threshold at 0.135 MeV. The evaluated $n, X\gamma$ cross sections were obtained from calculations with the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

Platinum

DATA SUMMARY AND GENERAL COMMENTS

References to experimental data for natural platinum and its various isotopes are listed in UCRL-50400, Vol. 3. The evaluated data for natural Pt are shown in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Total cross section data for natural Pt are shown graphically on pages 9-92 to 9-95 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 9-98. The evaluated total cross sections, which were obtained from the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering cross sections for natural Pt are given on page 9-96 of UCRL-50400, Vol. 7, Part B, Rev. 1. The evaluated elastic cross sections (UCRL-50400, Vol. 15, Part B) were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections, with the experimental elastic cross section data used as a guide.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

There are no experimental elastic scattering angular distributions for Pt. In the evaluation, the elastic angular distributions were assumed to be isotropic for neutron energies below 100 keV. Above 100 keV, the elastic angular distributions were obtained from spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Experimental n, n' data for natural Pt are given on pages 9-58 to 9-61 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n, n' cross sections, which were represented as a continuum with a threshold at 0.15 MeV, are shown in UCRL-50400, Vol. 15, Part B. These evaluated n, n' data were obtained by combining the experimental data with nuclear systematics.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the preequilibrium and direct-interaction

Platinum

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	93	7/05/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	14	7/05/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	30	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	30	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	19	7/05/72	0.0000+ 0	1.5000- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	12	7/05/72	0.0000+ 0	1.5000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	15	12/03/76	0.0000+ 0	1.5000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	12	12/03/76	0.0000+ 0	1.5000- 1	2.0000+ 1
N,2N	CROSS SECTION	13	7/05/72	-6.0700+ 0	6.1014+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	7/05/72	-6.0700+ 0	6.1014+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	14	12/03/76	-6.0700+ 0	6.1014+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	7	12/03/76	-6.0700+ 0	6.1014+ 0	2.0000+ 1
N,3N	CROSS SECTION	6	7/05/72	-1.3900+ 1	1.4000+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	4	7/05/72	-1.3900+ 1	1.4000+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.3900+ 1	1.4000+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.3900+ 1	1.4000+ 1	2.0000+ 1
N,G	CROSS SECTION	1416	7/05/72	7.7200+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/23/78	7.7200+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	7.7200+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	7.7200+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	7.7200+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	1.5000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	1.5000- 1	2.0000+ 1

portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 5 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 5 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model -- a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the preequilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

The threshold chosen for the n,2n evaluation was 6.1 MeV, which is the n,2n threshold for Pt¹⁹⁵. This threshold is an effective average over the principal isotopes of Pt. Experimental data for natural Pt are given on pages 9-62 and 9-63 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n,2n data, which were obtained by combining these experimental data with nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

An n,3n threshold of 14 MeV was selected for the Pt evaluation; this is an effective value for the principal isotopes of Pt. Since there are no experimental data for this reaction, the evaluated n,3n cross sections were obtained from nuclear systematics. These evaluated cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The same evaluation procedures used for the n,2n cross section discussed above were used here.

n, γ CROSS SECTION

Experimental neutron capture cross sections for natural Pt are shown graphically on page 9-97 of UCRL-50400, Vol. 7, Part B, Rev. 1; some

tabular values are given on pages 9-98 and 9-99. The evaluated neutron capture cross sections, which were obtained from these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n,γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

$n,X\gamma$ CROSS SECTION

There are no experimental $n,X\gamma$

data for Pt. In the evaluation, the $n,X\gamma$ cross section was represented by a continuum component with a threshold at 0.15 MeV. The evaluated $n,X\gamma$ cross sections were obtained from calculations with the NXCAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE $n,X\gamma$ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Gold-197

DATA SUMMARY AND GENERAL COMMENTS

References to experimental data for gold are given in UCRL-50400, Vol. 3. Since natural gold is almost entirely made up of Au¹⁹⁷, the evaluation given here for Au¹⁹⁷ is essentially the same as for natural gold. The evaluated data for gold are shown in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Total cross section data are shown graphically on pages 9-100 to 9-106 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on page 9-118. The evaluated total cross sections, which were obtained from these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

Elastic scattering data are shown graphically on page 9-107 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on page 9-119. The evaluated elastic scattering cross sections, which are shown in UCRL-50400, Vol. 15, Part B, were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections, with the experimental elastic cross section data used as a guide.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental elastic scattering angular distributions for gold at incident neutron energies between 0.35 and 8 MeV are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic angular distributions were assumed to be isotropic for neutron energies below 10 keV. Above 10 keV, the elastic angular distributions were obtained from the experimental data, supplemented at the higher energies by spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Experimental n,n' data for gold are shown graphically on pages 9-66 to 9-70 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on pages 9-78 and 9-79. The evaluated n,n' cross sections, which are represented as a continuum with a threshold at 80 keV, are shown in UCRL-50400, Vol. 15, Part B. These evaluated n,n' cross sections were obtained by combining the experimental data with nuclear systematics.

Gold-197

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REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	126	6/01/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ANGULAR DIST.	23	11/03/72	0.0000+ 0	1.0000- 2	2.0000+ 1
N,TOTAL ENERGY DEP.	40	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,LOCAL ENERGY DEP.	40	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	20	6/01/76	0.0000+ 0	8.0000- 2	2.0000+ 1
N,N'	20	6/29/72	0.0000+ 0	8.0000- 2	2.0000+ 1
N,ENERGY-ANGLE DIST.	20	6/29/72	0.0000+ 0	8.0000- 2	2.0000+ 1
N,TOTAL ENERGY DEP.	19	12/03/76	0.0000+ 0	8.0000- 2	2.0000+ 1
N,LOCAL ENERGY DEP.	12	6/01/75	-8.0800+ 0	8.0000- 2	2.0000+ 1
N,CROSS SECTION	13	12/03/76	-8.0800+ 0	8.1300+ 0	2.0000+ 1
N,ENERGY-ANGLE DIST.	9	12/03/76	-8.0800+ 0	8.1300+ 0	2.0000+ 1
N,TOTAL ENERGY DEP.	4	7/29/72	-1.4750+ 1	1.4826+ 1	2.0000+ 1
N,LOCAL ENERGY DEP.	4	7/29/72	-1.4750+ 1	1.4826+ 1	2.0000+ 1
N,ENERGY-ANGLE DIST.	4	12/03/76	-1.4750+ 1	1.4826+ 1	2.0000+ 1
N,TOTAL ENERGY DEP.	12	6/28/72	4.0000- 2	1.0000+ 1	2.0000+ 1
N,CROSS SECTION	2	3/28/78	4.0000- 2	1.0000+ 1	2.0000+ 1
N,LOCAL ENERGY DEP.	5	6/29/78	7.0300+ 0	7.0000+ 0	2.0000+ 1
N,TOTAL ENERGY DEP.	2	5/28/78	7.0300+ 0	7.0000+ 0	2.0000+ 1
N,LOCAL ENERGY DEP.	3583	4/03/76	6.5100+ 0	1.0000-10	2.0000+ 1
N,CROSS SECTION	2	2/23/78	6.5100+ 0	1.0000-10	2.0000+ 1
N,ENERGY DIST.	2	2/23/78	6.5100+ 0	1.0000-10	2.0000+ 1
N,G	2	11/21/76	6.5100+ 0	1.0000-10	2.0000+ 1
N,G	2	11/21/76	6.5100+ 0	1.0000-10	2.0000+ 1
N,G	15	2/23/78	0.0000+ 0	8.0000- 2	2.0000+ 1
N,XG	15	2/23/78	0.0000+ 0	8.0000- 2	2.0000+ 1

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation is also incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 6 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

$n,2n$ CROSS SECTION

The $n,2n$ threshold in Au^{197} is 8.12 MeV. Experimental $n,2n$ cross section data are shown graphically on pages 9-71 to 9-74 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular

values are given on page 9-79. The evaluated $n,2n$ cross sections, which were obtained by combining these experimental data with nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which are presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, page 24).

$n,3n$ CROSS SECTION

The $n,3n$ threshold in Au^{197} is 14.82 MeV. A single data point for this reaction is listed on page 9-79 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated $n,3n$ cross sections, which were obtained mainly from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The evaluation procedures used for the $n,2n$ reaction described above were also used here.

n,p CROSS SECTION

Experimental n,p data are shown graphically on page 9-76 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 9-80. The n,p reaction in Au^{197} is exoergic, but an effective threshold of about 1.0 MeV was used in the evaluation to account for coulomb barrier effects. The evaluated n,p cross sections, which were obtained mainly from the experimental data, are shown in UCRL-50400, Vol. 15, Part B.

n, α CROSS SECTION

The n, α reaction in Au^{197} is exoergic; however, an effective threshold of about 7 MeV was used in the evaluation. Graphical values of n, α experimental cross sections are shown on page 9-77 of UCRL-50400, Vol. 8, Rev. 1, Part B; a single tabular value is given on page 9-80. The evaluated n, α cross sections, which were obtained from the experimental data combined with nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

n, γ CROSS SECTION

Experimental neutron capture cross sections for Au^{197} are shown on pages 9-108 to 9-117 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on page 9-119. The evaluated neutron capture cross sections,

which were obtained from these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n,X γ CROSS SECTION

Experimental n,X γ data for Au^{197} are shown graphically on pages 9-74 to 9-76 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular experimental values are given on page 9-80. The evaluated n,X γ cross sections (which are represented as a continuum with a threshold at 80 keV) were obtained from the experimental data, supplemented by calculations with the NXGAMEL photon production code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE $n, X\gamma$
PROCESS

The photon angular distributions were assumed to be isotropic. The

photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Lead

DATA SUMMARY AND GENERAL COMMENTS

References to data for natural lead and its isotopes are given in UCRL-50400, Vol. 3. The evaluated data for natural lead are shown in UCRL-50400, Vol. 15, Part B. R. J. Howerton did the evaluation.

TOTAL CROSS SECTION

Experimental total cross section data are shown graphically on pages 10-11 to 10-25 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular data are given on pages 10-27 and 10-28. The evaluated total cross sections, which were obtained from these experimental data, are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

A few elastic scattering data points are tabulated on page 10-28 of UCRL-50400, Vol. 7, Part B, Rev. 1. The evaluated elastic scattering cross sections, which are shown in UCRL-50400, Vol. 15, Part B, were obtained by taking differences between the evaluated total cross sections and the sums of the evaluated nonelastic cross sections, with the experimental data used as a guide.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Extensive elastic scattering

angular distributions for lead at incident neutron energies between 0.35 and 8 MeV and between 13.5 and 15 MeV are shown in UCRL-50400, Vol. 19. In the evaluation, the elastic angular distributions were assumed to be isotropic for neutron energies below 10 keV. Above 10 keV, the elastic angular distributions were obtained from the experimental data, supplemented at the higher energies by spherical optical model calculations, in which the best-fit optical model parameters of Becchetti and Greenlees were used [*Phys. Rev.* 182, 1190 (1969)].

INELASTIC SCATTERING CROSS SECTION

Experimental n, n' data for lead are shown graphically on pages 10-20 to 10-22 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 10-25. The evaluated n, n' cross sections, which are represented as a continuum with a threshold at 0.56 MeV, are shown in UCRL-50400, Vol. 15, Part B. These evaluated n, n' cross sections were obtained by combining the experimental data with nuclear systematics.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to

Lead

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	156	7/26/77	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	19	1/03/72	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	37	11/14/74	0.0000+ 1	1.0000-13	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	37	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	21	7/26/77	0.0000+ 0	5.6000- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	13	7/26/77	0.0000+ 0	5.6000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	16	12/03/76	0.0000+ 0	5.6000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	11	12/03/76	0.0000+ 0	5.6000- 1	2.0000+ 1
N,2N	CROSS SECTION	16	7/26/77	-6.5900+ 0	6.7700+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	9	7/26/77	-6.5900+ 0	6.6221+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	17	12/03/76	-6.5900+ 0	6.6221+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	12	12/03/76	-6.5900+ 0	6.6221+ 0	2.0000+ 1
N,3N	CROSS SECTION	5	3/23/72	-1.4111+ 1	1.4180+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	3	3/04/72	-1.4111+ 1	1.4180+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.4111+ 1	1.4180+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.4111+ 1	1.4180+ 1	2.0000+ 1
N,G	CROSS SECTION	122	5/22/76	7.3500+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/23/78	7.3500+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/23/78	7.3500+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	7.3500+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	7.3500+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	15	2/23/78	0.0000+ 0	5.6000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/23/78	0.0000+ 0	5.6000- 1	2.0000+ 1

be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the alternative of entering anisotropic angular distributions into the evaluation would also be incorrect because the uncertainties in the reaction cross section are so large. For energies below the onset of the preequilibrium process, at about 7 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. Above 7 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a "temperature" component plus a "preequilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pages 19 to 22.

n,2n CROSS SECTION

A threshold of 6.6 MeV was chosen for the n,2n threshold in the lead evaluation; this is an effective threshold for the various isotopes of lead. Experimental n,2n data for natural lead are listed on page 10-25 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated n,2n cross sections, which were obtained by combining

these experimental data with nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons, which were presented in tabular form, are derived from temperature model calculations, with the assigned temperatures consistent with systematics (UCRL-50400, Vol. 15, Part A, page 24).

n,3n CROSS SECTION

There are no experimental data for the n,3n reaction in lead. In the evaluation, an effective n,3n threshold of 14.2 MeV was used. This is the n,3n threshold for Pb^{208} , and it is a representative average over all of the isotopes of lead. The evaluated n,3n cross sections, which were obtained from nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The evaluation procedures used for the n,2n reaction described above were also used here.

n, γ CROSS SECTION

Experimental neutron capture cross sections for lead are shown graphically on pages 10-26 and 10-27 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on page 10-28. The evaluated capture cross sections, which were based on experimental data and nuclear systematics, are shown in UCRL-50400, Vol. 15, Part B.

PHOTON PRODUCTION FROM n, γ REACTIONS

The spectrum of photons from the neutron capture process at thermal neutron energies was taken from the measurements of V. J. Orphan *et al.*, Gulf General Atomic Rept. GA-10248 (1970). This spectrum was assumed to apply at all incident neutron energies up to 20 MeV, but the photon multiplicity was adjusted so as to conserve the total energy of the reaction.

n, $X\gamma$ CROSS SECTION

Experimental n, $X\gamma$ data for lead

are shown graphically on pages 10-23 and 10-24 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabular values are given on page 10-26. The evaluated n, $X\gamma$ cross sections (which are represented as a continuum with a threshold at 0.56 MeV) were obtained from the experimental data, supplemented by calculations with the NXGAMEL photon production code, using systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pages 38 to 41.

SPECTRA OF PHOTONS FROM THE n, $X\gamma$ PROCESS

The photon angular distributions were assumed to be isotropic. The photon energy distributions were obtained from the systematics of Perkins, Haight, and Howerton cited above.

Thorium-231

DATA SUMMARY AND GENERAL COMMENTS

The only experimental data for ^{231}Th are listed on pp. 10-66 of UCRL-50400, Vol. 7, Part B, Rev. 1. These three fission-cross-section data points are at neutron energies between 1.5 and 2 MeV. The evaluations for this isotope are constructed wholly from empiricisms and model calculations, except for the fission cross sections, which are constrained to match the three data points mentioned above. This evaluation was done in February 1976 by R. J. Howerton. The evaluated data for ^{231}Th are shown graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

For energies below 0.1 MeV, the elastic cross section is assumed to have a constant value of 11.0 barns, except for an unresolved resonance region that is assumed to extend from 2.5 eV to 1 keV. From 1 to 100 keV the cross section is obtained from systematics. From 100 keV to 1 MeV, optical model calculations are used, with a modification to include an estimated correction for compound nucleus elastic scattering. From 1 MeV to 20 MeV, the cross section values are based on spherical optical

model calculations. The best-fit optical model parameters of Becchetti and Greenlees were used in the calculation [Phys. Rev. 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies below 0.01 MeV, the elastic scattering angular distribution is assumed to be isotropic in the center-of-mass system. From 0.15 to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering reaction is assumed to have a threshold at 0.05 MeV, to rise above the threshold in the usual sigmoid shape, and to reach an effective plateau at about 0.5 MeV. At higher energies, it is calculated by taking the difference between an assumed nonelastic cross section and the sum of the fission and capture cross sections. For energies above the $n,2n$ threshold at 5.15 MeV, the inelastic scattering cross section is assumed to decrease as competitive processes become energetically possible. In accordance with

Thorium-231

06/09/78

	REACTION	POINTS	DATE	G-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	43	2/14/76	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	19	2/14/76	0.0000+ 2	1.0000- 20	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	43	2/14/76	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	43	2/14/76	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	22	2/14/76	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	15	2/14/76	0.0000+ 0	5.0000- 20	2.0000+ 1	
N,N'	N TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	5.0000- 20	2.0000+ 1	
N,N'	N LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	5.0000- 20	2.0000+ 1	
N,2N	CROSS SECTION	19	2/14/76	-5.1200+ 0	5.1500+ 0	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	10	2/14/76	-5.1200+ 0	5.1500+ 0	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	20	12/03/76	-5.1200+ 0	5.1500+ 0	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	14	12/03/76	-5.1200+ 0	5.1500+ 0	2.0000+ 1	
N,3N	CROSS SECTION	11	2/14/76	-1.1910+ 1	1.1970+ 1	2.0000+ 1	
N,3N	N ENERGY-ANGLE DIST.	6	2/14/76	-1.1910+ 1	1.1970+ 1	2.0000+ 1	
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1910+ 1	1.1970+ 1	2.0000+ 1	
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1910+ 1	1.1970+ 1	2.0000+ 1	
N,4N	CROSS SECTION	5	2/14/76	-1.7150+ 1	1.7230+ 1	2.0000+ 1	
N,4N	N ENERGY-ANGLE DIST.	3	2/14/76	-1.7150+ 1	1.7230+ 1	2.0000+ 1	
N,4N	N TOTAL ENERGY DEP.	3	12/03/76	-1.7150+ 1	1.7230+ 1	2.0000+ 1	
N,4N	N LOCAL ENERGY DEP.	3	12/03/76	-1.7150+ 1	1.7230+ 1	2.0000+ 1	
N,F	CROSS SECTION	15f	2/14/76	1.8000+ 2	1.0000-10	2.0000+ 1	
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1	
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1	
N,F	N ENERGY-ANGLE DIST.	5	2/14/76	1.8000+ 2	1.0000-10	2.0000+ 1	
N,F	N NEUTRONS/FISSION	5	2/14/76	1.8000+ 2	1.0000-10	2.0000+ 1	
N,F	G ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1	
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1	
N,F	N NEUTRONS/FISSION	1	3/01/76	1.8000+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G	CROSS SECTION	138	2/14/76	6.4300+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.4300+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	2/17/78	6.4300+ 0	1.0000-10	2.0000+ 1	
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.4300+ 0	1.0000-10	2.0000+ 1	
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.4300+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,YG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1	

the usual systematics for these elements, the inelastic scattering falls to an effectively constant value, which represents direct-interaction plus pre-equilibrium reactions. The cross section for the total inelastic scattering process is assumed to remain constant at a value of 0.3 barns from 17 to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a "temperature" component plus a "pre-equilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium

process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 5.15 MeV. Above threshold, the n,2n reaction cross section rises in the usual systematic way (described in UCRL-50400, Vol. 15, Part A, p. 23), reaches a plateau at about 7 MeV, and continues parallel to the nonelastic cross section at the higher energies. The opening of the n,3n channel at 12 MeV causes a decrease in the n,2n cross section, and the opening of the n,4n channel at 17.5 MeV causes a further decrease.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The threshold for the n,3n reaction is 11.97 MeV. The cross section is assumed to rise in the usual shape from threshold to a plateau region at

13 MeV, where it has a value of about 1 barn. This value is obtained by subtracting the sum of the other inelastic reactions from the total nonelastic cross section. The $n,3n$ cross section is almost constant from 13 to 17.5 MeV, and it falls off above this energy due to competition from the $n,4n$ reaction, reaching a value of 0.55 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is 17.23 MeV. The cross section is assumed to rise in a linear manner from threshold to a value of 0.5 barns at 13.5 MeV, and then remain constant up to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$

reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

A value of 30 barns is assumed for the fission cross section at 0.025 eV, as estimated from systematics. This value is then extrapolated on a $1/v$ basis down to an energy of 10^{-10} MeV and up to an energy of 2.5 eV. An unresolved resonance region is assumed to extend from 2.5 eV to 1 keV. Above 1 keV, the cross section is extrapolated smoothly up to the three experimental data points between 1.5 and 2 MeV (see UCRL-50400, Vol. 7, Part B, Rev. 1, pp. 10-66). Above 2 MeV the fission cross section is obtained from nuclear systematics.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Because of the absence of data, the values for $\bar{\nu}$ are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in Nucl. Sci. and Eng. 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted by fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, and $n,3nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas [*Nucl. Sci. and Eng.* 46, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross sections for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity in the lower energy range is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum. The spectrum of photons from Th^{231} fission is assumed to be the same as the spectrum of photons from U^{235} fission.

CROSS SECTION FOR THE (n, γ) REACTION

The Q-value for the n, γ reaction is 6.43 MeV. A value of 180 barns is

assumed for the capture cross section at 0.025 eV, as estimated from systematics. This value is then extrapolated on a $1/v$ basis down to an energy of 10^{-10} MeV and up to an energy of 2.5 eV. An unresolved resonance region is assumed to extend from 2.5 eV to 1 keV. Above 1 keV the n, γ cross section is obtained from systematics (UCRL-50400, Vol. 15, Part A, pp. 29 to 31).

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 50 keV, photon production is assumed to originate only from capture and fission processes. From 50 keV to 20 MeV, the NXGAMEL code is used to calculate the photon cross sections and spectra. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is

discussed in UCRL-50400, Vol. 15,
Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,

the photon spectra associated with
total photon production above 50 keV
(except for the fission and capture
photons) are calculated with the
NXGAMEL code.

Thorium-232

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{232}_{90}\text{Th}$ are listed in UCRL-50400, Vol. 3. The evaluated data for ^{232}Th are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton in October 1972, with an update on the capture cross sections in August 1974.

In the evaluation for this isotope, values derived from ENDF/B MAT-1296 were used, with some modification, for the elastic scattering and capture cross sections up to 4 keV.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for ^{232}Th are shown graphically on pp. 10-67 to 10-80 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental values are shown on p. 10-91.

ELASTIC SCATTERING CROSS SECTION

As stated above, values derived from ENDF/B MAT-1296 are used after some modification for incident neutron energies below 4 keV. Graphs of the experimental and evaluated cross sections are shown on p. 10-81 of UCRL-50400, Vol. 7, Part B, Rev. 1; a few tabulated experimental values are given on p. 10-91. Values between 4 keV and 0.6 MeV are obtained by

interpolation, and values at energies above 7 MeV (the highest tabulated cross section value) are calculated from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. For energies below 0.4 MeV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 0.5 to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The experimental inelastic scattering data are given on pp. 10-54 to 10-58 (graphical displays) and pp. 10-63 and 10-64 (tabular displays) in UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section rises from threshold at 0.05 MeV to a plateau region at about 2 MeV, where it has a value of about 2.8 barns. It falls off sharply above 6 MeV due to the onset of the $n,2n$ reaction.

Thorium-232

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	2983	8/02/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	13	1/03/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	29	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	LOCAL ENERGY DEP.	29	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	62	10/20/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	15	7/04/77	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	20	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	16	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	17	10/20/72	-6.3400+ 0	6.5000+ 0	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	11	7/04/77	-6.3400+ 0	6.5000+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	17	12/03/76	-6.3400+ 0	6.5000+ 0	2.0000+ 1
N,2N	LOCAL ENERGY DEP.	11	12/03/76	-6.3400+ 0	6.5000+ 0	2.0000+ 1
N,3N	CROSS SECTION	8	10/20/72	-1.1560+ 1	1.1610+ 1	2.0000+ 1
N,3N	ENERGY-ANGLE DIST.	5	10/20/72	-1.1560+ 1	1.1610+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	5	12/03/76	-1.1560+ 1	1.1610+ 1	2.0000+ 1
N,3N	LOCAL ENERGY DEP.	5	12/03/76	-1.1560+ 1	1.1610+ 1	2.0000+ 1
N,4N	CROSS SECTION	2	10/20/72	-1.8350+ 1	1.8500+ 1	2.0000+ 1
N,4N	ENERGY-ANGLE DIST.	3	10/20/72	-1.8350+ 1	1.8500+ 1	2.0000+ 1
N,4N	TOTAL ENERGY DEP.	2	12/03/76	-1.8350+ 1	1.8500+ 1	2.0000+ 1
N,4N	LOCAL ENERGY DEP.	2	12/03/76	-1.8350+ 1	1.8500+ 1	2.0000+ 1
N,F	CROSS SECTION	34	4/13/77	1.7000+ 2	1.0000+ 0	2.0000+ 1
N,F	TOTAL ENERGY DEP.	3	12/03/76	1.7000+ 2	1.0000+ 0	2.0000+ 1
N,F	LOCAL ENERGY DEP.	2	12/03/76	1.7000+ 2	1.0000+ 0	2.0000+ 1
N,F	ENERGY-ANGLE DIST.	7	10/20/72	1.7000+ 2	1.0000+ 0	2.0000+ 1
N,F	NEUTRONS/FISSION	6	10/20/72	1.7000+ 2	1.0000+ 0	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.7000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.7000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.7000+ 2	1.0000+ 0	2.0000+ 1
N,G	CROSS SECTION	5535	8/02/74	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	4.7900+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1

DELAYED

Above the $n,2n$ threshold, the n,n' reaction cross section is derived by finding the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The experimental $n,2n$ data and the evaluated $n,2n$ cross section curve are shown on pp. 10-59 and 10-60 of UCRL-50400, Vol. 8, Rev. 1, Part B. Since the experimental measurements cover the entire range from threshold to 20 MeV, the evaluated $n,2n$ cross section curve is derived from these experimental data.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

There is one measurement of the $n,3n$ cross section, which is given on p. 10-64 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated $n,3n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The $n,3n$ threshold is at 11.61 MeV, and the cross section rises to a value of 1.25 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is 18.43 MeV. The cross section is assumed to rise in a linear manner from threshold to a value of about 0.2 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons for the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

Measurements of the fission cross section are shown on pp. 10-82 to 10-84 of UCRL-50400, Vol. 7, Part B, Rev. 1. The present evaluation was based on the recent ratio data of J. W. Behrens (private communication,

1977), which were normalized to the ENDL U^{235} fission cross section values.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The experimental data and the evaluated values for $\bar{\nu}$ are shown graphically on pp. 10-90 and 10-91 of UCRL-50400, Vol. 7, Part B, Rev. 1, and some tabulated experimental values are given on p. 10-92. At the higher energies, the values for $\bar{\nu}$ were obtained by using the slope as predicted from fission systematics, with an accounting made for the onset of the $n,n'f$, $n,2nf$, and $n,3nf$ reactions.

FISSION SPECTRUM

The fission temperature was obtained in accordance with the systematics of Howerton and Doyas [*Nucl. Sci. and Eng.* 46, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum was calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity in the lower energy range is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum. The spectrum of photons from Th^{232} fission is assumed to be the same as the spectrum of photons from U^{235} fission.

CROSS SECTION FOR THE n,γ REACTION

The experimental data and the evaluated data for the capture reaction are shown graphically on pp. 10-85 to 10-89 of UCRL-50400, Vol. 7, Part B, Rev. 1, and some tabulated experimental data are listed on p. 10-92. As stated above, the evaluated capture cross sections below 4 keV were derived from ENDF/B MAT-1296 with some modifications. At energies above 4 keV, the capture cross section was obtained by matching to the experimental data and by using systematics [UCRL-50400, Vol. 15, Part A, pp. 29 to 31].

PHOTON PRODUCTION FROM (n,γ) REACTIONS

Photon production from the neutron capture reaction was handled by using

multiplicities and normalized spectra. The photon multiplicities for these reactions were derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons was assumed to be the same as that for the measured U^{238} photon spectrum.

$n,X\gamma$ CROSS SECTION

Experimental values for the $n,X\gamma$ cross section are shown graphically on pp. 10-60 to 10-62 of UCRL-50400, Vol. 8, Rev. 1, Part B, and some tabulated values are given on p. 10-65. In the evaluation, these data were combined with calculations of the NXGAMEL code, using the systematics developed by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of evaluating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE $(n,X\gamma)$ PROCESS

The photon spectra associated with total photon production above 50 keV (except for the fission and capture photons) were calculated by using the NXGAMEL code mentioned above.

Thorium-233

DATA SUMMARY AND GENERAL COMMENTS

The only experimental data points listed for ${}_{90}\text{Th}^{233}$ are for three fission cross sections measured at neutron energies between 1.5 and 2.5 MeV (p. 10-91 of UCRL-50400, Vol. 7, Part B, Rev. 1). A few early spectrum-averaged fission and capture cross sections are listed in UCRL-50400, Vol. 3. With the exception of the fission cross sections, which were constrained to match the three experimental data points mentioned above, the evaluations for this isotope were constructed from empiricisms and model calculations. The evaluated data for Th^{233} are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

ELASTIC SCATTERING CROSS SECTION

For energies below 0.1 MeV, the elastic cross section was assumed to have a constant value of 11.0 barns, except for an unresolved resonance region that was assumed to extend from 2.5 eV to 1 keV. From 0.1 MeV to 1 MeV, optical model calculations were used, with a modification to include an estimated correction for compound nucleus elastic scattering. From 1 MeV to 20 MeV, the cross

section values were calculated from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies below 0.01 MeV, the elastic scattering angular distribution was assumed to be isotropic in the center-of-mass system. From 0.15 to 20 MeV, the angular distributions were calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering reaction was assumed to have a threshold at 0.05 MeV and to rise above the threshold in the usual sigmoid shape, reaching an effective plateau at about 0.5 MeV. The reaction continued to higher energies where it was derived by finding the difference between an assumed nonelastic cross section and the sum of the fission and capture cross sections. The threshold of the $n,2n$ reaction is at 4.81 MeV. For energies greater than the threshold of the $n,2n$ reaction,

Thorium-233

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	43	2/14/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	15	2/14/76	0.0000+ 0	2.0000- 1	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	34	2/14/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	34	2/14/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	21	2/14/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	17	2/14/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	21	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	19	2/14/76	-4.7800+ 0	4.8100+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	16	2/14/76	-4.7800+ 0	4.8100+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	20	12/03/76	-4.7800+ 0	4.8100+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	13	12/03/76	-4.7800+ 0	4.8100+ 0	2.0000+ 1
N,3N	CROSS SECTION	14	2/14/76	-1.1220+ 1	1.1270+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	6	2/14/76	-1.1220+ 1	1.1270+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1220+ 1	1.1270+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1220+ 1	1.1270+ 1	2.0000+ 1
N,4N	CROSS SECTION	5	2/14/76	-1.6340+ 1	1.6340+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	4	2/14/76	-1.6340+ 1	1.6420+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	3	12/03/76	-1.6340+ 1	1.6411+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	3	12/03/76	-1.6340+ 1	1.6411+ 1	2.0000+ 1
N,F	CROSS SECTION	130	2/14/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	5	2/14/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	2/14/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8000- 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	121	5/29/76	6.1800+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.1800+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.1800+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.1800+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.1800+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1

DELAYED

the inelastic scattering cross section was assumed to decrease as competitive processes became energetically possible. In accordance with the usual systematics for these elements, the inelastic scattering falls to an effectively constant value, which represents direct-interaction plus pre-equilibrium reactions. The cross section for the total inelastic scattering process was assumed to remain constant at a value of 0.3 barn from 17 to 20 MeV.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering processes were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model -- a "temperature" component plus a "pre-

equilibrium and unresolved direct-interaction" component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The threshold for the n,2n reaction is 4.81 MeV. Above threshold, the n,2n reaction cross section rises in the usual systematic way, as described in UCRL-50400, Vol. 15, Part A, p. 23. It reaches a plateau at about 7 MeV, and continues parallel to the non-elastic cross section at the higher energies. The opening of the n,3n channel at 11 MeV causes a decrease in the n,2n cross section, and the opening of the n,4n channel at 16.5 MeV causes a further decrease. Between 13.5 MeV and 17.0 MeV, the n,2n cross section has a value of 0.75 barns.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form and are derived from temperature model calculations, with the assigned

temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is 11.27 MeV. The cross section is assumed to rise in the usual shape from threshold to a plateau region at 13 MeV, where it has a value of about 1 barn. This value was obtained by subtracting the sum of the other inelastic reactions from the total nonelastic cross section. The n,3n cross section is almost constant from 13 to 17 MeV, and it decreases above this energy due to competition from the n,4n reaction, reaching a value of 0.55 barn at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction was assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction were obtained in a manner similar to the method described above for the n,2n reaction, with a proper accounting made of the neutron multiplicity and the average neutron energy.

n,4n CROSS SECTION

The threshold for the n,4n reaction is 16.42 MeV. The cross section was

assumed to rise linearly from threshold to a value of 0.5 barn at 17.6 MeV, and then remain constant to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,4n REACTION

The angular distribution of secondary neutrons from the n,4n reaction was assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons was obtained as described above for the n,2n and n,3n secondaries.

FISSION CROSS SECTION

An estimated value of 15 barns was assumed for the fission cross section at 0.025 eV. This value was then extrapolated on a $1/v$ basis down to an energy of 10^{-10} MeV and up to an energy of 2.5 eV. An unresolved resonance region was assumed to extend from 2.5 eV to 1 keV. Above 1 keV, the cross section was extrapolated smoothly up to the three experimental data points between 1.5 and 2 MeV (UCRL-50400, Vol. 7, Part B, Rev. 1, p. 10-91). Above 2 MeV the fission cross section was obtained from nuclear systematics.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

In the absence of data, the values for $\bar{\nu}$ were obtained from systematics [UCRL-50400, Vol. 15, Part A, p. 54;

Nucl. Sci. Eng. 62, 438 (1977)]. At the higher energies, the values for $\bar{\nu}$ were obtained by using the slope predicted from fission systematics, taking into account the onset of the $n, n'f$, $n, 2nf$, and $n, 3nf$ reactions.

FISSION SPECTRUM

The fission temperature was obtained in accordance with the systematics of Howerton and Doyas [*Nucl. Sci. Eng.* 40, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum was calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission was entered as a multiplicity applied to the fission cross section. The photon multiplicity in the lower energy range was obtained by assuming a total photon energy from fission of 6.2 MeV, and dividing this value by the average energy in the photon spectrum. The spectrum of photons from Th^{233} fission was assumed to be the same as

the spectrum of photons from U^{235} fission.

CROSS SECTION FOR THE (n, γ) REACTION

The Q-value for the n, γ reaction is 6.18 MeV. An estimated value of 1400 barns was assumed for the capture cross section at 0.025 eV. This value was then extrapolated on a $1/v$ basis down to an energy of 10^{-10} MeV and up to an energy of 2.5 eV. An unresolved resonance region was assumed to extend from 2.5 eV to 1 keV. Above 1 keV the n, γ cross section was obtained from systematics, (UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction was handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions were derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons was assumed to be the same as that for the measured U^{238} photon spectrum.

$n, X\gamma$ CROSS SECTION

For energies below 50 keV, photon production was assumed to originate only from capture and fission processes. From 50 keV to 20 MeV, the

NXGAMEL code was used to calculate the photon cross sections and spectra.

This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 50 keV (except for the fission and capture photons) were calculated by using the NXGAMEL code.

Uranium-233

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{233}_{92}\text{U}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, values derived from ENDF/B MAT-1260 were used with some modification for the elastic scattering, capture, and fission cross sections below 60 eV.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for ^{233}U are shown graphically on pp. 11-19 to 11-32 of UCRL-50400, Vol. 7, Part B, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

As stated above, values derived from ENDF/B MAT-1260 were used with some modification for incident neutron energies below 60 eV. The experimental elastic scattering data, which cover this same energy range, are shown on p. 11-33 of UCRL-50400, Vol. 7, Part B, Rev. 1, and the evaluated curve is shown on p. 11-34 of this same reference. From 60 eV to 500 keV, the evaluated cross sections were

obtained by subtracting the nonelastic cross section from the measured total cross section. Values at the higher neutron energies were obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies below 40 keV, the elastic scattering was assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions were calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section has a threshold at 0.1 MeV. It rises to a plateau at 4 MeV, and it falls off sharply above 6 MeV due to the onset of the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n' reaction cross section was assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

Uranium-233

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	343	6/15/73	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	20	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	33	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	33	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	32	3/13/70	0.0000+ 0	1.0000- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	11	11/03/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	1.0000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	14	12/03/76	0.0000+ 0	1.0000- 1	2.0000+ 1
N,2N	CROSS SECTION	12	12/28/74	-5.9000+ 0	6.0000+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	8	11/03/72	-5.9000+ 0	6.0000+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	14	12/03/76	-5.9000+ 0	6.0000+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	10	12/03/76	-5.9000+ 0	6.0000+ 0	2.0000+ 1
N,3N	CROSS SECTION	6	12/28/74	-1.3180+ 1	1.3500+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	11/03/72	-1.3180+ 1	1.3500+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	3	12/03/76	-1.3180+ 1	1.3500+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	3	12/03/76	-1.3180+ 1	1.3500+ 1	2.0000+ 1
N,F	CROSS SECTION	1613	5/22/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	5	11/03/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	13	12/24/74	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	3/26/71	1.8000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	1954	6/15/73	6.8400+ 0	1.0000-10	2.0000+ 1
N,G	N ENERGY-ANGLE DIST.	2	2/17/78	6.8400+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.8400+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.8400+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.8400+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	1.0000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	1.0000- 1	2.0000+ 1

DELAYED

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The $n,2n$ threshold is at 5.77 MeV. Since there are no experimental data for this reaction, the cross section was based on systematics. The evaluated $n,2n$ cross section is shown in UCRL-50400, Vol. 15, Part

B. This cross section rises to a peak value of 0.7 barns at 12 MeV, and it then decreases due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form and are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The threshold for the $n,3n$ reaction is at 13.07 MeV. The cross section was assumed to rise in the usual shape from threshold to a plateau region at 18 MeV, where it has a value of about 0.44 barns.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction was assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction were obtained in a manner similar to the method described above for the $n,2n$ reaction, with an

accounting made of the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

Extensive measurements of the fission cross section are shown on pp. 11-34 to 11-52 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on p. 11-65. In the evaluation, which is shown on p. 11-52 of this reference, values derived from ENDF/B MAT-1260 with some modifications were used below 60 eV, and the Behrens and Carlson ratios (private communication) were used above 1 keV, with a normalization to the LLL ENDL fission cross sections for U^{235} . Values between 60 eV and 1 keV were obtained by interpolation, using the experimental data as a guide.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The experimental data and the evaluated values for $\bar{\nu}$ are shown graphically on pp. 11-56 to 11-58 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental values are given on pp. 11-65 and 11-66. Evaluated curves for prompt and delayed $\bar{\nu}$ are shown on pp. 11-58 and 11-59 of this reference. At the higher energies, the values for $\bar{\nu}$ were obtained by using the slope predicted from fission systematics and taking into

account the onset of the $n, n'f$, $n, 2nf$, and $n, 3nf$ reactions.

FISSION SPECTRUM

The fission temperature was obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 48, 414 (1971). Above the thresholds for second-, third- and fourth-chance fission, the spectrum was calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all incident energies, the cross section for photon production from fission was entered as a multiplicity applied to the fission cross section. The photon multiplicity was obtained by assuming a total photon energy from fission of 6.2 MeV, and dividing this value by the average energy in the photon spectrum. The spectrum of photons from U^{233} fission was assumed to be the same as the spectrum of photons from U^{235} fission.

CROSS SECTION FOR THE (n, γ) REACTION

Experimental and evaluated values

for the n,γ cross section are shown on pp. 11-53 to 11-55 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental values are given on p. 11-65. The evaluated cross sections up to 60 eV are based on the data of ENDF/B MAT-1260. From 60 eV to 1 MeV, the cross sections were based on the experimental data. Above 1 MeV, the n,γ cross sections were obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n,γ) REACTIONS

Photon production from the neutron capture reaction was handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions were derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons was assumed to be the same as that for the measured U^{238} photon spectrum.

$n,X\gamma$ CROSS SECTION

For energies below 0.1 MeV, photon production was assumed to originate only from capture and fission processes. From 0.1 to 20 MeV, in the absence of measurements, the photon production cross sections and spectra were calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE $(n,X\gamma)$ PROCESS

As stated in the previous section, the photon spectra associated with total photon production, except for the fission and capture photons, were calculated by using the NXGAMEL code.

Uranium-234

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{92}\text{U}^{234}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

The fission ratio measurements of J. W. Behrens and G. W. Carlson (UCRL-78704, Oct. 12, 1976) were used to evaluate the fission cross section for this isotope; these measurements were normalized to the LLL ENDL fission cross section values for U^{235} . In the absence of data, most of the other evaluated cross sections were obtained from nuclear systematics.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for U^{234} are shown graphically on pp. 11-67 and 11-68 of UCRL-50400, Vol. 7, Part B, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

A thermal neutron value for the elastic scattering cross section is given on p. 11-70 of UCRL-50400, Vol. 7, Part B, Rev. 1. In the evaluation, the elastic cross section was assigned

a value of 12 barns for neutron energies below 10 keV. From 10 keV to 500 keV the cross section was estimated from nuclear systematics. Above 500 keV the values for the elastic cross section were calculated from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies up to 40 keV, the elastic scattering angular distribution was assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV the angular distributions were calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section has a threshold at about 40 keV. It rises sharply above threshold, then more gently, eventually reaching a value of 1.75 barns at 5 MeV. Above 7 MeV the n, n' cross section falls rapidly due to the onset of the $n, 2n$ reaction. Above the $n, 2n$

Uranium-234

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	37	11/03/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	28	11/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	LOCAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	19	11/15/72	0.0000+ 0	4.4000- 2	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	13	11/15/72	0.0000+ 0	4.4000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	23	12/03/76	0.0000+ 0	4.4000- 2	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	16	12/03/76	0.0000+ 0	4.4000- 2	2.0000+ 1
N,2N	CROSS SECTION	13	11/15/72	-6.8400+ 0	6.8700+ 0	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	7	11/15/72	-6.8400+ 0	6.8700+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	16	12/03/76	-6.8400+ 0	6.8700+ 0	2.0000+ 1
N,2N	LOCAL ENERGY DEP.	8	12/03/76	-6.8400+ 0	6.8700+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	11/15/72	-1.2590+ 1	1.2650+ 1	2.0000+ 1
N,3N	ENERGY-ANGLE DIST.	4	11/15/72	-1.2590+ 1	1.2650+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	4	12/03/76	-1.2590+ 1	1.2650+ 1	2.0000+ 1
N,3N	LOCAL ENERGY DEP.	4	12/03/76	-1.2590+ 1	1.2650+ 1	2.0000+ 1
N,F	CROSS SECTION	40	11/22/75	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	ENERGY-ANGLE DIST.	6	11/15/72	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	NEUTRONS/FISSION	7	11/15/72	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	ENERGY DIST.	2	2/15/78	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000- 1	2.0000+ 1
N,G	CROSS SECTION	129	4/03/76	5.3100+ 0	1.0000-10	2.0000+ 1
N,G	ENERGY-ANGLE DIST.	2	2/17/78	5.3100+ 0	1.0000-10	2.0000+ 1
N,G	MULTIPLICITY	2	2/17/78	5.3100+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	5.3100+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	5.3100+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	4.4000- 2	2.0000+ 1
N,XG	ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	4.4000- 2	2.0000+ 1

DELAYED

threshold, the n,n' reaction cross section was assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distributions for inelastic scattering were assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons were derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons were characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The $n,2n$ threshold is at 6.87 MeV. Since there are no experimental data for this reaction, the cross section was based on systematics. The evaluated $n,2n$ cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section rises to a peak value of 0.8 barns at 11.5 MeV and decreases sharply above 13 MeV due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction was assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form and are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The threshold for the $n,3n$ reaction is at 12.64 MeV. The cross section is assumed to rise in the usual shape from threshold up to a plateau region at 16 MeV, where it has a value of about 0.45 barns; it then decreases slowly.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction was assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction were obtained in a manner similar to the method described above for the $n,2n$ reaction, taking into account the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

Extensive measurements of the fission cross section are shown on pp. 11-69 and 11-70 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on p. 11-71. In the evaluation the fission ratio measurements of Behrens and Carlson were used, as cited above; these measurements were normalized to the ENDL evaluated U^{235} fission cross sections.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Two experimental values for $\bar{\nu}$ are given on p. 11-71 of UCRL-50400, Vol. 7, Part B, Rev. 1. In general, the values for $\bar{\nu}$ were obtained from systematics [UCRL-50400, Vol. 15, Part A, p. 54; *Nucl. Sci. Eng.* 62, 438 (1977)]. At the higher energies, the values for $\bar{\nu}$ were obtained by using the slope predicted from fission systematics, taking into account the

onset of the $n,n'f$, $n,2nf$, and $n,3nf$ reactions.

FISSION SPECTRUM

The fission temperature was obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum was calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all incident neutron energies, the cross section for photon production from fission was entered as a multiplicity applied to the fission cross section. The photon multiplicity was obtained by assuming a total photon energy from fission of 6.2 MeV and dividing this value by the average energy in the photon spectrum. The spectrum of photons from U^{234} fission was assumed to be the same as that from U^{235} fission.

CROSS SECTION FOR THE (n,γ) REACTION

The only measured value for the

capture cross section, at thermal neutron energy, is given on p. 11-71 of UCRL-50400, Vol. 7, Part B, Rev.

1. In the absence of other data, the n,γ cross section was determined mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n,γ) REACTIONS

Photon production from the neutron capture reaction was handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions were derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons was assumed to be the same as that for the measured U^{238} photon spectrum.

$n,X\gamma$ CROSS SECTION

For energies below 44 keV, photon

production was assumed to originate only from capture and fission processes. From 44 keV to 20 keV, in the absence of measurements, the photon production cross sections and spectra were calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE $(n,X\gamma)$ PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 44 keV, except for the fission and capture photons, were calculated by using the NXGAMEL code.

Uranium-235

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{92}\text{U}^{235}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, values derived from ENDF/B MAT-1261 were adopted, with some modifications, for the elastic scattering, capture, and fission cross sections up to 82 eV.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for U^{235} are shown graphically on pp. 11-72 to 11-92 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental values are given on pp. 11-159 and 11-160.

ELASTIC SCATTERING CROSS SECTION

As stated above, values derived from ENDF/B MAT-1261 were used, after some modification, for incident neutron energies below 82 eV. Experimental values for the elastic scattering cross section from 0.19 eV to 2.3 MeV are given on pp. 11-93 to 11-95 and 11-160 in UCRL-50400, Vol.

7, Part B, Rev. 1. The experimental data are relatively sparse, so nuclear systematics were used over much of this range. Above 2.3 MeV, values were calculated from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental values are shown in UCRL-50400, Vol. 19 for incident neutron energies between 0.13 and 5.5 MeV. For energies less than or equal to 40 keV, the elastic scattering was assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions were calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The experimental inelastic scattering data are given on pp. 11-7 and 11-8 (graphical displays) and on pp. 11-12 to 11-14 (tabular displays) in UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated, inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section has a threshold at 20 keV

Uranium-235

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	235	1/27/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	28	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	25	12/15/77	0.0000+ 0	2.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	18	12/15/77	0.0000+ 0	2.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	35	12/03/76	0.0000+ 0	2.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	19	12/03/76	0.0000+ 0	2.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	16	12/15/77	-5.2300+ 0	5.2524+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	12/15/77	-5.2300+ 0	5.2524+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	19	12/03/76	-5.2300+ 0	5.2524+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	10	12/03/76	-5.2300+ 0	5.2524+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	1/27/76	-1.2000+ 1	1.2500+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	4	9/22/71	-1.2000+ 1	1.2500+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.2000+ 1	1.2500+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	3	12/03/76	-1.2000+ 1	1.2500+ 1	2.0000+ 1
N,4N	CROSS SECTION	3	5/04/71	-1.7890+ 1	1.7970+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	2	5/04/71	-1.7890+ 1	1.7970+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.7890+ 1	1.7970+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.7890+ 1	1.7970+ 1	2.0000+ 1
N,F	CROSS SECTION	1511	1/26/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	6	3/05/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	11	2/20/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	3/26/71	1.8000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	767	1/10/72	6.5500+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.5500+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.5500+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.5500+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.5500+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	2.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	2.0000- 2	2.0000+ 1

DELAYED

and rises up to a plateau region at about 3 MeV, where it has a value of about 2 barns. It falls off sharply above 6 MeV due to competition from the $n,2n$ and n,n' reactions. Above the $n,2n$ threshold, the n,n' reaction cross section was assumed to be the difference between the non-elastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

INELASTIC SCATTERING ANGULAR AND ENERGY DISTRIBUTIONS

The angular distribution for inelastic scattering was assumed to be isotropic in the laboratory system for all incident neutron energies. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions were derived from a temperature model; above 6 MeV, the secondary neutron distributions are characterized by a two-component model - a temperature component and a pre-equilibrium and unresolved direct-interaction component (see p. 21 of UCRL-50400, Vol. 15, Part A).

$n,2n$ CROSS SECTION

The only two measurements of the $n,2n$ cross section are at 7 and 8 MeV. Hence, the evaluated cross section for this reaction was based mostly on systematics. The evaluated $n,2n$ cross section is shown in

UCRL-50400, Vol. 15, Part B. The $n,2n$ reaction has a threshold at 5.35 MeV. The cross section rises rapidly to a value of about 0.6 barns at 9.0 MeV; it falls off sharply above 12 MeV due to competition from the $n,3n$ reaction, reaching a constant value of 0.2 barns at 16 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction are assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics, as described in UCRL-50400, Vol. 15, Part A, p. 24.

$n,3n$ CROSS SECTION

The threshold for the $n,3n$ reaction is at 12.2 MeV. The $n,3n$ cross section was assumed to rise in the usual shape from threshold to a plateau 17 MeV, then to decrease from 18 to 20 MeV due to competition from the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction was assumed to be isotropic

in the laboratory system. The tabular energy distributions of secondaries from this reaction were obtained in a manner similar to the method described above for the $n,2n$ reaction, taking into account the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 18.0 MeV. The $n,4n$ cross section was assumed to rise in a linear manner from threshold up to a value of 0.15 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction was assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons was obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

Measurements of the fission cross section are shown on pp. 11-96 to 11-135 (graphical) and on pp. 11-160 and 11-161 (tabular) of UCRL-50400, Vol. 7, Part B, Rev. 1. The fission cross sections for neutron energies below 82 eV are derived from ENDF/B MAT-1261. From 82 to 100 eV, a relatively constant value is assumed, which is a rough average of the values

reported in ECSIL Ref. 71-3062. From 100 eV to 0.001 MeV, the structure of ECSIL Ref. 71-3062 is followed. From 0.001 to 1 MeV, the evaluated data are based on the measurements of ECSIL Ref. 75-3899. From 1 to 20 MeV the data of Czirr and Sidhu (ECSIL Ref. 75-3131), as normalized by the experimenters, are used; this choice was made because of the agreement between their 14.6 MeV value and the absolute value measured by M. Cance and G. Grenier (as reported at the NEANDC/NEACRP Specialists Meeting on *Fast Neutron Fission Cross Sections of U^{233} , U^{238} , and Pu^{239}* , held at Argonne National Laboratory June 28-30, 1976). There is, however, a disagreement between the Czirr/Sidhu relative measurements and those of S. Cierjacks, which were also reported at the ANL conference). The Cierjacks results would imply an increase of about 8% in the fission cross section in the 14- to 15-MeV neutron energy range. As stated above, it was the agreement between Czirr/Sidhu and Cance/Grenier that led to the choice made for this evaluation.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The experimental data and the evaluated values for prompt $\bar{\nu}$ are shown graphically on pp. 11-143 to 11-149 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental

values are given on pp. 11-161 and 11-162. Corresponding values for delayed $\bar{\nu}$ are given on p. 11-150 (graphical) and on p. 11-162 (tabular) of this same reference. Both of these quantities are included in the evaluation, as shown in UCRL-50400, Vol. 15, Part B. The experimental values for both prompt and delayed $\bar{\nu}$ extend over most of the energy range involved in the evaluation.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* **40**, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity

is obtained by assuming a total photon energy from fission of 6.2 MeV, and dividing this value by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

Measurements of the capture cross section are given on pp. 11-136 to 11-142 of UCRL-50400, Vol. 7, Part B, Rev. 1; tabular values are given on p. 11-161. The values below 82 eV are derived from ENDF/B MAT-1261. From 82 eV to 0.003 MeV, a rough average of the data of ECSIL Ref. 67-1025 is used. From 0.003 to 0.018 MeV, the cross section is smoothly interpolated to match the experimental values up to 1.0 MeV of ECSIL Ref. 66-1025. From 1.0 to 20.0 MeV, the values adopted were obtained from systematics.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

Photon production from capture and fission processes is handled explicitly, as described above. Measurements of the total photon production cross section are shown on p. 11-11 of UCRL-50400, Vol. 8, Rev. 1, Part B. For neutron energies between 20 keV and 20 MeV, the photon production cross sections and spectra are calculated with the NXGAMEL code; these calculations include photons from all reactions. The NXGAMEL code is based on systematics described by Perkins, Haight, and Howerton [*Nucl.*

Sci. Eng. 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production (except for the fission and capture photons) are calculated by using the NXGAMEL code.

Uranium-236

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{92}\text{U}^{236}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for U^{236} are shown graphically on pp. 11-163 and 11-164 of UCRL-50400, Vol. 7, Part B, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

The only experimental datum on elastic scattering for this isotope is a single thermal cross section value that is given on p. 11-170 of UCRL-50400, Vol. 7, Part B, Rev. 1. In the evaluation, the U^{236} elastic cross section is assigned a value of 12 barns for neutron energies below 10 keV. Above 50 keV, values for the elastic cross section are calculated from a spherical optical model, using the best fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)]. Values between 10 and 50 keV are obtained by interpolation on the basis of nuclear systematics.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies up to 40 keV the elastic scattering angular distribution is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section has a threshold at about 50 keV. It rises sharply to a value of about 2.25 barns in the plateau region (from 2 to 6 MeV), and it falls off rapidly above 6.5 MeV due to competition from the $n,2n$ and nn' reactions. Above the $n,2n$ threshold, the n,n' reaction cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	35	11/15/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	28	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	21	11/15/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	13	11/15/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	29	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	16	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	14	11/15/72	-6.5500- 0	6.5800+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	11/15/72	-6.5500- 0	6.5800+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	19	12/03/76	-6.5500- 0	6.5800+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	9	12/03/76	-6.5500- 0	6.5800+ 0	2.0000+ 1
N,3N	CROSS SECTION	8	12/28/74	-1.1850+ 1	1.1910+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	11/15/72	-1.1850+ 1	1.1910+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1850+ 1	1.1910+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1850+ 1	1.1910+ 1	2.0000+ 1
N,F	CROSS SECTION	40	2/02/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	6	11/15/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	6	11/15/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	127	10/27/75	5.1200+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.1200+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.1200+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.1200+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.1200+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1

DELAYED

for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The n,2n threshold is at 6.57 MeV. Since there are no experimental data for this reaction, the cross section is based on systematics. The evaluated n,2n cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section rises to a peak value of 1.2 barns at 11 MeV, and it decreases sharply above 12 MeV due to competition from the n,3n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 11.9 MeV. The cross section is assumed to rise in the usual shape from threshold up to a plateau region at 14 MeV, where it has a value of about 0.7 barn; it then decreases slowly.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction, taking into account the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

Measurements of the fission cross

section are shown on pp. 11-165 to 11-167 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on p. 11-170. The evaluated data were based on the LLL ratio measurements of Behrens and Carlson for energies above 0.17 MeV. The ENDL U²³⁵ fission cross sections are used for the normalization. At lower energies, the subthreshold fission cross section follows the general trend but not the detailed structure of the data in ECSIL Ref. 70-943 from 30 eV to 0.002 MeV. Between 0.002 MeV and 0.17 MeV and from 0.0001 eV to 30 eV the cross section is based on systematics.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Experimental values for $\bar{\nu}$ are given on pp. 11-169 and 11-170 of UCRL-50400, Vol. 7, Part B, Rev. 1. In general, the $\bar{\nu}$ values are obtained as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ were obtained by using the slope predicted from fission systematics, taking into account the onset of the n,n'f, n,2nf, and n,3nf reactions.

FISSION SPECTRUM

The fission temperature was obtained in accordance with the systematics of Howerton and Doyas [*Nucl.*

Sci. Eng. 46, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum was calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all incident neutron energies, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV and then dividing this value by the average energy in the photon spectrum. The spectrum of photons from U²³⁴ fission is assumed to be the same as the spectrum of photons from U²³⁵ fission.

CROSS SECTION FOR THE (n, γ) REACTION

Experimental data for the n, γ capture reaction are given on pp. 11-167 and 11-168 of UCRL-50400, Vol. 7, Part B, Rev. 1; some thermal data are given on p. 11-170. In the absence of other data, the n, γ cross section is determined in part from systematics [UCRL-50400, Vol. 15,

Part A, pp. 29 to 31]. Some unidentified low-energy, total cross section peaks are attributed to corresponding peaks in the capture cross section.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 50 keV, photon production is assumed to originate only from capture and fission processes. This assumption ignores photon production from inelastic

scattering below 50 keV, but the uncertainties in the various cross sections and spectra are larger than any reasonably assumed contribution from inelastic scattering in this range. From 50 keV to 20 MeV, in the absence of measurements, the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 50 keV (except for the fission and capture photons) were calculated by using the NXGAMEL code.

Uranium-237

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{92}\text{U}^{237}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

Since the only experimental data that exist for this isotope are fission and absorption data, most of the evaluated cross sections are obtained from nuclear systematics.

TOTAL CROSS SECTION

The evaluated total cross sections for U^{237} are shown graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

For energies below 50 keV, the elastic cross section is obtained from systematics; it is kept at an almost constant value of about 12 barns. Above 50 keV the values for the elastic cross section are calculated from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies up to 40 keV the

elastic scattering angular distribution is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section has a threshold at 20 keV. It rises rapidly to a value of 2.5 barns from 3 to 5 MeV, and it falls rapidly above 5 MeV due to the onset of the $n,2n$ and nn' reactions. Above the $n,2n$ threshold, the n,n' reaction cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncer-

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	45	6/08/78	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	20	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	35	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	35	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	31	6/08/78	0.0000+ 0	2.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	11	11/15/72	0.0000+ 0	2.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	26	12/03/76	0.0000+ 0	2.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	17	12/03/76	0.0000+ 0	2.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	11	11/15/72	-5.1200+ 0	5.1500+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	11/15/72	-5.1200+ 0	5.1500+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	15	12/03/76	-5.1200+ 0	5.1500+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	11	12/03/76	-5.1200+ 0	5.1500+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	11/15/72	-1.1670+ 1	1.1720+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	11/15/72	-1.1670+ 1	1.1720+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1670+ 1	1.1720+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1670+ 1	1.1720+ 1	2.0000+ 1
N,F	CROSS SECTION	104	6/08/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	5	11/15/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	7	11/15/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	173	6/08/78	6.1400+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.1400+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.1400+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.1400+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.1400+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	2.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	2.0000- 2	2.0000+ 1

DELAYED

tainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The n,2n threshold is at 5.15 MeV. Since there are no experimental data for this reaction, the cross section is based on systematics. The evaluated n,2n cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section rises rapidly from threshold to a plateau region ranging from 7.5 to 11.5 MeV, where it has a value of about 1.3 barns. Above 11.5 MeV the n,2n cross section falls off sharply due to competition from the n,2n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 11.72 MeV. The cross section is assumed to rise in the usual shape from threshold up to a plateau region at 15 MeV, where it has a value of about 0.85 barn. It then decreases with the onset of n,3nf process.

ANGULAR AND ENERGY DISTRIBUTIONS FOR n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction. The method takes into account the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

Experimental fission measurements for neutron energies between 45 eV and 1 keV and from 100 keV to 5 MeV are shown on p. 11-171 to UCRL-50400, Vol. 7, Part B, Rev. 1. The evaluated fission cross section curve plus some tabulated fission data are shown on p. 11-172 of that reference. From 0.0001 eV to 0.55 eV, the cross section is assumed to be constant at the measured thermal value of 0.35 barns. From 0.55 eV to 45 eV it is assumed that there is an unresolved resonance region in the subthreshold fission cross section. From 45 eV to 1 keV the fission cross section follows the general trends of the measured data from the Pommard bomb shot experiment. From 1 keV to 0.1 MeV a smooth interpolation between the measurements is used. For energies greater than 0.1 MeV, the general trend of the Pommard data is followed to 0.5 MeV. Above 0.5 MeV, a smooth interpolation is made to the 1.5 MeV value reported in ECSIL Ref. 70-2273. The values of Ref. 70-2273 are used from 1.5 to 2.25 MeV. In the energy range from 2.25 to 20 MeV, the systematics of fission cross sections were used as the basis of the evaluation.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

In the absence of data, the values

for $\bar{\nu}$ are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained by using the slope predicted from fission systematics. The method takes into account the onset of the n,n'f, n,2nf, and n,3nf reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971).

Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by first assuming a total photon energy from fission of

6.2 MeV and then dividing this value by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

In the absence of data, the n, γ cross section is determined from the systematics described in UCRL-50400, Vol. 15, Part A, pp. 29-31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 20 keV, photon production is assumed to originate only from capture and fission processes. From 20 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 20 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Uranium-238

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{92}\text{U}^{238}$ are summarized of UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, values derived from ENDF/B MAT-1262 were adopted, with some modifications, for the elastic scattering and capture cross sections below 1 keV.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for U^{238} are shown graphically on pp. 11-173 to 11-185 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental values are given on p. 11-203.

ELASTIC SCATTERING CROSS SECTION

Experimental elastic scattering cross-section values that extend up to 1.5 MeV are shown graphically on p. 11-186 of UCRL-50400, Vol. 7, Part B, Rev. 1; some values at higher energies are given in tabular form on p. 11-204. As stated above, values derived from ENDF/B MAT-1262 are used with some modification for energies less than 1 keV. For energies greater than 1 keV the values were obtained by differencing the measured

total cross sections and the evaluated nonelastic cross section.

ELASTIC SCATTERING ANGULAR DISTRIBUTION

Experimental elastic scattering angular distributions are shown in UCRL-50400, Vol. 19. For energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. For energies of 75 keV and above, the elastic scattering angular distributions are taken from experimental measurements and from optical model calculations, using the spherical optical model parameters of Becchetti and Greenlees (the best-fit values are given in *Phys. Rev.* 182, 1190 (1969)).

INELASTIC SCATTERING CROSS SECTION

The experimental inelastic scattering data are given on pp. 11-19 to 11-21 (graphical displays) and on p. 11-30 (tabular values) in UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated inelastic scattering cross sections are shown in UCRL-50400, Vol. 15, Part B. In the evaluation, the total inelastic scattering cross section is composed of contributions from 21 inelastic levels plus a contribution from the n, n' continuum. The total n, n' cross section falls off sharply above 6 MeV

Uranium-238

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	453	11/05/75	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	27	11/05/75	0.0000+ 0	1.0000- 2	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	36	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	36	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	22	2/02/76	0.0000+ 0	1.9000+ 0	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	10	11/05/75	0.0000+ 0	1.9000+ 0	2.0000+ 1	
N,N'	N TOTAL ENERGY DEP.	10	12/03/76	0.0000+ 0	1.9000+ 0	2.0000+ 1	
N,N'	N LOCAL ENERGY DEP.	9	12/03/76	0.0000+ 0	1.9000+ 0	2.0000+ 1	
N,N'	CROSS SECTION	21	2/02/76	0.0000+ 0	4.5189- 2	2.0000+ 1	LEVEL = 4.5000- 2 MEV
N,N'	N ANGULAR DIST.	9	11/05/75	0.0000+ 0	4.5189- 2	2.0000+ 1	LEVEL = 4.5000- 2 MEV
N,N'	N TOTAL ENERGY DEP.	9	12/03/76	0.0000+ 0	4.5189- 2	2.0000+ 1	LEVEL = 4.5000- 2 MEV
N,N'	N LOCAL ENERGY DEP.	9	12/03/76	0.0000+ 0	4.5189- 2	2.0000+ 1	LEVEL = 4.5000- 2 MEV
N,N'	CROSS SECTION	13	2/02/76	0.0000+ 0	1.4862- 1	2.0000+ 1	LEVEL = 1.4800- 1 MEV
N,N'	N ANGULAR DIST.	6	11/05/75	0.0000+ 0	1.4862- 1	2.0000+ 1	LEVEL = 1.4800- 1 MEV
N,N'	N TOTAL ENERGY DEP.	7	12/03/76	0.0000+ 0	1.4862- 1	2.0000+ 1	LEVEL = 1.4800- 1 MEV
N,N'	N LOCAL ENERGY DEP.	7	12/03/76	0.0000+ 0	1.4862- 1	2.0000+ 1	LEVEL = 1.4800- 1 MEV
N,N'	CROSS SECTION	8	2/02/76	0.0000+ 0	3.0929- 1	2.0000+ 1	LEVEL = 3.0800- 1 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	3.0929- 1	2.0000+ 1	LEVEL = 3.0800- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	3.0929- 1	2.0000+ 1	LEVEL = 3.0800- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	3.0929- 1	2.0000+ 1	LEVEL = 3.0800- 1 MEV
N,N'	CROSS SECTION	17	11/05/75	0.0000+ 0	6.8305- 1	4.0000+ 0	LEVEL = 6.8000- 1 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	6.8305- 1	2.0000+ 1	LEVEL = 6.8000- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	6.8305- 1	4.0000+ 0	LEVEL = 6.8000- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	6.8305- 1	4.0000+ 0	LEVEL = 6.8000- 1 MEV
N,N'	CROSS SECTION	16	11/05/75	0.0000+ 0	7.3507- 1	4.0000+ 0	LEVEL = 7.3200- 1 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	7.3507- 1	2.0000+ 1	LEVEL = 7.3200- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	7.3507- 1	4.0000+ 0	LEVEL = 7.3200- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	7.3507- 1	4.0000+ 0	LEVEL = 7.3200- 1 MEV
N,N'	CROSS SECTION	13	11/05/75	0.0000+ 0	8.3047- 1	4.0000+ 0	LEVEL = 8.2700- 1 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	8.3047- 1	2.0000+ 1	LEVEL = 8.2700- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	8.3047- 1	4.0000+ 0	LEVEL = 8.2700- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	8.3047- 1	4.0000+ 0	LEVEL = 8.2700- 1 MEV
N,N'	CROSS SECTION	14	11/05/75	0.0000+ 0	9.3390- 1	4.0000+ 0	LEVEL = 9.3000- 1 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	9.3390- 1	2.0000+ 1	LEVEL = 9.3000- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	9.3390- 1	4.0000+ 0	LEVEL = 9.3000- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	9.3390- 1	4.0000+ 0	LEVEL = 9.3000- 1 MEV
N,N'	CROSS SECTION	12	11/05/75	0.0000+ 0	9.7106- 1	4.0000+ 0	LEVEL = 9.6700- 1 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	9.7106- 1	2.0000+ 1	LEVEL = 9.6700- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	9.7106- 1	4.0000+ 0	LEVEL = 9.6700- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	9.7106- 1	4.0000+ 0	LEVEL = 9.6700- 1 MEV
N,N'	CROSS SECTION	12	11/05/75	0.0000+ 0	1.0040+ 0	4.0000+ 0	LEVEL = 1.0000+ 0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	1.0040+ 0	2.0000+ 1	LEVEL = 1.0000+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0040+ 0	4.0000+ 0	LEVEL = 1.0000+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0040+ 0	4.0000+ 0	LEVEL = 1.0000+ 0 MEV
N,N'	CROSS SECTION	12	11/05/75	0.0000+ 0	1.0453+ 0	4.0000+ 0	LEVEL = 1.0410+ 0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	1.0453+ 0	2.0000+ 1	LEVEL = 1.0410+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0453+ 0	4.0000+ 0	LEVEL = 1.0410+ 0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0453+ 0	4.0000+ 0	LEVEL = 1.0410+ 0 MEV
N,N'	CROSS SECTION	12	11/05/75	0.0000+ 0	1.0644+ 0	4.0000+ 0	LEVEL = 1.0600+ 0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	1.0644+ 0	2.0000+ 1	LEVEL = 1.0600+ 0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.0644+ 0	4.0000+ 0	LEVEL = 1.0600+ 0 MEV

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	REACTION	POINTS	DATE	Q-VALUE	E-MULT.	E-MA*		
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.0644+0	4.0000+0	LEVEL	1.0600+0 MEV
N,N'	N CROSS SECTION	12	11/05/75	0.0000+0	1.1247+0	4.0000+0	LEVEL	1.1200+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.1247+0	4.0000+0	LEVEL	1.1200+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.1247+0	4.0000+0	LEVEL	1.1200+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.1247+0	4.0000+0	LEVEL	1.1200+0 MEV
N,N'	N CROSS SECTION	10	11/05/75	0.0000+0	1.1649+0	4.0000+0	LEVEL	1.1600+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.1649+0	2.0000+1	LEVEL	1.1600+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.1649+0	4.0000+0	LEVEL	1.1600+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.1649+0	4.0000+0	LEVEL	1.1600+0 MEV
N,N'	N CROSS SECTION	11	11/05/75	0.0000+0	1.2251+0	4.0000+0	LEVEL	1.2200+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.2251+0	2.0000+1	LEVEL	1.2200+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.2251+0	4.0000+0	LEVEL	1.2200+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.2251+0	4.0000+0	LEVEL	1.2200+0 MEV
N,N'	N CROSS SECTION	10	11/05/75	0.0000+0	1.2753+0	4.0000+0	LEVEL	1.2700+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.2753+0	2.0000+1	LEVEL	1.2700+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.2753+0	4.0000+0	LEVEL	1.2700+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.2753+0	4.0000+0	LEVEL	1.2700+0 MEV
N,N'	N CROSS SECTION	9	11/05/75	0.0000+0	1.3054+0	4.0000+0	LEVEL	1.3000+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.3054+0	2.0000+1	LEVEL	1.3000+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.3054+0	4.0000+0	LEVEL	1.3000+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.3054+0	4.0000+0	LEVEL	1.3000+0 MEV
N,N'	N CROSS SECTION	9	11/05/75	0.0000+0	1.3667+0	4.0000+0	LEVEL	1.3600+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.3667+0	2.0000+1	LEVEL	1.3600+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.3667+0	4.0000+0	LEVEL	1.3600+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.3667+0	4.0000+0	LEVEL	1.3600+0 MEV
N,N'	N CROSS SECTION	8	11/05/75	0.0000+0	1.4149+0	4.0000+0	LEVEL	1.4100+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.4149+0	2.0000+1	LEVEL	1.4100+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.4149+0	4.0000+0	LEVEL	1.4100+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.4149+0	4.0000+0	LEVEL	1.4100+0 MEV
N,N'	N CROSS SECTION	9	11/05/75	0.0000+0	1.4430+0	4.0000+0	LEVEL	1.4370+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.4430+0	4.0000+0	LEVEL	1.4370+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.4430+0	4.0000+0	LEVEL	1.4370+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.4430+0	4.0000+0	LEVEL	1.4370+0 MEV
N,N'	N CROSS SECTION	11	11/05/75	0.0000+0	1.4761+0	4.0000+0	LEVEL	1.4700+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.4761+0	4.0000+0	LEVEL	1.4700+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.4761+0	4.0000+0	LEVEL	1.4700+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.4761+0	4.0000+0	LEVEL	1.4700+0 MEV
N,N'	N CROSS SECTION	13	11/05/75	0.0000+0	1.6318+0	5.0000+0	LEVEL	1.6250+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.6318+0	5.0000+0	LEVEL	1.6250+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.6318+0	5.0000+0	LEVEL	1.6250+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.6318+0	5.0000+0	LEVEL	1.6250+0 MEV
N,N'	N CROSS SECTION	11	11/05/75	0.0000+0	1.8829+0	5.0000+0	LEVEL	1.8750+0 MEV
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+0	1.8829+0	5.0000+0	LEVEL	1.8750+0 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+0	1.8829+0	5.0000+0	LEVEL	1.8750+0 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+0	1.8829+0	5.0000+0	LEVEL	1.8750+0 MEV
N,N'	N CROSS SECTION	15	12/15/71	-6.0403+0	6.0656+0	2.0000+1		
N,N'	N ENERGY-ANGLE DIST.	3	2/09/74	-6.0400+0	6.0656+0	2.0000+1		
N,N'	N TOTAL ENERGY DEP.	17	12/03/76	-6.0400+0	6.0656+0	2.0000+1		
N,N'	N LOCAL ENERGY DEP.	11	12/03/76	-6.0400+0	6.0656+0	2.0000+1		
N,N'	N CROSS SECTION	3	2/02/76	-1.1450+1	1.1500+1	2.0000+1		
N,N'	N ENERGY-ANGLE DIST.	6	2/09/74	-1.1450+1	1.1500+1	2.0000+1		
N,N'	N TOTAL ENERGY DEP.	5	12/03/76	-1.1450+1	1.1500+1	2.0000+1		

Uranium-238 (Cont.)

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1450+ 1	1.1500+ 1	2.0000+ 1	
N,4N	N CROSS SECTION	3	3/12/71	-1.7820+ 1	1.8000+ 1	2.0000+ 1	
N,4N	N ENERGY-ANGLE DIST.	2	2/09/74	-1.7820+ 1	1.8000+ 1	2.0000+ 1	
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.7820+ 1	1.8000+ 1	2.0000+ 1	
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.7820+ 1	1.8000+ 1	2.0000+ 1	
N,F	N CROSS SECTION	41	2/02/76	1.8000+ 2	4.5000+ 1	2.0000+ 1	
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	4.5000+ 1	2.0000+ 1	
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	4.5000+ 1	2.0000+ 1	
N,F	N ENERGY-ANGLE DIST.	8	1/17/70	1.8000+ 2	4.5000+ 1	2.0000+ 1	
N,F	N NEUTRONS/FISSION	5	12/24/74	1.8000+ 2	4.5000+ 1	2.0000+ 1	
N,F	G ENERGY DIST.	2	2/16/78	1.8000+ 2	4.5000+ 1	2.0000+ 1	
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	4.5000+ 1	2.0000+ 1	
N,F	N NEUTRONS/FISSION	4	3/26/71	1.8000+ 2	4.5000+ 1	2.0000+ 1	DELAU
N,G	G CROSS SECTION	1473	4/03/76	4.8000+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	4.8000+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	2/17/78	4.8000+ 0	1.0000-10	2.0000+ 1	
N,G	G TOTAL ENERGY DEP.	2	11/21/76	4.8000+ 0	1.0000-10	2.0000+ 1	
N,J	G LOCAL ENERGY DEP.	2	11/21/76	4.8000+ 0	1.0000-10	2.0000+ 1	
N,XG	G CROSS SECTION	12	2/10/78	0.0000+ 0	1.0000+ 0	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	12	2/18/78	0.0000+ 0	1.0000+ 0	2.0000+ 1	
N,XG	G CROSS SECTION	10	1/29/73	0.0000+ 0	5.0000- 2	1.0000+ 0	PHOTON = 5.0000- 2 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	5.0000- 2	2.0000+ 1	PHOTON = 5.0000- 2 MEV
N,XG	G CROSS SECTION	9	1/29/73	0.0000+ 0	1.5000- 1	1.0000+ 0	PHOTON = 1.0000- 1 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.5000- 1	2.0000+ 1	PHOTON = 1.0000- 1 MEV
N,XG	G CROSS SECTION	9	1/29/73	0.0000+ 0	1.5100- 1	1.0000+ 0	PHOTON = 1.5000- 1 MEV
N,XG	G ANGULAR DIST.	2	5/31/73	0.0000+ 0	1.5100- 1	2.0000+ 1	PHOTON = 1.5000- 1 MEV

due to competition from the $n,2n$ reaction. The threshold for n,n' scattering is at 45 keV (the energy of the first inelastic level). The total n,n' cross section is held constant for neutron energies between 10 and 20 MeV to account for pre-equilibrium and unresolved direct-interaction cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium

process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

Experimental data for the $n,2n$ reaction are shown graphically on pp. 11-22 and 11-23 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabulated values are given on p. 11-31. The evaluated $n,2n$ cross section is shown graphically in UCRL-50400, Vol. 15, Part B. The threshold for the $n,2n$ reaction is at 6.17 MeV. At neutron energies up to 16 MeV, the $n,2n$ evaluation is based on experimental data. For energies above 16 MeV, the $n,2n$ cross section is assigned a linearly decreasing value due to competition from the $n,3n$ and $n,4n$ reactions.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

$n,3n$ CROSS SECTION

Experimental data for the $n,3n$

reaction are shown graphically on pp. 11-23 and 11-24 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabulated values are given on p. 11-31. The threshold for the $n,3n$ reaction is at 11.32 MeV. The evaluated $n,3n$ cross section curve is shown in UCRL-50400, Vol. 15, Part B. The $n,3n$ cross section rises rapidly above threshold up to a plateau region that extends from 16 to 18 MeV. Above 18 MeV the $n,3n$ cross section falls due to competition from the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method takes into account the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The $n,4n$ cross section has a threshold at 17.89 MeV. Tabular values of the two measured data points are given on p. 11-31 of UCRL-50400, Vol. 8, Rev. 1, Part B; the evaluated $n,4n$ cross section curve is shown in UCRL-50400, Vol. 15, Part B. The

$n,4n$ cross section rises almost linearly from threshold to a value of 0.35 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

Experimental measurements of the U^{238} fission cross section are shown graphically on pp. 11-187 to 11-192 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental values are given on p. 11-204. The fission cross sections for the ENDL U^{238} evaluation are based on the LLL ratio measurements of Behrens and Carlson, normalized to the ENDL U^{235} evaluated fission cross section. The evaluated cross section is shown graphically on p. 11-191 of UCRL-50400, Vol. 7, Part B, Rev. 1.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The experimental data and the evaluated values for prompt $\bar{\nu}$ are shown graphically on pp. 11-199 to 11-201 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental

values are given on p. 11-205. Corresponding values for delayed $\bar{\nu}$ are given on p. 11-202 (graphical) and on p. 11-206 (tabular) of this same reference. Plots of these quantities are shown in UCRL-50400, Vol. 15, Part B. The measurements of prompt $\bar{\nu}$ extend over the entire range of energies used in the evaluation. The measurements of delayed $\bar{\nu}$ extend to about 7 MeV, with some measurements at 14 to 15 MeV. In the evaluation, the value for delayed $\bar{\nu}$ is held constant at a value of 0.03 for all neutron energies above 9 MeV.

FISSION SPECTRUM

Measurements of the U^{238} fission temperature are listed in UCRL-50400, Vol. 3. Fission temperatures for the U^{238} evaluation are obtained by combining this experimental information with the systematics of Howerton and Doyas [*Nucl. Sci. Eng.* 46, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by first assuming a total photon energy from fission of 6.2 MeV and then dividing this value by the average energy of the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

Measurements of the U^{238} capture cross section are shown graphically on pp. 11-192 to 11-199 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabular values are given on pp. 11-204 and 11-205. As stated above, the evaluated values for the capture cross section below 1 keV are based on the data in ENDF/B MAT-1262. Above 1 keV, the n, γ cross section is obtained from the experimental data, which extend over the entire range of energies covered by the evaluation.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is obtained from

experimental data on thermal neutron capture in U^{238} .

n,X γ CROSS SECTION

Measurements of the partial n,X γ cross section to the continuum extend from 1.09 MeV to 14.8 MeV. However, measurements of the photon production from the excitation of discrete levels extend down to 0.6 MeV. These data are shown in graphical form on pp. 11-25 to 11-28 of UCRL-50400, Vol. 8, Rev. 1, Part B; some tabulated values are given on p. 11-32. In the evaluation, the measured n,X γ cross section values are used to check energies above 1.09 MeV; but the cross section and spectra are obtained from NXGAMEL. Photon production from the lowest levels is included in the form of

line spectra that cover the neutron range from threshold up to 1.09 MeV.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

Photons from the lowest levels in U^{238} inelastic scattering are entered in the form of line spectra for neutron energies up to 1.09 MeV. Photons from intermediate levels in inelastic scattering are entered as a continuum; the spectra of these photons are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975); a summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41. Above 1.09 MeV, the photon spectra are obtained from experimental data.

Uranium-239

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{92}\text{U}^{239}$ consist of just two spectrum-averaged thermal fission measurements and four fission cross section values between 1.5 and 2.5 MeV. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the absence of experimental data, the evaluated cross sections for this isotope are obtained from nuclear systematics.

TOTAL CROSS SECTION

The evaluated total cross sections for U^{239} are shown graphically in UCRL-50400, Vol. 15, Part B. The rise above 1 eV in this cross section corresponds to an assumed unresolved resonance region.

ELASTIC SCATTERING CROSS SECTION

The elastic scattering cross section for energies below 50 keV is kept almost constant at a value of about 12 barns. Between 50 and 500 keV the cross section is obtained from nuclear systematics. For energies above 500 keV, the values for the elastic cross section are based on spherical optical model calculations, using the best-fit optical

model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies up to 40 keV the elastic scattering angular distribution is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section has a threshold at 50 keV. It rises rapidly above 200 keV to a plateau value of 3 barns at 3 MeV, and then falls rapidly above 5 MeV due to the onset of the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n' reaction is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for

Uranium-239

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	48	6/08/78	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	20	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	36	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	LOCAL ENERGY DEP.	36	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	25	6/08/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	12	11/15/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	28	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	18	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	14	11/15/72	-4.8000+ 0	4.8300+ 0	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	7	11/15/72	-4.8000+ 0	4.8300+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	17	12/03/76	-4.8000+ 0	4.8300+ 0	2.0000+ 1
N,2N	LOCAL ENERGY DEP.	10	12/03/76	-4.8000+ 0	4.8300+ 0	2.0000+ 1
N,3N	CROSS SECTION	12	11/15/72	-1.0950+ 1	1.1000+ 1	2.0000+ 1
N,3N	ENERGY-ANGLE DIST.	5	11/15/72	-1.0950+ 1	1.1000+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	5	12/03/76	-1.0950+ 1	1.1000+ 1	2.0000+ 1
N,3N	LOCAL ENERGY DEP.	5	12/03/76	-1.0950+ 1	1.1000+ 1	2.0000+ 1
N,4N	CROSS SECTION	5	11/15/72	-1.6070+ 1	1.6150+ 1	2.0000+ 1
N,4N	ENERGY-ANGLE DIST.	4	11/15/72	-1.6070+ 1	1.6150+ 1	2.0000+ 1
N,4N	TOTAL ENERGY DEP.	3	12/03/76	-1.6070+ 1	1.6150+ 1	2.0000+ 1
N,4N	LOCAL ENERGY DEP.	3	12/03/76	-1.6070+ 1	1.6150+ 1	2.0000+ 1
N,F	CROSS SECTION	160	6/08/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	ENERGY-ANGLE DIST.	4	11/15/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	NEUTRONS/FISSION	2	11/15/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	184	6/08/78	5.9300+ 0	1.0000-10	2.0000+ 1
N,G	ENERGY-ANGLE DIST.	2	2/17/78	5.9300+ 0	1.0000-10	2.0000+ 1
N,G	MULTIPLICITY	2	2/17/78	5.9300+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	5.9300+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	5.9300+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,XG	ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1

DELAYED

inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model -- a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The n,2n threshold is at 4.82 MeV. Since there are no experimental data for this reaction, the cross section is based on systematics. The evaluated n,2n cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section rises rapidly from threshold up to a plateau region ranging from 7 to 11 MeV, where it

has a value of 1.9 barns. Above 11 MeV the n,2n cross section falls off sharply due to competition from the n,3n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 10.99 MeV. The cross section is assumed to rise in the usual shape from threshold up to a plateau region at 13.5 MeV, where it has a value of 1.4 barns. Above 15.5 MeV, the n,3n cross section falls off rapidly due to competition from the n,4n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described

above for the n,2n reaction. The method takes into account the neutron multiplicity and the average neutron energy.

n,4n CROSS SECTION

The threshold for the n,4n cross section is at 16.14 MeV. The cross section is assumed to rise in the usual sigmoid shape to a value of 0.75 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,4n REACTION

The angular distribution of secondary neutrons from the n,4n reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the n,2n and n,3n secondaries.

FISSION CROSS SECTION

Fission cross sections for U^{239} have been measured at thermal neutron energies (spectrum-averaged) and from 1.5 to 2.5 MeV. The thermal fission cross section value is extrapolated on a $1/v$ basis from thermal energies to 1 eV, where an enhancement due to an assumed unresolved resonance region is included. The assumed unresolved resonance region is terminated at 100 eV, and the fission cross section is decreased to match the lower-energy $1/v$ extrapolation. From 100 eV to

1.5 MeV the cross sections are based on the systematics for nonthreshold fission reactions. From 1.5 to 2.5 MeV the available U^{239} fission cross sections are used, and at the higher energies the fission cross section is obtained from nuclear systematics.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

In the absence of data, the values for $\bar{\nu}$ are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained by using the slope predicted from fission systematics. The method takes into account the onset of the n,n'f, n,2nf, n,3nf, and n,4nf reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas [*Nucl. Sci. Eng.* 46, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all neutron energies, the cross section for photon production from fission is entered as a multiplicity that is applied to the fission cross section. The photon multiplicity is obtained by first assuming a total photon energy from fission of 6.2 MeV and then dividing this value by the average energy of the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

In the absence of data, the n, γ cross section is determined from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of

secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n, $X\gamma$ CROSS SECTION

For energies below 50 keV, photon production is assumed to originate only from capture and fission processes. From 50 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400; Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n, $X\gamma$) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 50 keV (except for the fission and capture photons) are calculated by using the NXGAMEL code.

Uranium-240

DATA SUMMARY AND GENERAL COMMENTS

There are no experimental data for ${}^{240}_{92}\text{U}$. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the absence of experimental data, the evaluated cross sections for this isotope are obtained solely on the basis of nuclear systematics.

TOTAL CROSS SECTION

The evaluated total cross sections for ${}^{240}\text{U}$ are shown in UCRL-50400, Vol. 15, Part B. The plateau region in this cross section from 0.5 eV to 100 eV corresponds to an assumed unresolved resonance region.

ELASTIC SCATTERING CROSS SECTION

The elastic scattering cross section for energies below 100 eV is held constant at a value of 8 barns. Between 100 eV and 500 keV the cross section is obtained from systematics. For energies above 500 keV, the values for the elastic cross section are based on spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies up to 40 keV the elastic scattering angular distribution is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 10 keV to a plateau value of about 2.5 barns at about 2 MeV, and falls off rapidly above 6 MeV due to competition from the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n' reaction is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross section.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction

Uranium-240

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	33	11/15/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	28	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	18	11/15/72	0.0000+ 0	1.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	11	11/15/72	0.0000+ 0	1.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	20	12/03/76	0.0000+ 0	1.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	13	12/03/76	0.0000+ 0	1.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	13	11/15/72	-5.9300+ 0	5.9600+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	6	11/15/72	-5.9300+ 0	5.9600+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	20	12/03/76	-5.9300+ 0	5.9600+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	11	12/03/76	-5.9300+ 0	5.9600+ 0	2.0000+ 1
N,3N	CROSS SECTION	10	11/15/72	-1.0740+ 1	1.0800+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	11/15/72	-1.0740+ 1	1.0800+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.0740+ 1	1.0800+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.0740+ 1	1.0800+ 1	2.0000+ 1
N,4N	CROSS SECTION	5	11/15/72	-1.6880+ 1	1.7000+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	3	11/15/72	-1.6880+ 1	1.7000+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	3	12/03/76	-1.6880+ 1	1.7000+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	3	12/03/76	-1.6880+ 1	1.7000+ 1	2.0000+ 1
N,F	CROSS SECTION	17	11/15/72	1.8000+ 2	1.0000+ 0	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000+ 0	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000+ 0	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	6	11/15/72	1.8000+ 2	1.0000+ 0	2.0000+ 1
N,F	N NEUTRONS/FISSION	6	11/15/72	1.8000+ 2	1.0000+ 0	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000+ 0	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000+ 0	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000+ 0	2.0000+ 1
N,G	CROSS SECTION	139	2/27/76	6.0800+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.0800+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.0800+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.0800+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.0800+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	1.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	1.0000- 2	2.0000+ 1

DELAYED

portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The $n,2n$ threshold is at 5.96 MeV. Since there are no experimental data for this reaction, the cross section is based on systematics. The evaluated $n,2n$ cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section rises in the usual shape from threshold up to a value of 1.85 barns at 10 MeV, and then it falls off sharply above 11.5 MeV due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics, as described in UCRL-50400, Vol. 15, Part A, p. 24.

$n,3n$ CROSS SECTION

The threshold for the $n,3n$ reaction is at 10.78 MeV. The cross section is assumed to rise in the usual shape from threshold up to a value of 1.4 barns at 16.5 MeV. Above this energy it decreases sharply due to competition from the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method takes into account the neutron

multiplicity and the average neutron energy.

n,4n CROSS SECTION

The threshold for the n,4n reaction is at 16.95 MeV. This cross section is assumed to rise in the usual sigmoid shape to a value of 0.85 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,4n REACTION

The angular distribution of secondary neutrons from the n,4n reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained in the same manner as described above for the n,2n and n,3n secondaries.

FISSION CROSS SECTION

In the absence of data, the fission cross section for U^{240} is determined entirely from systematics. The effective threshold for this nucleus is at about 1 MeV. The fission cross section rises sharply above 1 MeV, and it exhibits several plateau regions at the higher energies. The regions correspond to the onset of the second-chance, third-chance, etc., fission channels.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

In the absence of data, the values

for $\bar{\nu}$ were obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained by using the slope predicted from fission systematics. The method takes into account the onset of the n,n'f, n,2nf, n,3nf, and n,4nf reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all neutron energies, the cross section for photon production from fission is entered as a multiplicity that is applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV and dividing this value by the average

energy of the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

In the absence of data the n, γ cross section is determined from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n, γ CROSS SECTION

For energies below 10 keV, photon

production is assumed to originate only from capture and fission processes. From 10 keV to 20 MeV (in the absence of measurements), the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n, γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Neptunium-237

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{237}_{93}\text{Np}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out R. J. Howerton.

In the evaluation for this isotope, values derived from ENDF/B MAT-1263 are used, with some modification, for the elastic scattering, capture, and fission cross sections up to 30 eV.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for ${}^{237}_{93}\text{Np}$ are shown graphically on pp. 11-208 to 11-215 of UCRL-50400, Vol. 7, Part B, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

As stated above, values derived from ENDF/B MAT-1263 are used with some modification for incident neutron energies below 36 eV. In the absence of experimental data, values at the higher energies are obtained from nuclear systematics and from calculations based on a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

There are no experimental data for ${}^{237}_{93}\text{Np}$ elastic scattering angular distributions. For energies less than or equal to 40 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

There are no experimental data for this reaction. The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section has a threshold at 35 keV. It rises sharply above threshold, then more gently, reaching a value of 2.1 barns at 5.5 MeV. Above 7 MeV, this cross section falls off sharply due to the onset of the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n' reaction cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for

Neptunium-237

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	423	4/20/73	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	20	5/10/73	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	36	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	36	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	25	3/02/77	0.0000+ 0	3.5000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	12	4/20/73	0.0000+ 0	3.5000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	19	12/03/76	0.0000+ 0	3.5000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	16	12/03/76	0.0000+ 0	3.5000- 2	2.0000+ 1
N,2N	CROSS SECTION	21	3/02/77	-6.5370+ 0	6.5700+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	8	4/20/73	-6.5370+ 0	6.5700+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	19	12/03/76	-6.5370+ 0	6.5700+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	12	12/03/76	-6.5370+ 0	6.5700+ 0	2.0000+ 1
N,3N	CROSS SECTION	9	3/02/77	-1.2310+ 1	1.2400+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	5/20/73	-1.2310+ 1	1.2400+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.2310+ 1	1.2400+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.2310+ 1	1.2400+ 1	2.0000+ 1
N,F	CROSS SECTION	174	3/02/77	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	5	4/20/73	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	6	7/21/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	1269	4/20/73	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.4800+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	3.5000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	3.5000- 2	2.0000+ 1

DELAYED

inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The n,2n threshold is at 6.65 MeV. The only experimental measurements for this reaction are in the energy range from about 13.7 to 15 MeV. They are shown on pp. 11-34 (graphical) and 11-35 (tabulated) of UCRL-50400, Vol. 8, Rev. 1, Part B. For neutron energies below 13.7 MeV and above 15 MeV, the evaluation is based on nuclear

systematics. The evaluated n,2n cross section is shown in UCRL-50400, Vol. 15, Part B. The n,2n cross section rises to a plateau region from 11 to 13 MeV, where it has a value of 0.75 barn. Above 13 MeV it decreases sharply due to competition from the n,3n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 12.36 MeV. The cross section is assumed to rise up to a value of 0.87 barn at 18 MeV and then decrease slowly to a value of 0.65 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic

in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method takes into account the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

Extensive measurements of the fission cross section are shown on pp. 11-215 to 11-224 and on p. 11-226 of UCRL-50400, Vol. 7, Part B, Rev. 1. As stated above, the fission cross sections below 36 eV are derived from ENDF/B MAT-1263 with some modification. The fission cross sections above 20 keV are obtained from the ratio measurements of Behrens and Carlson, as normalized to the ENDL LLL fission cross sections for U^{235} . In the energy region between 36 eV and 20 keV, the fission cross section is based on the experimental data in this energy region.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only measurements of $\bar{\nu}$ for Np^{237} are some early spectrum-averaged data that are listed in UCRL-50400, Vol. 3. The evaluated values for the total and delayed $\bar{\nu}$ are shown in UCRL-50400, Vol. 15, Part B. In general, the values for $\bar{\nu}$ for Np^{237}

are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained by using the slope predicted from fission systematics. The method takes into account the onset of the $n,n'f$, $n,2nf$, and $n,3nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all incident neutron energies, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by first assuming a total photon energy from fission of 6.2 MeV and then dividing this value by the

average energy in the photon spectrum. The spectrum of photons from Np^{237} fission is assumed to be the same as the spectrum of photons from U^{235} fission.

CROSS SECTION FOR THE (n,γ) REACTION

Measurements of the capture cross section are shown on pp. 11-225 and 11-226 of UCRL, Vol. 7, Part B, Rev. 1; the evaluated capture cross sections are illustrated on p. 11-226 of this reference. As stated above, the capture cross sections below 36 eV are derived from ENDF/B MAT-1263, with some modification. At the higher energies, the capture cross sections are obtained from experimental data and from systematics [UCRL-50400, Vol. 15, Part A, pp. 29 to 31].

PHOTON PRODUCTION FROM (n,γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total

available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

$n,X\gamma$ CROSS SECTION

For energies below 35 keV, photon production is assumed to originate only from capture and fission processes. From 35 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE $(n,X\gamma)$ PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 35 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Plutonium-238

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{94}\text{Pu}^{238}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

Due to the scarcity of experimental data, the evaluated cross sections for this isotope are based largely on nuclear systematics.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for Pu^{238} are shown graphically on p. 11-227 of UCRL-50400, Vol. 7, Part B, Rev. 1; a tabulated thermal value is given on p. 11-337 of this same reference.

ELASTIC SCATTERING CROSS SECTION

There are no experimental data listed for the elastic scattering cross section. The elastic cross section for energies below 50 keV is deduced from nuclear systematics. For neutron energies of 50 keV and above, the elastic cross section values are based on spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies up to 40 keV, the elastic scattering angular distributions are assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 50 keV up to a value of 1.22 barns at 500 keV, then drops to a plateau region from 1 to 6 MeV (where it has a value of 1 barn), and finally drops off rapidly above 7 MeV due to competition with the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n' reaction is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this

Plutonium-238

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	399	1/03/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	20	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	33	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	33	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	13	11/15/72	0.0000+ 0	3.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	12	11/15/72	0.0000+ 0	3.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	31	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	18	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	10	11/15/72	-7.0000+ 0	7.0500+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	5	11/15/72	-7.0000+ 0	7.0500+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	17	12/03/76	-7.0000+ 0	7.0500+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	8	12/03/76	-7.0000+ 0	7.0500+ 0	2.0000+ 1
N,3N	CROSS SECTION	5	11/15/72	-1.2860+ 1	1.2950+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	4	11/15/72	-1.2860+ 1	1.2950+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.2860+ 1	1.2950+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.2860+ 1	1.2950+ 1	2.0000+ 1
N,F	CROSS SECTION	574	1/03/75	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	4	11/15/72	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	17	11/15/72	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8600+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	629	1/03/75	5.6600+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.6600+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.6600+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.6600+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.6600+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1

DELAYED

assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model - a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The n,2n threshold is at 7.03 MeV. Since there are no experimental data for this reaction, the n,2n cross section is based on systematics. The evaluated n,2n cross sections are shown in UCRL-50400, Vol. 15, Part B. It rises to a peak value of 0.6 barn and then falls due to competition with the n,3n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 12.91 MeV. The n,3n cross section is assumed to rise to a peak value of 0.3 barns at 17 MeV and then to decrease slowly.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction. The method takes into account the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

Rather extensive measurements of the fission cross section are shown on pp. 11-228 to 11-234 of UCRL-50400, Vol. 7, Part B, Rev. 1; a few tabulated values are listed on p. 11-237 of this reference. The evaluated fission cross sections are displayed graphically on p. 11-234. The experimental data cover most of the energy range except for a gap between 6 and 13 MeV. Interpolation procedures based on nuclear systematics are used to obtain the fission cross sections in the region of the gap.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Two experimental values for $\bar{\nu}$ are given on p. 11-237 of UCRL-50400, Vol. 7, Part B, Rev. 1. In general, the values for $\bar{\nu}$ are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained from the slope predicted by fission systematics. The method takes into account the onset of the $n, n'f$, $n, 2nf$, and $n, 3nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971).

Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all incident neutron energies, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by first assuming a total photon energy from fission of 6.2 MeV and then dividing this value by the average energy in the photon spectrum. The spectrum of photons from Pu^{238} fission is assumed to be the same as that from U^{235} fission.

CROSS SECTION FOR THE (n, γ) REACTION

Experimental capture cross section data are shown graphically on pp. 11-235 and 11-236 of UCRL-50400, Vol. 7, Part B, Rev. 1; a tabular thermal energy value is given on p. 11-237. The evaluated capture cross sections are displayed graphically in UCRL-50400, Vol. 15, Part B. The experi-

mental capture data only extend up to 200 keV in energy. At the higher energies, the capture cross section is determined mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n, γ CROSS SECTION

For energies below 50 keV, photon

production is assumed to originate only from capture and fission processes. From 50 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n, γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 50 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Plutonium-239

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{94}\text{Pu}^{239}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, values derived from ENDF/B MAT-1264 are adopted, with some modification, for the elastic scattering, capture, and fission cross sections up to 30 eV.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for Pu^{239} are shown graphically on pp. 11-238 to 11-252 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental values are given on p. 11-297.

ELASTIC SCATTERING CROSS SECTION

Tabulated experimental values of the elastic scattering cross section at 0.5 and 1 MeV are given on p. 11-297 of UCRL-50400, Vol. 7, Part B, Rev. 1; experimental data from 3 to 15 MeV are shown graphically on p. 11-253 of this reference. As stated above, values derived from ENDF/B MAT-1264 are used with some modification for incident neutron energies

below 30 eV. Nuclear systematics are used to interpolate the evaluated cross sections between 30 eV and 3 MeV. Between 3 and 15 MeV the evaluated data are based on measurements. Above 15 MeV, values are calculated from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

Experimental measurements between 0.5 and 5.5 MeV are shown in UCRL-50400, Vol. 19; the tabulated data points for these measurements are given in UCRL-50400, Vol. 10. For energies less than or equal to 40 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions are obtained from experiment and from spherical optical model calculations, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

Experimental inelastic scattering data are given on p. 11-39 of UCRL-50400, Vol. 8, Rev. 1, Part B. The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. In the

Plutonium-239

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	542	1/02/78	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	28	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	31	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	36	1/02/78	0.0000+ 0	4.0000- 1	2.0000+ 1	
N,N'	N ANGULAR DIST.	4	1/05/71	0.0000+ 0	4.0000- 1	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	12	3/18/71	0.0000+ 0	4.0000- 1	2.0000+ 1	
N,N'	N TOTAL ENERGY DEP.	20	12/03/76	0.0000+ 0	4.0000- 1	2.0000+ 1	
N,N'	N LOCAL ENERGY DEP.	17	12/03/76	0.0000+ 0	4.0000- 1	2.0000+ 1	
N,N'	CROSS SECTION	21	2/02/76	0.0000+ 0	5.7241- 2	2.0000+ 1	LEVEL = 5.7000- 2 MEV
N,N'	N ANGULAR DIST.	2	5/27/70	0.0000+ 0	5.7241- 2	2.0000+ 1	LEVEL = 5.7000- 2 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	5.7241- 2	2.0000+ 1	LEVEL = 5.7000- 2 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	5.7241- 2	2.0000+ 1	LEVEL = 5.7000- 2 MEV
N,N'	CROSS SECTION	19	2/02/76	0.0000+ 0	7.6321- 2	2.0000+ 1	LEVEL = 7.6000- 2 MEV
N,N'	N ANGULAR DIST.	2	5/27/70	0.0000+ 0	7.6321- 2	2.0000+ 1	LEVEL = 7.6000- 2 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	7.6321- 2	2.0000+ 1	LEVEL = 7.6000- 2 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	7.6321- 2	2.0000+ 1	LEVEL = 7.6000- 2 MEV
N,N'	CROSS SECTION	9	2/02/76	0.0000+ 0	1.6469- 1	2.0000+ 1	LEVEL = 1.6400- 1 MEV
N,N'	N ANGULAR DIST.	2	5/27/70	0.0000+ 0	1.6469- 1	2.0000+ 1	LEVEL = 1.6400- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.6469- 1	2.0000+ 1	LEVEL = 1.6400- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	1.6469- 1	2.0000+ 1	LEVEL = 1.6400- 1 MEV
N,N'	CROSS SECTION	15	2/02/76	0.0000+ 0	2.8721- 1	2.0000+ 1	LEVEL = 2.8600- 1 MEV
N,N'	N ANGULAR DIST.	2	5/27/70	0.0000+ 0	2.8721- 1	2.0000+ 1	LEVEL = 2.8600- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.8721- 1	2.0000+ 1	LEVEL = 2.8600- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	2.8721- 1	2.0000+ 1	LEVEL = 2.8600- 1 MEV
N,N'	CROSS SECTION	14	2/02/76	0.0000+ 0	3.3240- 1	2.0000+ 1	LEVEL = 3.3100- 1 MEV
N,N'	N ANGULAR DIST.	2	5/27/70	0.0000+ 0	3.3240- 1	2.0000+ 1	LEVEL = 3.3100- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	3.3240- 1	2.0000+ 1	LEVEL = 3.3100- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	3.3240- 1	2.0000+ 1	LEVEL = 3.3100- 1 MEV
N,N'	CROSS SECTION	12	2/02/76	0.0000+ 0	3.9165- 1	2.0000+ 1	LEVEL = 3.9000- 1 MEV
N,N'	N ANGULAR DIST.	2	5/27/70	0.0000+ 0	3.9165- 1	2.0000+ 1	LEVEL = 3.9000- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	12/03/76	0.0000+ 0	3.9165- 1	2.0000+ 1	LEVEL = 3.9000- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	12/03/76	0.0000+ 0	3.9165- 1	2.0000+ 1	LEVEL = 3.9000- 1 MEV
N,2N	CROSS SECTION	21	1/02/78	-5.6100+ 0	5.6400+ 0	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	7	30/47/20	-5.6100+ 0	5.6400+ 0	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	20	12/03/76	-5.6100+ 0	5.6400+ 0	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	12	12/03/76	-5.6100+ 0	5.6400+ 0	2.0000+ 1	
N,3N	CROSS SECTION	10	1/02/78	-1.2510+ 1	1.2563+ 1	2.0000+ 1	
N,3N	N ENERGY-ANGLE DIST.	4	1/05/71	-1.2510+ 1	1.2563+ 1	2.0000+ 1	
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.2510+ 1	1.2563+ 1	2.0000+ 1	
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.2510+ 1	1.2563+ 1	2.0000+ 1	
N,4N	CROSS SECTION	2	1/02/78	-1.8550+ 1	1.8628+ 1	2.0000+ 1	
N,4N	N ENERGY-ANGLE DIST.	2	1/05/71	-1.8550+ 1	1.8628+ 1	2.0000+ 1	
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.8550+ 1	1.8628+ 1	2.0000+ 1	
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.8550+ 1	1.8628+ 1	2.0000+ 1	
N,F	CROSS SECTION	923	2/20/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	N ENERGY-ANGLE DIST.	6	3/05/76	1.8500+ 2	1.0000-10	2.0000+ 1	
N,F	N NEUTRONS/FISSION	8	5/26/75	1.8500+ 2	1.0000-10	2.0000+ 1	
N,F	G ENERGY DIST.	2	2/16/78	1.8600+ 2	1.0000-10	2.0000+ 1	

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,F	G MULTIPLICITY	2	2/16/78	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	N NEUTRONS/FISSION	5	11/27/76	1.8600+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G	CROSS SECTION	484	2/20/76	6.5300+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.5300+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	2/17/78	6.5300+ 0	1.0000-10	2.0000+ 1	
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.5300+ 0	1.0000-10	2.0000+ 1	
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.5300+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	16	2/18/78	0.0000+ 0	3.0000- 1	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	16	2/18/78	0.0000+ 0	3.0000- 1	2.0000+ 1	
N,XG	CROSS SECTION	9	11/30/72	0.0000+ 0	6.0000- 2	3.0200- 1	PHOTON ≈ 6.0000- 2 MEV
N,XG	G ANGULAR DIST.	2	5/13/73	0.0000+ 0	6.0000- 2	3.0200- 1	PHOTON ≈ 6.0000- 2 MEV
N,XG	CROSS SECTION	9	11/30/72	0.0000+ 0	8.0000- 2	3.0200- 1	PHOTON ≈ 8.0000- 2 MEV
N,XG	G ANGULAR DIST.	2	5/13/73	0.0000+ 0	8.0000- 2	3.0200- 1	PHOTON ≈ 8.0000- 2 MEV
N,XG	CROSS SECTION	1	11/30/72	0.0000+ 0	1.6000- 1	3.0200- 1	PHOTON ≈ 1.6000- 1 MEV
N,XG	G ANGULAR DIST.	2	5/13/73	0.0000+ 0	1.6000- 1	3.0200- 1	PHOTON ≈ 1.6000- 1 MEV

evaluation, the total inelastic scattering cross section is composed of contributions from six inelastic levels plus an n, n' continuum. The total n, n' cross section falls off sharply above 6 MeV due to competition from the $n, 2n$ reaction. The threshold for n, n' scattering is at 57 keV (the energy of the first inelastic level). The total n, n' cross section is held constant for neutron energies between 8 and 15 MeV to account for pre-equilibrium and unresolved direct-interaction cross sections, and it then falls off at the higher energies.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering from the six levels are assumed to be isotropic in the center-of-mass system for all incident energies. Continuum inelastic scattering is assumed to be isotropic in the laboratory system for incident energies less than 9 MeV. For incident energies greater than 9 MeV, forward peaking is assumed, with a 3 to 1 ratio in the 0° to 90° anisotropy at 15 MeV. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions

of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n, 2n$ CROSS SECTION

The $n, 2n$ threshold is at 5.68 MeV. Since there are no experimental data for this reaction, the cross section is based on systematics. The evaluated $n, 2n$ cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section rises to a value of 0.43 barns at 9 MeV, maintains that value to 11.0 MeV, then decreases due to competition from higher fission modes and multiple neutron emission processes, finally reaching a value of 0.05 barn at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n, 2n$ REACTION

The angular distribution of secondary neutrons from the $n, 2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 12.71 MeV. The cross section is assumed to rise from threshold to a value of 0.29 barns at 17 MeV. Above this energy it decreases gradually to a value of 0.15 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction. The method takes into account the neutron multiplicity and the average neutron energy.

n,4n CROSS SECTION

The threshold for the n,4n cross section is at 18.59 MeV. The n,4n cross section is assumed to rise linearly above threshold to a value of 0.015 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,4n REACTION

The angular distribution of secondary neutrons from the n,4n reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained in the same manner

as described above for the n,2n and n,3n secondaries.

FISSION CROSS SECTION

Measurements of the fission cross section are shown on pp. 11-254 to 11-277 (graphical) and on pp. 11-297 and 11-298 (tabular) of UCRL-50400, Vol. 7, Part B, Rev. 1. The fission cross sections for neutron energies below 30 eV are derived from ENDF/B MAT-1264. The fission cross sections for neutron energies between 30 eV and 1 keV are obtained by averaging over the experimental data. For neutron energies between 1 keV and 20 MeV, the fission cross sections are obtained from the ratio measurements of Behrens and Carlson at LLL, as normalized to the LLL ENDL U²³⁵ fission cross sections.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The experimental data and the evaluated values for prompt $\bar{\nu}$ are shown graphically on pp. 11-281 to 11-286 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated experimental values are given on pp. 11-298 and 11-299. Corresponding values for delayed $\bar{\nu}$ are given on pp. 11-286 and 11-287 (graphical) and on p. 11-299 (tabular) of this same reference. Both of these quantities are included in the evaluation, as is shown in

UCRL-50400, Vol. 15, Part B.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is then divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

Measurements of the capture cross section are given on pp. 11-278 to 11-281 of UCRL-50400, Vol. 7, Part B, Rev. 1; tabular values are given on

p. 11-298. The values below 30 eV are derived from ENDF/B MAT-1264.

From 30 eV to 1 MeV, the evaluated capture cross section values are obtained as averages over the experimental data. Above 1 MeV, the values are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 0.3 MeV, photon production is handled explicitly, as described above; photons from inelastic scattering are explicitly entered in this energy region. From 0.3 MeV to 20 MeV, the n,X γ cross sections are based on experimental measurements and on calculations with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. Experimental n,X γ

cross section data are shown graphically on p. 11-38 of UCRL-50400, Vol. 8, Rev. 1, Part B. The photon spectra, which include photons from all reactions (except fission and capture) are obtained from calculations with the NXGAMEL code. A summary of this method of calculating photon production data is discussed

in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE $(n, X\gamma)$ PROCESS

As stated in the previous section, the photon spectra associated with photon production (except for fission and capture processes) above 0.3 MeV are calculated with the NXGAMEL code.

Plutonium-240

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{94}\text{Pu}^{240}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, values derived from ENDF/B MAT-1265 are adopted, with some modification, for the elastic scattering, fission, and capture cross sections below 4 keV.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for Pu^{240} are shown graphically on pp. 11-301 to 11-317 of UCRL-50400, Vol. 7, Part B, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

Experimental values for the elastic scattering cross section between 0.3 and 1.5 MeV are shown on p. 11-317 of UCRL-50400, Vol. 7, Part B, Rev. 1; the evaluated cross sections are shown on p. 11-318. As stated above, values derived from ENDF/B MAT-1265 were used, with some modification, for energies below 4 keV. For energies between 4 and 50 keV, the elastic scattering cross section

values are obtained by differencing the measured total cross sections and the evaluated nonelastic cross sections. For energies between 50 keV and 20 MeV, the elastic scattering cross sections are derived from the experimental data and from spherical optical model calculations. The latter use the best-fit parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 40 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. Excitation functions for five levels plus a continuum make up the total inelastic scattering cross section. The level excitation functions are based on the experimental data of A. B. Smith and J. F. Whalen given in ECSIL Ref. 3146. The data were measured at incident neutron energies between 0.35 and 1.5

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MeV. For lesser and greater energies the excitation functions are based on nuclear systematics. The upper four levels are subsumed into the continuum cross section for incident neutron energies greater than 2.5 MeV. The first level is assumed to have a constant cross section of 0.1 barns for neutron energies from 1.6 to 20.0 MeV.

The continuum inelastic scattering cross section is assumed to have a threshold at 0.95 MeV. From threshold to 8 MeV, it is derived by subtraction of the sum of other nonelastic reaction cross sections from the assumed total-nonelastic cross section. From 8 MeV to 20 MeV, the continuum cross section is assumed constant at 0.25 barns, and is composed exclusively of preequilibrium inelastic scattering reactions.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

Angular distributions of secondary neutrons from level scattering are assumed to be isotropic in the center-of-mass system. The angular distributions for continuum inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large

that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model -- a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The n,2n threshold is at 6.56 MeV. Since there are no experimental data for this reaction, the cross section is based on systematics. The evaluated n,2n cross section is shown in UCRL-50400, Vol. 15, Part B. This cross section rises sharply from threshold, reaching a value of 0.65 barns at 12 MeV, and falls off sharply above this energy due to competition from the n,3n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction

is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 12.24 MeV. This cross section is assumed to rise sharply from threshold and to have a value of roughly 0.3 barns between 13 and 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction. The method takes into account the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

Measurements of the fission cross section are shown on pp. 11-318 to 11-323 (graphical) and on p. 11-327 (tabular) of UCRL-50400, Vol. 7, Part B, Rev. 1. The fission cross sections for neutron energies below 4 keV are derived from ENDF/B MAT-

1265. The fission cross sections for energies between 4 MeV and 160 keV are obtained by averaging over the experimental data. For neutron energies between 160 keV and 20 MeV, the fission cross sections are obtained from the ratio measurements of Behrens and Carlson at LLL, as normalized to the LLL ENDF fission cross sections for ^{235}U .

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Experimental values for prompt $\bar{\nu}$ are given on pp. 11-326 and 11-327 of UCRL-50400, Vol. 7, Part B, Rev. 1. In the evaluation, both prompt $\bar{\nu}$ and delayed $\bar{\nu}$ are included. Values for these quantities are shown in UCRL-50400, Vol. 15, Part B. In the absence of a complete set of data, the values for $\bar{\nu}$ are obtained partly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 48, 438 (1977).

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular

spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all incident neutron energies, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by first assuming a total photon energy from fission of 6.2 MeV and then dividing this value by the average energy in the photon spectrum. The spectrum of photons from Pu^{238} fission is assumed to be the same as that from U^{235} fission.

CROSS SECTION FOR THE (n,γ) REACTION

Experimental capture cross section data are shown graphically on pp. 11-324 and 11-325 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated thermal values are given on p. 11-327 of this reference. The evaluated capture cross sections are displayed graphically on p. 11-325 of this same reference. As stated above, the values below 4 keV are derived from ENDF/B MAT-1265. The values between 4 keV and 350 keV are obtained by fitting to the experimental data. At energies above 350 keV, the capture cross sections are determined from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n,γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,γ CROSS SECTION

For energies below 50 keV, photon production is assumed to originate only from capture and fission processes. From 50 keV to 20 keV (in the absence of measurements) the photon production cross sections and spectra for photons arising from all reactions except fission are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 52, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 50 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Plutonium-241

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{241}_{94}\text{Pu}$ are summarized in UCRL-50400, Vol. 3. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the absence of experimental data, evaluated cross sections for some of the reactions are obtained entirely from systematics, as described in UCRL-50400, Vol. 15, Part A.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for Pu^{241} are shown graphically on pp. 11-328 to 11-334 of UCRL-50400, Vol. 7, Part B, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

Experimental values for the elastic scattering cross section between 3 eV and 30 eV are shown on p. 11-334 of UCRL-50400, Vol. 7, Part B, Rev. 1; the evaluated elastic cross sections are shown on p. 11-335 of this reference. In the absence of data, values for the elastic scattering cross section over most of the energy range are obtained by taking the difference between the measured total

cross section and the evaluated total inelastic cross section. Some additional information on the elastic scattering cross section at energies of 50 keV and above is also obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 152, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 40 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 50 keV to a value of roughly 1.75 barns in a plateau region that extends from 1 to 5 MeV, and then drops off above 5 MeV due to competition from the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n' reaction is assumed to be the difference between the nonelastic

Plutonium-241

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	38	11/15/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	28	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	31	5/29/78	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	31	5/29/78	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	17	11/15/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	11	11/15/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	20	5/29/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	15	5/29/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	13	11/15/72	-5.2400+ 0	5.0000+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	6	11/15/72	-5.2400+ 0	5.0000+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	17	5/29/78	-5.2400+ 0	5.0000+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	10	5/29/78	-5.2400+ 0	5.0000+ 0	2.0000+ 1
N,3N	CROSS SECTION	8	11/15/72	-1.1780+ 1	1.1850+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	11/15/72	-1.1780+ 1	1.1850+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	5/29/78	-1.1780+ 1	1.1850+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	5/29/78	-1.1780+ 1	1.1850+ 1	2.0000+ 1
N,4N	CROSS SECTION	4	11/15/72	-1.7430+ 1	1.7600+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	3	11/15/72	-1.7430+ 1	1.7600+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	5/29/78	-1.7430+ 1	1.7600+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	5/29/78	-1.7430+ 1	1.7600+ 1	2.0000+ 1
N,F	CROSS SECTION	124	3/16/76	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	5/29/78	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	5/29/78	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	4	11/15/72	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	11/15/72	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8600+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	120	11/15/72	6.3000+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.3000+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.3000+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	5/29/78	6.3000+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	5/29/78	6.3000+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1

DELAYED

cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The $n,2n$ threshold is at 5.26 MeV.

Since there are no data for this reaction, the $n,2n$ cross section is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The $n,2n$ cross section rises sharply to a value of about 1 barn in a plateau region that extends from 6 to 12 MeV, and then falls rapidly above 12 MeV due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

$n,3n$ CROSS SECTION

The threshold for the $n,3n$ reaction is at 11.82 MeV. The $n,3n$ cross section is assumed to rise to a value of about 0.6 barn in a plateau region extending from 12 to 17.5 MeV, and then drop off rapidly due to competition from the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of

secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method takes into account the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 17.50 MeV. The $n,4n$ cross section is assumed to rise rapidly to a plateau region from 18 to 20 MeV, where it has a value of about 0.3 barns.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

Extensive measurements of the fission cross section are shown on pp. 11-335 to 11-349 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on pp. 11-351 and 11-352 of this reference. The evaluated fission cross sections are shown on p. 11-349. The experimental data

cover the entire energy range of the evaluation; the evaluated fission cross sections are obtained as averages over the experimental data.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Experimental values for prompt $\bar{\nu}$ are shown graphically on pp. 11-349 and 11-350 of UCRL-50400, Vol. 7, Part B, Rev. 1; some tabulated values are given on p. 11-352. Values for delayed $\bar{\nu}$ are given on p. 11-351 (graphical) and p. 11-353 (tabular) of this reference. The evaluations for these quantities are displayed graphically in UCRL-50400, Vol. 15, Part B.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas [*Nucl. Sci. Eng.* 46, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all incident neutron energies, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by first assuming a total photon energy from fission of 6.2 MeV and then dividing this value by the average energy in the photon spectrum. The spectrum of photons from Pu^{241} fission is assumed to be the same as that from U^{235} fission.

CROSS SECTION FOR THE (n, γ) REACTION

The only measurement of the capture cross section is a thermal neutron value that is listed on p. 11-352 of UCRL-50400, Vol. 7, Part B, Rev. 1. The Q-value for the n, γ reaction is 6.30 MeV. The evaluated capture cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. In the absence of data, these cross sections are determined mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra.

The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 50 keV, photon production is assumed to originate only from capture and fission processes. From 50 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 50 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Plutonium-242

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ^{242}Pu are summarized in UCRL-50400, Vol. 3. The evaluated data are displayed graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, values derived from ENDF/B MAT-1161 are adopted, with some modification, for the elastic scattering, fission, and capture cross sections below 75 eV.

TOTAL CROSS SECTION

The experimental total cross sections for ^{242}Pu are shown graphically on pp. 11-354 and 11-355 of UCRL-50400, Vol. 7, Part B, Rev. 1; the evaluated total cross sections are displayed on p. 11-356 of this same reference.

ELASTIC SCATTERING CROSS SECTIONS

There are no experimental data for the elastic scattering cross sections. As stated above, values derived from ENDF/B MAT-1161 are used, with some modification, for energies below 75 eV. For energies between 75 eV and 150 keV, the elastic scattering cross sections are obtained by differencing

the measured total cross sections and the evaluated nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 keV and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at 150 keV.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. The total inelastic scattering cross section is composed of four level excitation functions and a continuum excitation function that represents unresolved level excitation and preequilibrium pro-

Plutonium-242

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REACTION		POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	759	5/02/78	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2	2.0000+ 1	
N,ELASTIC	N TOTAL ENERGY DEP.	38	5/29/78	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	N LOCAL ENERGY DEP.	38	5/29/78	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	22	5/16/78	0.0000+ 0	7.4000- 1	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	14	5/16/78	0.0000+ 0	7.4000- 1	2.0000+ 1	
N,N'	N TOTAL ENERGY DEP.	17	5/29/78	0.0000+ 0	7.4000- 1	2.0000+ 1	
N,N'	N LOCAL ENERGY DEP.	14	5/29/78	0.0000+ 0	7.4000- 1	2.0000+ 1	
N,N'	CROSS SECTION	26	5/16/78	0.0000+ 0	4.5000- 2	2.0000+ 1	LEVEL = 4.4500- 2 MEV
N,N'	N ANGULAR DIST.	2	5/16/78	0.0000+ 0	4.5000- 2	2.0000+ 1	LEVEL = 4.4500- 2 MEV
N,N'	N TOTAL ENERGY DEP.	2	5/29/78	0.0000+ 0	4.4686- 2	2.0000+ 1	LEVEL = 4.4500- 2 MEV
N,N'	N LOCAL ENERGY DEP.	2	5/29/78	0.0000+ 0	4.4686- 2	2.0000+ 1	LEVEL = 4.4500- 2 MEV
N,N'	CROSS SECTION	21	5/16/78	0.0000+ 0	1.5000- 1	2.0000+ 1	LEVEL = 1.4900- 1 MEV
N,N'	N ANGULAR DIST.	2	5/16/78	0.0000+ 0	1.5000- 1	2.0000+ 1	LEVEL = 1.4900- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	5/29/78	0.0000+ 0	1.4962- 1	2.0000+ 1	LEVEL = 1.4900- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	5/29/78	0.0000+ 0	1.4962- 1	2.0000+ 1	LEVEL = 1.4900- 1 MEV
N,N'	CROSS SECTION	19	5/16/78	0.0000+ 0	3.1000- 1	2.0000+ 1	LEVEL = 3.0000- 1 MEV
N,N'	N ANGULAR DIST.	2	5/16/78	0.0000+ 0	3.1000- 1	2.0000+ 1	LEVEL = 3.0000- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	5/29/78	0.0000+ 0	3.0125- 1	2.0000+ 1	LEVEL = 3.0000- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	5/29/78	0.0000+ 0	3.0125- 1	2.0000+ 1	LEVEL = 3.0000- 1 MEV
N,N'	CROSS SECTION	16	5/16/78	0.0000+ 0	6.9000- 1	2.0000+ 1	LEVEL = 6.8000- 1 MEV
N,N'	N ANGULAR DIST.	2	5/16/78	0.0000+ 0	6.9000- 1	2.0000+ 1	LEVEL = 6.8000- 1 MEV
N,N'	N TOTAL ENERGY DEP.	2	5/29/78	0.0000+ 0	6.8284- 1	2.0000+ 1	LEVEL = 6.8000- 1 MEV
N,N'	N LOCAL ENERGY DEP.	2	5/29/78	0.0000+ 0	6.8284- 1	2.0000+ 1	LEVEL = 6.8000- 1 MEV
N,2N	CROSS SECTION	23	5/02/78	-6.3000- 0	6.3300+ 0	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	10	12/01/75	-6.3000- 0	6.3300+ 0	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	15	5/29/78	-6.3000- 0	6.3300+ 0	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	10	5/29/78	-6.3000- 0	6.3300+ 0	2.0000+ 1	
N,3N	CROSS SECTION	13	5/02/78	-1.1540+ 1	1.1590+ 1	2.0000+ 1	
N,3N	N ENERGY-ANGLE DIST.	6	12/01/75	-1.1540+ 1	1.1590+ 1	2.0000+ 1	
N,3N	N TOTAL ENERGY DEP.	5	5/29/78	-1.1540+ 1	1.1590+ 1	2.0000+ 1	
N,3N	N LOCAL ENERGY DEP.	5	5/29/78	-1.1540+ 1	1.1590+ 1	2.0000+ 1	
N,4N	CROSS SECTION	2	5/02/78	-1.8070+ 1	1.8150+ 1	2.0000+ 1	
N,4N	N ENERGY-ANGLE DIST.	3	12/01/75	-1.8070+ 1	1.8150+ 1	2.0000+ 1	
N,4N	N TOTAL ENERGY DEP.	2	5/29/78	-1.8070+ 1	1.8150+ 1	2.0000+ 1	
N,4N	N LOCAL ENERGY DEP.	2	5/29/78	-1.8070+ 1	1.8150+ 1	2.0000+ 1	
N,F	CROSS SECTION	416	3/15/76	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	N TOTAL ENERGY DEP.	2	5/29/78	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	N LOCAL ENERGY DEP.	2	5/29/78	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	N ENERGY-ANGLE DIST.	4	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	N NEUTRONS/FISSION	4	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	G ENER Y DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G	CROSS SECTION	1271	12/01/75	5.0400+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.0400+ 0	1.0000-10	2.0000+ 1	
N,G	G MULTIPLICITY	2	2/17/78	5.0400+ 0	1.0000-10	2.0000+ 1	
N,G	N TOTAL ENERGY DEP.	2	5/29/78	5.0400+ 0	1.0000-10	2.0000+ 1	
N,G	N LOCAL ENERGY DEP.	2	5/29/78	5.0400+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	4.4000- 2	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	4.4000- 2	2.0000+ 1	

cesses. The four level excitation functions are based on measurements for U^{238} and Pu^{240} , nuclei that have structures almost identical to that of Pu^{242} . The cross sections for the upper three levels are subsumed into the continuum cross section for neutron energies greater than 5 MeV. The cross section for the excitation of the first level is assumed constant at 0.1 barns for neutron energies from 2 to 20 MeV.

The continuum inelastic scattering cross section is assumed to have a threshold at 0.75 MeV. From threshold to 8 MeV it is derived by subtraction of the sum of the other nonelastic reaction cross sections from the assumed total-nonelastic cross section. From 8 to 20 MeV it is assumed constant at 0.285 barns and is composed exclusively of preequilibrium inelastic scattering reactions.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

Angular distributions of secondary neutrons from level scattering are assumed to be isotropic in the center-of-mass system. The angular distributions for continuum inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this

assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model - a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The n,2n threshold is at 6.33 MeV. Since there are no experimental data for this reaction, the cross section is based on systematics. The evaluation in UCRL-50400, Vol. 15, Part B. The cross section rises sharply above threshold, reaching a maximum value of 1 barn near 12 MeV. It falls rapidly above 12 MeV due to competition from the n,3n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 11.59 MeV. The cross section rises sharply above threshold and then falls gradually for energies up to 20 MeV, with an average cross section value of about 0.5 barns over this energy range.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction. The method takes into account the neutron multiplicity and the average neutron energy.

n,4n CROSS SECTION

The threshold for the n,4n reaction is at 18.15 MeV. The n,4n cross section is assumed to rise linearly above threshold to a value of 0.1 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,4n REACTION

The angular distribution of secondary neutrons from the n,4n reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the n,2n and n,3n secondaries.

FISSION CROSS SECTION

Measurements of the fission cross section are shown on pp. 11-356 to 11-360 (graphical) and on p. 11-361 (tabular) of UCRL-50400, Vol. 7, Part B, Rev. 1; the evaluated fission cross sections are displayed graphically on p. 11-360 of this reference. The fission cross section for energies below 75 eV are derived from ENDF/B MAT-1161. Above 75 eV, the fission cross sections are obtained as averages over experimental data, that essentially cover the entire energy range. In particular, the fission cross sections above 100 keV are based on the LLL fission ratio measurements of Behrens, Browne, and Carlson, as normalized to the LLL ENDL fission cross sections for U²³⁵.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Experimental values for prompt and delayed $\bar{\nu}$ are given on p. 11-362 of UCRL-50400, Vol. 7, Part B, Rev. 1. The evaluated $\bar{\nu}$ cross sections are shown in UCRL-50400, Vol. 15, Part B. In the absence of a complete set of data, the values for $\bar{\nu}$ are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977).

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total

photon energy from fission of 6.2 MeV. This value is then divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

Experimental capture cross section data are given on pp. 11-361 and 11-362 of UCRL-50400, Vol. 7, Part B, Rev. 1; the evaluated data are displayed graphically on p. 11-361. As stated above, the values below 75 eV are derived from ENDF/B MAT-1161. The values over most of the energy range above 75 eV are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 44 keV, photon production is assumed to originate only from capture and fission processes. From 44 keV to 20 MeV (in

the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 44 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Plutonium-243

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{94}\text{Pu}^{243}$ include three fission cross section data points between 1.5 and 2 MeV, a few spectrum-averaged fission data points, and a few spectrum-averaged capture data points. The data are listed in UCRL-50400, Vol. 3. Since there are so few experimental data points for Pu^{243} , the present evaluation is based mainly on systematics. The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, the elastic scattering, fission, and capture cross sections below 1 keV are taken from a Savannah River Laboratory (SRL) evaluation supplied by F. J. McCrosson. The SRL cross sections are in the form of group constants and include a set of resonance parameters for seven resonances below 20 eV. The resonance parameter data were combined with the background group cross sections, assuming linear interpolability between the nominal energies of the group cross sections. The resulting pointwise data set was then modified and extended as described below.

TOTAL CROSS SECTION

The evaluated total cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As stated above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. Since there are no experimental elastic scattering data for this isotope, these evaluated cross sections are obtained entirely from systematics. For energies between 1 keV and 150 keV, the elastic scattering cross sections are obtained by differencing the evaluated total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated

Plutonium-243

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N.ELASTIC	CROSS SECTION	143	12/01/75	0.0000+0	1.0000-10	2.0000+1
N.ELASTIC	N ANGULAR DIST.	19	12/01/75	0.0000+0	1.0000-10	2.0000+1
N.ELASTIC	N TOTAL ENERGY DEP.	38	12/01/75	0.0000+0	1.0000-10	2.0000+1
N.ELASTIC	N LOCAL ENERGY DEP.	38	12/01/75	0.0000+0	1.0000-10	2.0000+1
N.N'	CROSS SECTION	25	12/01/75	0.0000+0	6.0000-10	2.0000+1
N.N'	N ENERGY-ANGLE DIST.	17	12/01/75	0.0000+0	6.0000-10	2.0000+1
N.N'	N TOTAL ENERGY DEP.	22	12/03/76	0.0000+0	6.0000-10	2.0000+1
N.N'	N LOCAL ENERGY DEP.	18	12/03/76	0.0000+0	6.0000-10	2.0000+1
N.2N	CROSS SECTION	20	12/01/75	-5.0392+0	5.0600-10	2.0000+1
N.2N	N ENERGY-ANGLE DIST.	10	12/01/75	-5.0392+0	5.0600-10	2.0000+1
N.2N	N TOTAL ENERGY DEP.	19	12/03/76	-5.0392+0	5.0600-10	2.0000+1
N.2N	N LOCAL ENERGY DEP.	13	12/03/76	-5.0392+0	5.0600-10	2.0000+1
N.3N	CROSS SECTION	14	12/01/75	-1.1333+1	1.1380-10	2.0000+1
N.3N	N ENERGY-ANGLE DIST.	6	12/01/75	-1.1333+1	1.1380-10	2.0000+1
N.3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1333+1	1.1380-10	2.0000+1
N.3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1333+1	1.1380-10	2.0000+1
N.4N	CROSS SECTION	7	12/01/75	-1.6581+1	1.6650-10	2.0000+1
N.4N	N ENERGY-ANGLE DIST.	4	12/01/75	-1.6581+1	1.6650-10	2.0000+1
N.4N	N TOTAL ENERGY DEP.	3	12/03/76	-1.6581+1	1.6650-10	2.0000+1
N.4N	N LOCAL ENERGY DEP.	3	12/03/76	-1.6581+1	1.6650-10	2.0000+1
N.F	CROSS SECTION	359	12/01/75	2.0000+2	1.0000-10	2.0000+1
N.F	N TOTAL ENERGY DEP.	2	12/03/76	2.0000+2	1.0000-10	2.0000+1
N.F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000+2	1.0000-10	2.0000+1
N.F	N ENERGY-ANGLE DIST.	5	12/01/75	2.0000+2	1.0000-10	2.0000+1
N.F	N NEUTRONS/FISSION	5	12/01/75	2.0000+2	1.0000-10	2.0000+1
N.F	G ENERGY DIST.	2	2/16/78	2.0000+2	1.0000-10	2.0000+1
N.F	G MULTIPLICITY	2	2/16/78	2.0000+2	1.0000-10	2.0000+1
N.F	N NEUTRONS/FISSION	2	3/01/76	2.0000+2	1.0000-10	2.0000+1
N.G	CROSS SECTION	327	12/01/75	6.0200+0	1.0000-10	2.0000+1
N.G	G ENERGY-ANGLE DIST.	2	2/17/79	6.0200+0	1.0000-10	2.0000+1
N.G	G MULTIPLICITY	2	2/17/79	6.0200+0	1.0000-10	2.0000+1
N.G	N TOTAL ENERGY DEP.	2	11/21/76	6.0200+0	1.0000-10	2.0000+1
N.G	N LOCAL ENERGY DEP.	2	11/21/76	6.0200+0	1.0000-10	2.0000+1
N.XG	CROSS SECTION	20	2/18/78	0.0000+0	6.0000-10	2.0000+1
N.XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+0	6.0000-10	2.0000+1

DELAYED

from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 keV and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at 150 keV.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 60 keV to a peak value of about 2.5 barns at 1 MeV, it has a plateau value of about 2.25 barns from 1 to 6 MeV and then falls off rapidly above 6 MeV due to competition from the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic

angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model - a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The $n,2n$ threshold is at 5.06 MeV. Since there are no experimental data for this reaction, the cross section is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises sharply above threshold and has a plateau value of about 1.3 barns between 7 and 12 MeV. It falls rapidly above 12 MeV due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$

reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics [UCRL-50400, Vol. 15, Part A, p. 24].

n,3n CROSS SECTION

The threshold for the n,3n reaction is at 11.38 MeV. The cross section rises sharply above threshold reaching a plateau value of about 0.9 barns from 12.5 to 16.5 MeV, and then falls rapidly due to competition from the n,4n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction. The method takes into account the neutron multiplicity and the average neutron energy.

n,4n CROSS SECTION

The threshold for the n,4n reaction is at 16.65 MeV. The cross section

rises sharply above threshold, reaching a plateau value of about 0.5 barns between 17 and 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,4n REACTION

The angular distribution of secondary neutrons from the n,4n reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the n,2n and n,3n secondaries.

FISSION CROSS SECTION

The few fission data points that have been measured for this isotope are described in the data summary at the beginning of this report. As mentioned above, the fission cross sections below 1 keV are taken from the SRL evaluation for this isotope. The fission cross sections at the higher energies are obtained from systematics. The fission cross section rises sharply above 1 MeV, exhibiting several plateau regions at the higher energies. These regions correspond to the onset of second-chance, third-chance, etc., fission channels.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

In the absence of data, the values

for $\bar{\nu}$ are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method takes into account the onset of the $n, n'f$, $n, 2nf$, and $n, 3nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 44 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is then divided by the

average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

The few experimental measurements of the capture cross section are described in the data summary at the beginning of this report. As stated above, the capture cross sections below 1 keV are taken from the SRL evaluation for this isotope. The values for the higher energies are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

$n, X\gamma$ CROSS SECTION

For energies below 60 keV, photon production is assumed to originate only from capture and fission processes. From 60 keV to 20 MeV (in

the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE $(n,X\gamma)$ PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 60 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Americium-241

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{95}\text{Am}^{241}$ include

- Three sets of total cross sections for energies below 1 keV

- One n,2n measurement to a metastable state in Am^{240}

- One set of absorption measurements

- Fourteen sets of fission data

- Three sets of n, γ cross sections to specific isomers

- Two thermal measurements of $\bar{\nu}$

- Fourteen sets of spectrum-averaged cross sections

- Eight measured resonance integrals

- Three sets of averaged resonance parameters

- Nine sets of resonance parameters.

The data are listed in UCRL-50400, Vol. 3.

In the evaluation for this isotope, ENDF/B MAT-1056 values are adopted for the following reactions:

- The elastic scattering cross section for incident neutron energies below 0.05 MeV

- The fission cross section for

incident neutron energies below 0.05 MeV

- The n, γ cross section for incident energies below 0.01 MeV. The cross section splits into two separate reactions, one leading to the ground state and the other to the metastable state of Am^{242} .

The evaluated data are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

TOTAL CROSS SECTION

The experimental and evaluated total cross sections for Am^{241} are shown graphically on pp. 11-366 to 11-371 of UCRL-50400, Vol. 7, Part B, Rev. 1.

ELASTIC SCATTERING CROSS SECTION

As stated above, the ENDF/B MAT-1056 values are used for incident neutron energies below 0.05 MeV. From 1 to 20 MeV, values are calculated from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)]. For values intermediate between 0.05 and 1 MeV, a smooth connection is made that follows the systematics of the elastic scattering cross section.

Americium-241

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	REACTION	POINTS	DATE	G-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	212	5/02/78	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	18	8/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	34	8/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	34	8/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	15	3/02/78	0.0000+ 0	5.0000+ 0	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	14	8/15/75	0.0000+ 0	5.0000+ 0	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	20	12/03/76	0.0000+ 0	5.0000+ 0	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	5.0000+ 0	2.0000+ 1
N,2N	CROSS SECTION	15	3/02/78	-5.9300+ 0	5.9500+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	9	8/15/75	-5.9300+ 0	5.9500+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	19	12/03/76	-5.9300+ 0	5.9548+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	10	12/03/76	-5.9300+ 0	5.9548+ 0	2.0000+ 1
N,3N	CROSS SECTION	5	3/02/78	-1.2600+ 1	1.2600+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	8/15/75	-1.2600+ 1	1.2600+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.2600+ 1	1.2651+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.2600+ 1	1.2653+ 1	2.0000+ 1
N,F	CROSS SECTION	1536	8/13/77	2.0000+ 0	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 0	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 0	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	3	8/15/75	2.0000+ 0	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	8/15/75	2.0000+ 0	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0000+ 0	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 0	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/78	2.0000+ 0	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	656	6/02/77	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	652	6/02/77	5.5280+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.5280+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.5280+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.5280+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.5280+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000+ 0	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000+ 0	2.0000+ 1

DELAYED

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies below 0.1 MeV, the elastic scattering angular distribution is assumed to be isotropic in the center-of-mass system. From 0.5 to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. From 0.1 to 0.5 MeV, the angular distributions are obtained by interpolation.

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering reaction is assumed to have a threshold at 0.05 MeV. It rises above the threshold in the usual sigmoid shape to a maximum of 2.75 barns at 0.75 MeV, and then falls off due to competition from the fission reaction. This falloff is gradual up to about 2 MeV. The inelastic scattering cross section in this energy region is obtained by subtracting the measured fission cross-section from the assumed nonelastic cross section. The latter is obtained from systematics and from optical model calculations. At 5.5 MeV, the inelastic scattering cross section is assumed to decrease to compensate for the rise of the n,n' reaction. At 5.95 MeV, the $n,2n$ threshold is reached; above this energy the n,n' reaction cross section is assumed to be the

difference between the nonelastic cross section and the sum of the total fission cross section and the $n,2n$ cross section. Thus, the cross section falls to a value of 0.15 barns at 7 MeV, then to 0.1 barn at 9 MeV, and then is assumed to be constant at 0.1 barns for the higher energies.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distribution for inelastic scattering is assumed to be isotropic in the laboratory system at all incident neutron energies. Although this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the inelastic scattering neutron spectrum, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would amount to swallowing the elephant and straining at the gnat. However, energy distributions are included in the evaluation in tabular form. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the distributions are derived from a temperature model. Above 6 MeV, some of the secondary neutrons are assumed to be associated with pre-equilibrium or direct-interaction processes and were therefore given forward-peaked angular distributions. The method used in

selecting the fraction of the inelastically scattered neutrons that are associated with the pre-equilibrium process is discussed in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The only measurement of the n,2n cross section is listed on p. 11-49 of UCRL-50400, Vol. 8, Rev. 1, Part B; this is a single point at 14.1 MeV representing the production of the metastable state in Am^{240} . Not enough is known about the Am^{240} decay scheme to use this measurement for obtaining a 14-MeV value for the n,2n reaction. Consequently, the n,2n reaction is derived entirely from systematics. The Q-value for the n,2n reaction is -5.93 MeV. Above the threshold, at 5.95 MeV, the n,2n reaction cross section rises in the usual systematic way (see UCRL-50400, Vol. 15, Part A, p. 23), reaching a plateau at about 7 MeV. It then continues parallel to the nonelastic cross section at the higher energies. With the onset of the n,2nf reaction, at about 11.5 MeV, the n,2n cross section starts to decrease due to competition from the n,3n reaction causes a further decrease in the n,2n cross section to a value of about 0.15 barns at 13 MeV. The cross

section is assumed to be constant at the 0.15-barn value from 13 MeV to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

There are no measurements for the n,3n cross section. The Q-value is -12.60 MeV, with a threshold at 12.65 MeV. The reaction is assumed to rise linearly from threshold to a value of 0.35 barns at 13 MeV. The 13-MeV value is obtained by subtracting the sum of the other inelastic reactions from the total nonelastic cross section. The 0.35-barn cross section value is assumed to remain constant from 13 MeV to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n

reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described for the $n,2n$ reaction. The method takes into account the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

Measurements of the fission cross section are shown graphically on pp. 11-372 to 11-377 of UCRL-50400, Vol. 7, Part B, Rev. 1. In this evaluation, the fission cross sections of ENDF/B MAT-1056 are used for neutron energies below 0.001 MeV. Above 0.001 MeV the LLL fission cross section ratios of J. W. Behrens and J. C. Browne (UCID-17324, Nov. 19, 1976) are used, as normalized to the ENDL U^{235} fission cross section data. The latter are based on the experimental U^{235} fission data of Czirr and Sidhu.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only measurements of $\bar{\nu}$ for Am^{241} are at 0.0253 eV (p. 11-378 of UCRL-50400, Vol. 7, Part B, Rev. 1). After a renormalization of the experimental values on the basis of the low-energy $\bar{\nu}$ value for U^{235} (to which these measurements are

normalized), a value of 3.11 is selected for the low-energy $\bar{\nu}$ value of Am^{241} . This value is approximately 1.6% larger than the value obtained from the systematics described in UCRL-50400, Vol. 15, Part A, p. 34, and in *Nucl. Sci. Eng.* 62, 438 (1977). Values for $\bar{\nu}$ at higher neutron energies are obtained with the slope predicted from fission systematics. The method takes into account the onset of the n,n' fission, $n,2n$ fission, and $n,3n$ fission reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multipli-

city in the lower energy range is obtained by assuming a total photon energy from fission of 6.2 MeV, and dividing this value by the average energy in the photon spectrum. The spectrum of photons from Am^{241} fission is assumed to be the same as the spectrum of photons from U^{235} fission.

CROSS SECTION FOR THE (n,γ) REACTION

The data for the (n,γ) reaction are given on pp. 11-377 and 11-378 of UCRL-50400, Vol. 7, Part B, Rev. 1. The n,γ reaction leads to a metastable state of Am^{242} (half-life of 152 years) in about 90% of the capture reactions. The remaining 10% of the capture events lead to the ground state of Am^{242} . There is also a metastable state with a half-life of 0.014 seconds, but the cross section for the excitation of this state is relatively insignificant compared to the cross sections for the other two states. The cross sections for the excitation of the major levels have all been measured at thermal neutron energy. The Q-value is 5.528 MeV for the ground state capture reaction, and it is 5.480 MeV for capture in the metastable state. The cross sections for these two reactions are obtained by splitting the capture cross section into two parts, with 90% of the cross section corresponding to the

metastable state and 10% to the ground state. The capture cross section values are obtained from ENDF/B MAT-1056 for energies below 10 keV; from Weston and Todd, *Nucl. Sci. Eng.* 61, 356 (1976) for energies between 10 keV and 350 keV; and from systematics at the higher energies.

PHOTON PRODUCTION FROM (n,γ) REACTIONS

Photon production from the two neutron capture reactions is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

$n,X\gamma$ CROSS SECTION

For energies below 50 keV, photon production is assumed to originate only from capture and fission processes. From 50 keV to 20 MeV, the NXGAMEL code is used to calculate the photon cross sections and spectra. This code is based on systematics described by Perkins, Haight and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section,
the photon spectra associated with
total photon production above 50 keV
(except for the photons from the

fission and capture reactions) are
calculated with the NXGAMEL code.
The contribution to these spectra of
the photons from fission is obtained
with the measured photon spectrum
for U²³⁵.

Americium-242M

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{95}\text{Am}^{242\text{m}}$ are summarized in UCRL-50400, Vol. 3. The data consist of

- Fission measurements
- Two measurements of prompt $\bar{\nu}$ at thermal neutron energy
- Two measurements of the capture cross section — one at thermal neutron energy and one averaged over the fission spectrum.

Due to the scarcity of experimental data, most of the evaluation is based on systematics. This evaluation was carried out by R. J. Howerton. The evaluated data are displayed graphically in UCRL-50400, Vol. 15, Part B.

TOTAL CROSS SECTION

The evaluated total cross sections for $\text{Am}^{242\text{m}}$ are displayed graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

In the absence of data, the elastic scattering cross section is assumed to remain approximately constant at a value of about 12 barns for all energies below 10 keV. From 50 keV to 20 MeV, the values for the

elastic cross section are obtained from a spherical optical model, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)]. The values between 10 keV and 50 keV are obtained by interpolation.

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies below 40 keV, the elastic scattering angular distribution is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions are obtained from a spherical optical model, using the Becchetti and Greenlees parameters. From 40 to 50 keV the angular distributions are obtained by interpolation.

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering cross section is assumed to have a threshold at 100 keV, rising to a peak value of 1.4 barns at 5 MeV. It falls off sharply above 5.6 MeV due to competition with the $n,2n$ reaction. The evaluated inelastic scattering cross section is shown graphically in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for

Americium-242M

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	25	11/15/72	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	21	1/03/72	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	35	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	35	11/14/74	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	13	3/02/78	0.0000+ 0	1.0000- 1	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	10	11/15/72	0.0000+ 0	1.0000- 1	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	21	12/03/76	0.0000+ 0	1.0000- 1	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	14	12/03/76	0.0000+ 0	1.0000- 1	2.0000+ 1
N,2N	CROSS SECTION	11	11/15/72	-5.5300+ 0	5.6000+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	6	11/15/72	-5.5300+ 0	5.6000+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	17	12/03/76	-5.5300+ 0	5.6000+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	10	12/03/76	-5.5300+ 0	5.6000+ 0	2.0000+ 1
N,3N	CROSS SECTION	8	11/15/72	-1.1250+ 1	1.1300+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	11/15/72	-1.1250+ 1	1.1300+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1250+ 1	1.1300+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1250+ 1	1.1300+ 1	2.0000+ 1
N,4N	CROSS SECTION	3	11/15/72	-1.8130+ 1	1.8250+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	3	11/15/72	-1.8130+ 1	1.8250+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.8130+ 1	1.8250+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.8130+ 1	1.8250+ 1	2.0000+ 1
N,F	CROSS SECTION	498	3/02/78	1.9200+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	1.9200+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.9200+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	4	11/15/72	1.9200+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	4	11/15/72	1.9200+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	1.9200+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	1.9200+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.9200+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	490	11/15/72	6.3800+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.3800+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.3800+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.3800+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.3800+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	1.0000- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	1.0000- 1	2.0000+ 1

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inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The n,2n threshold is at 5.55 MeV. In the absence of measurements, the evaluation is based entirely on systematics. The evaluated n,2n cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises sharply above the

threshold, reaching a value of just over 1 barn at 11 MeV. It falls rapidly above 11.5 MeV due to competition with the n,3n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The n,3n threshold is at 11.3 MeV. The evaluated cross section rises sharply above threshold, reaching a plateau value of roughly 0.5 barns from 12 to 18 MeV, and then drops off due to competition with the n,4n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are

obtained in a manner similar to the method described above for the $n,2n$ reaction. The method takes into account the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The $n,4n$ reaction has a threshold at 18.20 MeV. It rises according to systematics to a value of 0.35 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

There are two extensive sets of ^{242}mAm fission data: ECSIL-1117 extends from 0.02 eV to 5.7 MeV, and ECSIL-1061 extends from 20 eV to 930 keV. The evaluated fission cross section is based on the ECSIL-1061 data over its measured range and on the ECSIL-1117 data over the remainder of its measured range. Above 5.7 MeV, the fission cross section is obtained from nuclear systematics.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Two measurements of prompt $\bar{\nu}$ at thermal energies are listed on p. 11-381 of UCRL-50400, Vol. 7, Part B, Rev. 1. The evaluated cross sections for $\bar{\nu}$ are shown in UCRL-50400, Vol. 15, Part B. Due to the scarcity of experimental data, the evaluations are based mainly on systematics. Values for $\bar{\nu}$ at the higher neutron energies are obtained with the slope predicted from fission systematics. The method takes into account the onset of the n,n' fission, $n,2n$ fission, and $n,3n$ fission reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

At all incident neutron energies, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is then divided by the average energy in the photon spectrum. The spectrum of photons from $\text{Am}^{242\text{m}}$ fission is assumed to be the same as the spectrum of photons from U^{235} fission.

CROSS SECTION FOR THE (n, γ) REACTION

The Q-value for the capture reaction is 6.38 MeV. For neutron energies below 2 keV, the capture cross section is set equal to one-tenth of the fission cross section; this result is based on an estimated (ECSIL-1117) capture-to-fission ratio of 0.1. For neutron energies above 2 keV, the capture cross section is based on systematics (UCRL-50400, Vol. 15, Part A, pp. 29 to 31).

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using

multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 100 keV, photon production is assumed to originate only from capture and fission processes. From 100 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production above 100 keV (except for the fission and capture photons) are calculated with the NXGAMEL code.

Americium-243

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{243}_{95}\text{Am}$ are listed in UCRL-50400, Vol. 3. The evaluated cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL).

TOTAL CROSS SECTION

The experimental total cross sections for ^{243}Am are shown on pp. 11-381 to 11-385 of UCRL-50400, Vol. 7, Part B, Rev. 1; the evaluated total cross sections are shown on p. 11-385.

ELASTIC SCATTERING CROSS SECTION

As stated above, the evaluated elastic scattering cross sections below 1 keV were taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the elastic scattering cross sections are obtained by differencing the total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross

sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at 150 keV.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 80 keV, reaching a peak value of about 2.5 barns at 705 keV to 1 MeV, falls off gradually for energies up to 6 MeV, and then falls rapidly due to the onset of the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n' cross section is assumed to be the difference between the nonelastic cross

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	1064	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2	2.0000+ 1	
N,ELASTIC	TOTAL ENERGY DEP.	39	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1	
N,ELASTIC	LOCAL ENERGY DEP.	39	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1	
N,N'	CROSS SECTION	26	12/01/75	0.0000+ 0	6.0000- 2	2.0000+ 1	
N,N'	ENERGY-ANGLE DIST.	14	12/01/75	0.0000+ 0	6.0000- 2	2.0000+ 1	
N,N'	TOTAL ENERGY DEP.	24	12/03/76	0.0000+ 0	6.0000- 2	2.0000+ 1	
N,N'	LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	6.0000- 2	2.0000+ 1	
N,2N	CROSS SECTION	18	12/01/75	-6.3738+ 0	6.4100+ 0	2.0000+ 1	
N,2N	ENERGY-ANGLE DIST.	9	12/01/75	-6.3738+ 0	6.4100+ 0	2.0000+ 1	
N,2N	TOTAL ENERGY DEP.	16	12/03/76	-6.3738+ 0	6.4100+ 0	2.0000+ 1	
N,2N	LOCAL ENERGY DEP.	9	12/03/76	-6.3738+ 0	6.4100+ 0	2.0000+ 1	
N,3N	CROSS SECTION	10	12/01/75	-1.1901+ 1	1.1950+ 1	2.0000+ 1	
N,3N	ENERGY-ANGLE DIST.	6	12/01/75	-1.1901+ 1	1.1950+ 1	2.0000+ 1	
N,3N	TOTAL ENERGY DEP.	5	12/03/76	-1.1901+ 1	1.1950+ 1	2.0000+ 1	
N,3N	LOCAL ENERGY DEP.	5	12/03/76	-1.1901+ 1	1.1950+ 1	2.0000+ 1	
N,4N	CROSS SECTION	3	12/01/75	-1.8424+ 1	1.8500+ 1	2.0000+ 1	
N,4N	ENERGY-ANGLE DIST.	3	12/01/75	-1.8424+ 1	1.8500+ 1	2.0000+ 1	
N,4N	TOTAL ENERGY DEP.	2	12/03/76	-1.8424+ 1	1.8500+ 1	2.0000+ 1	
N,4N	LOCAL ENERGY DEP.	2	12/03/76	-1.8424+ 1	1.8500+ 1	2.0000+ 1	
N,F	CROSS SECTION	72	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	ENERGY-ANGLE DIST.	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	ENERGY DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1	
N,G	CROSS SECTION	3345	12/01/75	5.3600+ 0	1.0000-10	2.0000+ 1	
N,G	ENERGY-ANGLE DIST.	2	2/17/78	5.3600+ 0	1.0000-10	2.0000+ 1	
N,G	MULTIPLICITY	2	2/17/78	5.3600+ 0	1.0000-10	2.0000+ 1	
N,G	TOTAL ENERGY DEP.	2	11/21/76	5.3600+ 0	1.0000-10	2.0000+ 1	
N,G	LOCAL ENERGY DEP.	2	11/21/76	5.3600+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	8.0000- 2	2.0000+ 1	
N,XG	ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	8.0000- 2	2.0000+ 1	

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section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic

angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction

is at 6.40 MeV. Graphical values of the $n,2n$ data are shown on pp. 11-49 and 11-50 of UCRL-50400, Vol. 8, Rev. 1, Part B; a tabular value is given on p. 11-50. The evaluated $n,2n$ cross sections are shown graphically on p. 11-50 of this reference. The evaluated cross sections rise rapidly to a broad plateau region that extends from 7 to 12 MeV, and they fall off above 12 MeV due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The threshold for the $n,3n$ reaction is at 11.95 MeV. The evaluated $n,3n$ cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. The cross section rises sharply from threshold, reaching a plateau value of roughly 0.7 barn between 13 and 18 MeV, and then

decreases due to competition from the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method takes into account the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 18.5 MeV. The cross section rises linearly to a value of 0.25 barns and then remains constant to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries

FISSION CROSS SECTION

The experimental fission data are shown graphically on pp. 11-386 and

11-387 of UCRL-50400, Vol. 7, Part B, Rev. 1; two tabulated values are given on p. 11-389. The evaluated fission cross sections are shown on p. 11-388 of this report. As mentioned above, the fission cross sections below 1 keV are taken from the SRL evaluation. The fission cross sections between 1 keV and 4 MeV are obtained as averages over the experimental data. The fission cross sections above 4 MeV are obtained from systematics, guided by the measured values at 14.5 MeV.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

In the absence of data, the values for $\bar{\nu}$ are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes

temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity in the lower energy range is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum. The spectrum of photons from Am^{243} fission is assumed to be the same as the spectrum of photons from U^{235} fission.

CROSS SECTION FOR THE (n, γ) REACTION

Experimental values for the capture reaction are shown graphically on p. 11-388 of UCRL-50400, Vol. 7, Part B, Rev. 1; two tabular values at thermal energy are given on p. 11-389. The evaluated capture cross sections are shown graphically on p. 11-389 of this reference. As stated above, the capture cross sections for energies below 1 keV are taken from the SRL

evaluation for this isotope. The values at higher energies are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for this reaction are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 80 keV, photon production is assumed to originate only from capture and fission processes. From 80 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

total photon production above 80 keV
(except for the fission and capture
photons) are calculated with the
NXGAMEL code.

Curium-242

DATA SUMMARY AND GENERAL COMMENTS

The few data points that exist for $^{242}_{96}\text{Cm}$ are listed in UCRL-50400, Vol. 3. These include a 14-MeV and a spectrum-averaged, fission cross-section measurement, a capture-cross-section resonance integral, and some measurements of prompt $\bar{\nu}$ for spontaneous fission. In the absence of other data, the evaluation is based mainly on systematics. This evaluation was carried out by R. J.

Howerton.

In the evaluation for $^{242}_{96}\text{Cm}$, the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL). The evaluated cross sections for $^{242}_{96}\text{Cm}$ are shown graphically on pp. 395 to 399 of UCRL-50400, Vol. 15, Part B.

TOTAL CROSS SECTION

There are no experimental data for this cross section. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As described above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 50 keV, the

elastic scattering cross sections are obtained by differencing the total and nonelastic cross sections. For energies between 50 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 40 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 45 keV, reaching a value of roughly 1.75 barns between 800 keV and 6 MeV, and then drops rapidly above 7 MeV due to competition from the $n,2n$ reaction. Above the threshold for the $n,2n$ reaction, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	827	2/02/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	21	2/02/76	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	35	2/02/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	35	2/02/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	27	2/02/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	16	2/02/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	18	12/03/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,2N	CROSS SECTION	14	2/02/76	-6.9700+ 0	7.0000+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	8	2/02/76	-6.9700+ 0	7.0000+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	14	12/03/76	-6.9700+ 0	7.0000+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	8	12/03/76	-6.9700+ 0	7.0000+ 0	2.0000+ 1
N,3N	CROSS SECTION	7	2/02/76	-1.3030+ 1	1.3090+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	2/02/76	-1.3030+ 1	1.3090+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.3030+ 1	1.3090+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.3030+ 1	1.3090+ 1	2.0000+ 1
N,F	CROSS SECTION	893	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	5	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	483	2/02/76	5.7000+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.7000+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.7000+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.7000+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.7000+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	4.5000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	4.5000- 2	2.0000+ 1

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and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model - a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 7.00 MeV. Since there are no

data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown on p. 398 of UCRL-50400, Vol. 15, Part B. The cross section rises from threshold, reaching a value of about 1 barn in the plateau region of 8 to 12 MeV, and then drops off above 13 MeV due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The $n,3n$ threshold is at 13.09 MeV. The evaluated cross section (which is shown on p. 398 of UCRL-50400, Vol. 15, Part B), rises from threshold, reaching a value of about 0.35 barns in the plateau region from 14 to 18 MeV, and then drops to a value of 0.15 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

FISSION CROSS SECTION

The only fission data are a 14-MeV cross section and a spectrum-averaged cross section. As stated above, the fission cross sections below 1 keV are taken from the SRL evaluation. The fission cross sections above 1 keV are obtained from systematics and from the one measured point near 14 MeV.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only measurements of this quantity are spontaneous fission values. The evaluations for $\bar{\nu}$ are shown in UCRL-50400, Vol. 15, Part B. In the absence of data, the evaluated $\bar{\nu}$ values are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the

values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, and $n,3nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235}

CROSS SECTION FOR THE (n, γ) REACTION

The only experimental datum for the capture process is a capture resonance integral. As described above, the capture cross sections below 1 keV are obtained from the SRL evaluation. Above 1 keV, the capture cross sections are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, pp 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 45 keV, photon production is assumed to originate only from capture and fission processes. From 45 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ) PROCESS

As stated in the previous section, the photon spectra associated with total photon production (except for the fission and capture reactions) are calculated with the NXGAMEL code.

Curium-243

DATA SUMMARY AND GENERAL COMMENTS

The few data points that have been measured for $^{96}\text{Cm}^{243}$ are listed in UCRL-50400, Vol. 3. Apart from a thermal measurement of prompt $\bar{\nu}$ and an absorption measurement, these data consist entirely of fission measurements and resonance parameters. In the absence of other data, the evaluation is based mainly on systematics. The evaluated cross sections are shown in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for Cm^{243} , the elastic scattering, fission, and capture cross sections below 1 keV are supplied by F. J. McCrosson of Savannah River Laboratory (SRL).

TOTAL CROSS SECTION

There are no experimental data for this reaction. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As described above, the evaluated elastic scattering cross sections below 1 keV were taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the

elastic scattering cross sections are obtained by differencing the total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 50 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at the higher energy.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 60 keV, reaching a value of just over 2 barns in the plateau region from 300 keV to

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	143	2/02/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	19	2/02/76	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	38	2/02/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	LOCAL ENERGY DEP.	38	2/02/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	25	2/02/76	0.0000+ 0	6.0000- 2	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	14	2/02/76	0.0000+ 0	6.0000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	23	12/03/76	0.0000+ 0	6.0000- 2	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	18	12/03/76	0.0000+ 0	6.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	10	2/02/76	-5.6900+ 0	5.7200+ 0	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	7	2/02/76	-5.6900+ 0	5.7200+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	19	12/03/76	-5.6900+ 0	5.7200+ 0	2.0000+ 1
N,2N	LOCAL ENERGY DEP.	11	12/03/76	-5.6900+ 0	5.7200+ 0	2.0000+ 1
N,3N	CROSS SECTION	6	2/02/76	-1.2660+ 1	1.2720+ 1	2.0000+ 1
N,3N	ENERGY-ANGLE DIST.	5	2/02/76	-1.2660+ 1	1.2720+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	4	12/03/76	-1.2660+ 1	1.2720+ 1	2.0000+ 1
N,3N	LOCAL ENERGY DEP.	1	12/03/76	-1.2660+ 1	1.2720+ 1	2.0000+ 1
N,4N	CROSS SECTION	2	2/02/76	-1.8740+ 1	1.8820+ 1	2.0000+ 1
N,4N	ENERGY-ANGLE DIST.	2	2/02/76	-1.8740+ 1	1.8820+ 1	2.0000+ 1
N,4N	TOTAL ENERGY DEP.	2	12/03/76	-1.8740+ 1	1.8820+ 1	2.0000+ 1
N,4N	LOCAL ENERGY DEP.	2	12/03/76	-1.8740+ 1	1.8820+ 1	2.0000+ 1
N,F	CROSS SECTION	1585	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	ENERGY-ANGLE DIST.	6	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	NEUTRONS/FISSION	5	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	219	2/02/76	6.8000+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.8000+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.8000+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.8000+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.8000+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	6.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	6.0000- 2	2.0000+ 1

DELAYED

1 MeV, drops off gradually from 1 MeV to about 6 MeV, and then falls rapidly due to competition from the $n,2n$ reaction. Above the threshold for the $n,2n$ reaction, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the

inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 5.72 MeV. Since there are no data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises from threshold, reaching a value of 0.85 barns in the plateau region of 8 to 12 MeV, and then drops off sharply above 13 MeV due to the onset of the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The $n,3n$ threshold is at 12.72 MeV. The evaluated cross section rises

sharply above threshold, reaching a plateau value of 0.4 barns from 13 to 19 MeV, and then drops due to competition from the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The $n,4n$ reaction has a threshold at 18.82 MeV. The cross section rises linearly and reaches a value of 0.1 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

The experimental fission cross

section data extend from 0.1 to 3 MeV; they are shown graphically on p. 11-300 of UCRL-50400, Vol. 7, Part B, Rev. 1. The evaluated fission cross sections are shown graphically on p. 11-391 of this same reference. As stated above, the fission cross sections below 1 keV are obtained from the SRL evaluation. The fission cross sections from 1 to 100 keV are obtained by interpolation; the fission cross sections from 100 keV to 3 MeV follow the experimental data of ECSIL-943. Above 3 MeV, the fission cross sections are obtained from nuclear systematics.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The one measurement of prompt $\bar{\nu}$ for thermal neutron energies is given on p. 11-391 of UCRL-50400, Vol. 7, Part B, Rev. 1. In the absence of other data, the evaluated values for $\bar{\nu}$ are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of

Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 40, 414 (1971).

Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

There are no experimental data for the capture cross section. As stated above, the capture cross sections below 1 keV are obtained from the SRL evaluation. Above 1 keV, the capture cross sections are obtained from

systematics (UCRL-50400, Vol. 15, Part A, pp. 29 to 31).

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 60 keV, photon production is assumed to originate only from capture and fission processes. From 60 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 60 keV
(except for the fission and capture
processes) are calculated with the
NXGAMEL code.

Curium-244

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{244}_{96}\text{Cm}$ are listed in UCRL-50400, Vol. 3. The evaluated cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL). Due to the scarcity of data for this isotope, the evaluation is in large part obtained from nuclear systematics.

TOTAL CROSS SECTION

The experimental total cross section data for $^{244}_{96}\text{Cm}$ are shown graphically on p. 11-391 of UCRL-50400, Vol. 7, Part B, Rev. 1; a tabulated thermal value is given on p. 11-397. The evaluated total cross sections are shown graphically on p. 11-392.

ELASTIC SCATTERING CROSS SECTION

As stated above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the elastic scattering cross sections are

obtained by differencing the total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at 150 keV.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 45 keV to a peak value of 2 barns at 800 keV, remains roughly constant from 800 keV to 7 MeV, and then falls off due to competition with the $n,2n$ reaction. Above the $n,2n$ threshold, the n,n'

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	827	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	39	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	39	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	27	12/01/75	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	16	12/01/75	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	18	12/03/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,2N	CROSS SECTION	15	12/01/75	-5.8000+ 0	6.8300+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	9	12/01/75	-6.8000+ 0	6.8300+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	15	12/03/76	-6.8000+ 0	6.8300+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	8	12/03/76	-6.8000+ 0	6.8300+ 0	2.0000+ 1
N,3N	CROSS SECTION	10	12/01/75	-1.2490+ 1	1.2550+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	6	12/01/75	-1.2490+ 1	1.2550+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.2490+ 1	1.2550+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.2490+ 1	1.2550+ 1	2.0000+ 1
N,4N	CROSS SECTION	2	12/01/75	-1.9470+ 1	1.9550+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	2	12/01/75	-1.9470+ 1	1.9550+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.9470+ 1	1.9550+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.9470+ 1	1.9550+ 1	2.0000+ 1
N,F	CROSS SECTION	895	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	1144	12/01/75	5.5200+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.5200+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.5200+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.5200+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.5200+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	4.5000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	4.5000- 2	2.0000+ 1

DELAYED

cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 6.83 MeV. Since there are no experimental data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises rapidly above threshold, reaches a plateau value of about 1 barn between 8 and 12 MeV, and then drops sharply above 12 MeV due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The $n,3n$ threshold is at 12.55 MeV. The evaluated cross section rises to a value of about 0.35 barns in the plateau region that extends from about 13 to 18 MeV, and then falls off, reaching a value of 0.1 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 19.55 MeV. The evaluated $n,4n$ cross section rises linearly to a value of 0.05 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

The experimental fission cross section data for Cm^{244} are shown graphically on pp. 11-392 to 11-394 of UCRL-50400, Vol. 7, Part B, Rev. 1; a few tabulated values are given on p. 11-398. The evaluated fission

cross section data are shown graphically on p. 11-395. As stated above, the fission cross sections below 1 keV are taken from the SRL evaluation. The fission cross sections between 1 keV and 3 MeV are obtained as averages over the experimental data. The fission cross sections between 3 and 20 MeV are obtained from systematics and from a few measured points near 14.5 MeV.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only experimental value for $\bar{\nu}$ is a series of spontaneous fission values that are listed on p. 11-398 of UCRL-50400, Vol. 3, Rev. 2. In the absence of other data, the evaluated $\bar{\nu}$ values are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission,

the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

Experimental values for the capture reaction are shown on pp. 11-395 to 11-397 of UCRL-50400, Vol. 7, Part B, Rev. 1; a tabulated thermal value is given on p. 11-398. The evaluated capture cross sections are shown graphically on p. 11-397. As mentioned above, the capture cross sections for energies below 1 keV are taken from the SRL evaluation. Between 1 and 10 keV, the capture cross

sections are obtained as averages over the experimental data. Above 10 keV, the capture cross sections are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, pp. 29 to 31.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 45 keV, photon production is assumed to originate only from capture and fission processes. From 45 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 45 keV
(except for the fission and capture
processes) are calculated with the
NXGAMEL code.

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DATA SUMMARY AND GENERAL COMMENTS

There are very few cross section measurements for ${}^{245}_{96}\text{Cm}$. The fission cross section has been measured in the LASL Physics-8 experiment over the energy range 20 eV to 2.8 MeV. All other cross sections were measured only at thermal energies. These include: two measurements of the fission cross section; two measurements of the capture cross section; one of $\bar{\nu}$; and one of the capture-to-fission ratio. These data are summarized in UCRL-50400, Vol. 3. This evaluation was carried out by R. J. Howerton.

The Savannah River Laboratory has developed sets of evaluated data for a considerable number of the trans-uranium isotopes. The point of departure for this evaluation is the SRL data set supplied by F. J. McCrosson of SRL. These cross sections are in the form of group constants, plus a set of resonance parameters for three resonances with energies less than 10 eV. The resonance parameter data have been combined with the background group cross sections. We have assumed linear interpolability between the nominal energies of the group cross sections.

The resulting pointwise data set was then modified, as described below. The SRL data set only consisted of cross sections for the fission, capture and elastic scattering reactions.

ELASTIC SCATTERING CROSS SECTION

For energies less than 0.1 MeV, the SRL values are used. From 0.1 to 1 MeV, optical model calculations of the elastic scattering cross section have been used after they were modified to include an estimated correction for compound nucleus elastic scattering. From 1 to 20 MeV, values calculated using a spherical optical model are used without modification. The optical model parameters are the best-fit values of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies less than or equal to 0.04 MeV, the elastic scattering angular distribution is assumed to be isotropic in the center-of-mass system. In the energy range from 0.04 to 1 MeV, a single entry is made at 0.5 MeV, with a forward-scattering to backward-scattering ratio of three. From 1 to 20 MeV, the angular distributions are calculated with a spherical

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	86	3/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	10	3/15/75	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	36	3/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	36	3/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	26	3/15/75	0.0000+ 0	6.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	14	3/15/75	0.0000+ 0	6.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	23	12/03/76	0.0000+ 0	6.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	18	12/03/76	0.0000+ 0	6.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	10	3/15/75	-5.5200+ 0	5.6000+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	3/15/75	-5.5200+ 0	5.6000+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	19	12/03/76	-5.5200+ 0	5.6000+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	11	12/03/76	-5.5200+ 0	5.6000+ 0	2.0000+ 1
N,3N	CROSS SECTION	6	3/15/75	-1.2320+ 1	1.2400+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	6	3/15/75	-1.2320+ 1	1.2400+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.2320+ 1	1.2400+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.2320+ 1	1.2400+ 1	2.0000+ 1
N,4N	CROSS SECTION	2	3/15/75	-1.8020+ 1	1.8200+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	3	3/15/75	-1.8020+ 1	1.8200+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.8020+ 1	1.8200+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.8020+ 1	1.8200+ 1	2.0000+ 1
N,F	CROSS SECTION	4336	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	6	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	6	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	219	3/15/75	6.4500+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	6.4500+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	6.4500+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	6.4500+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	6.4500+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	6.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	6.0000- 2	2.0000+ 1

DELAYED

optical model using the Becchetti and Greenlees parameters.

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering reaction is assumed to rise above a threshold at 0.06 MeV in the usual sigmoid shape, reaching an effective plateau at about 0.3 MeV, and continue to higher energies as the difference between an assumed nonelastic cross section and the sum of the fission and capture cross sections. The threshold of the $n,2n$ reaction is at approximately 5.6 MeV. For energies greater than the threshold of the $n,2n$ reaction, the inelastic scattering cross section is assumed to decrease as competitive processes became energetically possible. In accordance with the usual systematics for these elements, the inelastic scattering falls to an effectively constant value, which represents direct-interaction plus pre-equilibrium reactions. The cross section for the total inelastic scattering processes is assumed to remain essentially constant at about 0.25 barns over the energy range from 8 to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system

for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 5.54 MeV. Above threshold, the $n,2n$ cross section rises in the usual systematic way, reaching a plateau at about 8 MeV, and then continuing parallel to the nonelastic cross section. At the energy that corresponds to the opening of the $n,2nf$ channel, at about 11.5 MeV, the $n,2n$

cross section decreases due to the competition from this new reaction. At 12.4 MeV, where the threshold for the $n,3n$ reaction is reached, this competing process causes a further decrease of the $n,2n$ cross section to a value of about 0.25 barns at 13 MeV, from whence it falls gradually to a value of 0.2 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondaries are derived from temperature model calculations and are presented in tabular form. The assigned temperatures are consistent with observed systematics.

$n,3n$ CROSS SECTION

The threshold for the $n,3n$ reaction is at 12.37 MeV. The $n,3n$ cross section is assumed to rise above threshold in the usual shape, finally attaining a plateau value that is obtained by subtracting the sum of the other nonelastic reactions from the total nonelastic cross section. This yields a value of about 0.4 barns, which remains constant until the threshold of the $n,4n$ reaction is reached at 18.2 MeV, above which the cross section for the $n,3n$ reaction is assumed

to fall slowly, reaching a value of 0.3 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the results described for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 18.09 MeV. The $n,4n$ cross section is assumed to rise in a linear fashion to a value of 100 mbarns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distributions of the secondary neutrons from the $n,4n$ reaction are assumed to be isotropic in the laboratory system. The energy distribution of secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

For energies less than 20 eV, the

SRL evaluation is used. From 20 eV to 2.8 MeV, the fission cross section is based on the Physics-8 experimental data, with some smoothing of the data required from 0.01 to 2.8 MeV. Above 2.8 MeV, the fission cross section is obtained by nuclear systematics.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only available experimental value for $\bar{\nu}$ is reported in ECSIL-1912. However, the value reported there is approximately 11% greater than the value obtained by the systematics described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). In the discussion contained in ECSIL-1912, it is noted that the measured value is anomalously high. Hence, for the purposes of this evaluation, the intermediate value $\bar{\nu} = 3.60$ at zero neutron energy has been chosen. This adopted value is within about 5% of both the prediction from systematics and the experimental value of ECSIL-1912. For higher energies, the energy dependence is obtained from systematics, with allowances made for the onset of the $(n, n'f)$, $(n, 2nf)$, and $(n, 3nf)$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of

Howerton and Doyas [*Nucl. Sci. Eng.* 46, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The spectra are composites, weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the spectrum. The spectrum of photons from fission is deduced from the measurements for photons from U^{235} fission.

CROSS SECTIONS FOR THE (n, γ) REACTION

The Q-value for the n, γ reaction is 6.45 MeV. For energies less than 0.001 MeV, the SRL evaluation is used. From 0.001 to 20 MeV, the capture cross section is derived from systematics, as described on pp. 29 to 31 of UCRL-50400, Vol. 15, Part A.

PHOTON PRODUCTION FROM THE (n, γ) REACTION

Photon production from neutron capture is handled by using a multiplicity and a normalized spectrum. The photon multiplicity for this reaction is derived by dividing the average photon energy into the total available energy. The spectrum adopted for secondary photons is deduced from the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies less than 60 keV, photon production is assumed to occur

only from the capture and fission processes. From 60 keV to 20 MeV, the NXGAMEL code calculated the cross sections and spectra. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975).

SPECTRA OF PHOTONS FROM THE n,X γ PROCESS

As stated in the previous section, the photon spectra associated with photon production above 60 keV (except for the fission and capture processes) are calculated with the NXGAMEL code.

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DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{246}_{96}\text{Cm}$ are listed in UCRL-50400, Vol. 3. These data consist of a fairly extensive measurement of the fission cross section, some measurements of the capture cross section over low-energy resonances, and a few measurements of prompt $\bar{\nu}$ for spontaneous fission. In the absence of other data, much of the evaluation is based on systematics. This evaluation was carried out by R. J. Howerton.

In the evaluation of Cm^{246} , the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL). The evaluated cross sections for Cm^{246} are shown graphically on pp. 415 to 419 of UCRL-50400, Vol. 15, Part B.

TOTAL CROSS SECTION

There are no experimental data for this cross section. The evaluated total cross section data are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As described above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL

evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the elastic scattering cross sections are obtained by differencing the total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at the higher energy.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 43 keV, reaching a value of roughly 1.8 barns in

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	276	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	38	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	38	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	20	12/01/75	0.0000+ 0	4.3000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	4.3000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	4.3000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	4.3000- 2	2.0000+ 1
N,2N	CROSS SECTION	17	12/01/75	-6.4500+ 0	6.4800+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	9	12/01/75	-6.4500+ 0	6.4800+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	13	12/03/76	-6.4500+ 0	6.4800+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	9	12/03/76	-6.4500+ 0	6.4800+ 0	2.0000+ 1
N,3N	CROSS SECTION	11	12/01/75	-1.1970+ 1	1.2020+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	6	12/01/75	-1.1970+ 1	1.2020+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1970+ 1	1.2020+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.1970+ 1	1.2020+ 1	2.0000+ 1
N,4N	CROSS SECTION	3	12/01/75	-1.8750+ 1	1.8840+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	3	12/01/75	-1.8750+ 1	1.8840+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.8750+ 1	1.8840+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.8750+ 1	1.8840+ 1	2.0000+ 1
N,F	CROSS SECTION	305	12/01/75	2.0010+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	2.0010+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0010+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	5	12/01/75	2.0010+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	12/01/75	2.0010+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0010+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	433	12/01/75	5.1600+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.1600+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.1600+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.1600+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.1600+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	4.3000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	4.3000- 2	2.0000+ 1

DELAYED

the plateau region between 0.5 MeV and 6 MeV, and then decreases rapidly above 6.5 MeV due to competition from the $n,2n$ reaction. Above the threshold for the $n,2n$ reaction, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method

used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 6.48 MeV. Since there are no data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises from threshold, reaching a value of about 1.1 barns in the plateau region from 7 to 11.5 MeV, and then decreases above 12 MeV due to the onset of the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The threshold for the $n,3n$ reaction

is at 12.02 MeV. The evaluated $n,3n$ cross section rises from threshold to a value of about 0.8 barns in the plateau region from 13 to 18 MeV, and then decreases above 19 MeV due to competition from the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 18.84 MeV. The $n,4n$ cross section rises from threshold to a value of 0.3 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

As stated above, the SRL evaluated fission cross sections are used below 1 keV. From 1 keV to 2.8 MeV, the fission cross sections are based on the LASL Physics-8 experiment listed in ECSIL-3062. Above 2.8 MeV, the evaluated fission cross sections are obtained from systematics. The evaluated fission cross sections are shown graphically on p. 11-403 of UCRL-50400, Vol. 7, Part B, Rev. 1.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Only spontaneous fission values have been measured for $\bar{\nu}$. The evaluations for $\bar{\nu}$ are shown in UCRL-50400, Vol. 15, Part B. In the absence of data, the evaluated $\bar{\nu}$ values are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971).

Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

The experimental data for the capture cross section include graphs (p. 11-404 of UCRL-50400, Vol. 7, Part B, Rev. 1) and thermal tables (p. 11-405). As described above, the capture cross sections below 1 keV are obtained from the SRL evaluation. Above 1 keV, the capture cross sections are obtained from systematics,

as described on pp. 29 to 31 of UCRL-50400, Vol. 15, Part A.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n, γ CROSS SECTION

For energies below 43 keV, photon production is assumed to originate only from capture and fission processes. From 43 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 43 keV (except
for the fission and capture processes)
are calculated with the NXGAMEL code.

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DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{96}\text{Cm}^{247}$ are listed in UCRL-50400, Vol. 3. They are limited to some fission measurements and a few spectrum-averaged capture measurements. In the absence of other data, most of the evaluation is based on systematics. This evaluation was carried out by R. J. Howerton.

In the evaluation for Cm^{247} , the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL). The evaluated cross sections for Cm^{247} are shown graphically in UCRL-50400, Vol. 15, Part B.

TOTAL CROSS SECTION

There are no experimental data for this cross section. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As mentioned above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the elastic scattering cross sections are obtained by differencing the total and nonelastic cross sections.

For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* 182, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at the higher energy.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from threshold at 50 keV, reaching a value of roughly 1.3 barns in the plateau region between 0.7 MeV and 5 MeV, and then decreases rapidly above 5 MeV due to the onset of the $n,2n$ reaction. Above the threshold for the $n,2n$ reaction, the n,n' cross section is assumed to be the

difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model -- a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 5.18 MeV. Since there are no data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises from threshold, reaching a value of about 0.9 barns in the plateau region between 5.5 to 11.5 MeV, and then decreases due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The $n,3n$ threshold is at 11.65 MeV. The evaluated cross section rises from threshold, reaching a value of about 0.5 barns in the plateau region between 12 and 17 MeV, and then drops off rapidly due to competition from the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 17.20 MeV. The $n,4n$ cross section rises from threshold, reaching a value of 0.3 barns, and remains at that value to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

As described above, the SRL evaluated fission cross sections are used below 1 keV. From 1 keV to 1.9 MeV,

the fission cross sections are based on the LASL Physics-8 experiment listed in ECSIL-3062. Above 1.9 MeV, the evaluated fission cross sections are obtained from systematics. The evaluated fission cross sections and the experimental fission data are shown graphically on pp. 11-405 to 11-407 of UCRL-50400, Vol. 7, Part B, Rev. 1.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

There are no experimental measurements for $\bar{\nu}$. The evaluated values for total and delayed $\bar{\nu}$ are shown in UCRL-50400, Vol. 15, Part B. In the absence of data, the evaluated $\bar{\nu}$ values are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-

third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

Except for two spectrum-averaged values, there are no experimental capture-cross-section data for this isotope. As mentioned above, the capture cross sections below 1 keV are obtained from the SRL evaluation. Above 1 keV, the capture cross sec-

tions are obtained from systematics, as described on pp. 29 to 31 of UCRL-50400, Vol. 15, Part A.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 50 keV, photon production is assumed to originate only from capture and fission processes. From 50 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 50 keV
(except for the fission and capture
processes) are calculated with the
NXGAMEL code.

Curium-248

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{96}\text{Cm}^{248}$ are listed in UCRL-50400, Vol. 3. They are limited to fission and capture measurements and some spontaneous fission values for $\bar{\nu}$. In the absence of other data, most of the evaluation is based on systematics. This evaluation was carried out by R. J. Howerton.

In the evaluation for Cm^{248} , the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL). The evaluated cross sections for Cm^{248} are shown graphically in UCRL-50400, Vol. 15, Part B.

TOTAL CROSS SECTION

There are no experimental data for this cross section. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As mentioned above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the elastic scattering cross sections are obtained by differencing the total

and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at the higher energy.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from a threshold of 45 keV, reaching a value of roughly 1.9 barns in the plateau region between 0.7 MeV and 6 MeV, and then decreases rapidly above 6.5 MeV due to competition from

Curium-248

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	REACTION	POINTS	DATE	G-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	699	12/01/75	0.0000-0	1.0000-10	2.0000+1
N,ELASTIC	N ANGULAR DIST.	19	12/01/75	0.0000-0	1.0000-2	2.0000+1
N,ELASTIC	N TOTAL ENERGY DEP.	38	12/01/75	0.0000-0	1.0000-10	2.0000+1
N,ELASTIC	N LOCAL ENERGY DEP.	38	12/01/75	0.0000-0	1.0000-10	2.0000+1
N,N'	CROSS SECTION	19	12/01/75	0.0000-0	4.5000-2	2.0000+1
N,N'	N ENERGY-ANGLE DIST.	15	12/01/75	0.0000-0	4.5000-2	2.0000+1
N,N'	N TOTAL ENERGY DEP.	17	12/03/76	0.0000-0	4.5000-2	2.0000+1
N,N'	N LOCAL ENERGY DEP.	16	12/03/76	0.0000-0	4.5000-2	2.0000+1
N,2N	CROSS SECTION	15	12/01/75	-6.2000+0	6.2300+0	2.0000+1
N,2N	N ENERGY-ANGLE DIST.	9	12/01/75	-6.2000+0	6.2300+0	2.0000+1
N,2N	N TOTAL ENERGY DEP.	10	12/03/76	-6.2000+0	6.2300+0	2.0000+1
N,2N	N LOCAL ENERGY DEP.	9	12/03/76	-6.2000+0	6.2300+0	2.0000+1
N,3N	CROSS SECTION	13	12/01/75	-1.1360+1	1.1410+1	2.0000+1
N,3N	N ENERGY-ANGLE DIST.	6	12/01/75	-1.1360+1	1.1410+1	2.0000+1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1360+1	1.1410+1	2.0000+1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1360+1	1.1410+1	2.0000+1
N,4N	CROSS SECTION	5	12/01/75	-1.7810-1	1.7890+1	2.0000+1
N,4N	N ENERGY-ANGLE DIST.	3	12/01/75	-1.7810-1	1.7890+1	2.0000+1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.7810-1	1.7890+1	2.0000+1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.7810-1	1.7890+1	2.0000+1
N,F	CROSS SECTION	500	12/01/75	2.0000+2	1.0000-10	2.0000+1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	2.0000+2	1.0000-10	2.0000+1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000+2	1.0000-10	2.0000+1
N,F	N ENERGY-ANGLE DIST.	5	12/01/75	2.0000+2	1.0000-10	2.0000+1
N,F	N NEUTRONS/FISSION	5	12/01/75	2.0000+2	1.0000-10	2.0000+1
N,F	G ENERGY DIST.	2	2/16/78	2.0000+2	1.0000-10	2.0000+1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+2	1.0000-10	2.0000+1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+2	1.0000-10	2.0000+1
N,G	CROSS SECTION	966	12/01/75	4.7100+0	1.0000-10	2.0000+1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	4.7100+0	1.0000-10	2.0000+1
N,G	G MULTIPLICITY	2	2/17/78	4.7100+0	1.0000-10	2.0000+1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	4.7100+0	1.0000-10	2.0000+1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	4.7100+0	1.0000-10	2.0000+1
N,XG	CROSS SECTION	20	2/18/78	0.0000-0	4.5000-2	2.0000+1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000-0	4.5000-2	2.0000+1

DELAYED

the $n,2n$ reaction. Above the threshold for the $n,2n$ reaction, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-scattered neutrons to be associated with the pre-equilibrium

process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 6.23 MeV. Since there are no data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises from threshold, reaching a value of roughly 1.2 barns in the plateau region between 7 to 11 MeV, and then falls off due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The $n,3n$ threshold is at 11.41 MeV. The evaluated cross section rises rapidly above threshold, reaching a value of about 0.9 barns in the plateau region between 12 to 18 MeV,

and then decreases due to competition with the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 17.89 MeV. The cross section rises from threshold to a value of 0.35 barns and then remains at this value to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

As mentioned above, the SRL-evaluated fission cross sections are

used below 1 keV. From 1 keV to 2.8 MeV, the fission cross sections are obtained from the LASL Physics-8 experiment listed in ECSIL-3062. Above 2.8 MeV, the evaluated fission cross sections are obtained from systematics. The experimental fission data are given graphically on pp. 11-408 and 11-409 of UCRL-50400, Vol. 7, Part B, Rev. 1; a thermal value is given on p. 11-410. The evaluated fission cross sections are displayed graphically on p. 11-409.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

Only spontaneous fission values have been measured for $\bar{\nu}$. In the absence of data, the evaluated $\bar{\nu}$ values are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas [*Nucl. Sci. Eng.* 46, 414 (1971)]. Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated

with the FISPEC code, which assumes temperature model distributions for the pre-fission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235}

CROSS SECTION FOR THE (n, γ) REACTION

The few measurements of the capture cross section are shown graphically on p. 11-410 of UCRL-50400, Vol. 7, Part B, Rev. 1. As stated above, the capture cross sections below 1 keV are obtained from the SRL evaluation. Above 1 keV, the capture cross sections are obtained from systematics

(pp. 29 to 31 of UCRL-50400, Vol. 15, Part A).

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 45 keV, photon production is assumed to originate only from capture and fission processes. From 45 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 45 keV
(except for the fission and capture
processes) are calculated with the
NXGAMEL code.

Berkelium-249

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{97}\text{Bk}^{249}$ are listed in UCRL-50400, Vol. 3. They consist essentially of one fission data point at 5 MeV, three measurements of the thermal capture cross section, and a measurement of $\bar{\nu}$ for spontaneous fission. In the absence of other data, this evaluation is based largely on systematics. This evaluation was carried out by R. J. Howerton.

In the evaluation for Bk^{249} , the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL). The evaluated Bk^{249} cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

TOTAL CROSS SECTION

There are no experimental data for this cross section. The evaluated total cross sections are shown in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As mentioned above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the

elastic scattering cross sections are obtained by differencing the total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections were obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at the higher energy.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from a threshold of 50 keV, reaching a value of roughly 2.3 barns in the plateau region between 0.6 MeV and

Berkelium-249

6/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	209	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	38	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	38	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	23	12/01/75	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	16	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	18	12/01/75	-6.2000+ 0	6.2300+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	8	12/01/75	-6.2000+ 0	6.2300+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	18	12/03/76	-6.2000+ 0	6.2300+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	13	12/03/76	-6.2000+ 0	6.2300+ 0	2.0000+ 1
N,3N	CROSS SECTION	12	12/01/75	-1.1780+ 1	1.1830+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	6	12/01/75	-1.1780+ 1	1.1830+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1780+ 1	1.1830+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1780+ 1	1.1830+ 1	2.0000+ 1
N,4N	CROSS SECTION	5	12/01/75	-1.7800+ 1	1.7900+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	3	12/01/75	-1.7800+ 1	1.7900+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.7800+ 1	1.7900+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.7800+ 1	1.7900+ 1	2.0000+ 1
N,F	CROSS SECTION	125	12/01/75	2.0000- 0	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	2.0000- 0	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000- 0	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	2	12/01/75	2.0000- 0	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	12/01/75	2.0000- 0	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0000- 0	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000- 0	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000- 0	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	368	12/01/75	4.9700+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	3	2/17/78	4.9700+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	3	2/17/78	4.9700+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	4.9700+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	4.9700+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1

DELAYED

6 MeV, and then decreases rapidly above 6 MeV due to the onset of the $n,2n$ reaction. Above the threshold for the $n,2n$ reaction, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model -- a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the

inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 6.2 MeV. Since there are no experimental data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section has a rapid linear rise above threshold, reaching a value of roughly 1.6 barns in the plateau region that extends from 8 to 12 MeV, and then falls off due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24.

n,3n CROSS SECTION

The n,3n threshold is at 11.83 MeV. The evaluated cross section rises from threshold to a value of about 1.2 barns in the plateau region that extends from 13 to 18 MeV, and then drops off due to competition from the n,4n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction. The method accounts for the neutron multiplicity and the average neutron energy.

n,4n CROSS SECTION

The threshold for the n,4n reaction is at 17.9 MeV. The cross section rises rapidly to a value of 0.6 barns and then remains at this value to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,4n REACTION

The angular distribution of secondary neutrons from the n,4n reaction is assumed to be isotropic

in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the n,2n and n,3n secondaries.

FISSION CROSS SECTION

The only fission data point is a single fission measurement of 5 MeV. As described above, the SRL evaluated fission cross sections are used below 1 keV. Above 1 keV, the evaluated fission cross sections are obtained from systematics. The evaluated fission cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only experimental measurement of this quantity is a value for prompt $\bar{\nu}$ in spontaneous fission. Thus, the evaluated $\bar{\nu}$ values are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained from the slope predicted from fission systematics. The method accounts for the onset of the n,n'f, n,2nf, n,3nf, and n,4nf reactions.

FISSION SPECTRUM

The fission temperature is obtained

in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n, γ) REACTION

The only measurements of the capture cross section are three data points at thermal neutron energy. As stated at the beginning, the capture cross sections below 1 keV are

obtained from the SRL evaluation. Above 1 keV, the capture cross sections are obtained from systematics, as described on pp. 29 to 31 of UCRL-50400, Vol. 15, Part A.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 50 keV, photon production is assumed to originate only from capture and fission processes. From 50 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 50 keV
(except for the fission and capture
processes) are calculated with the
NXGAMEL code.

Californium-249

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{98}\text{Cf}^{249}$ are listed in UCRL-50400, Vol. 3. These data are limited to capture and fission measurements plus a thermal value for prompt $\bar{\nu}$. In the absence of other data, the evaluation is based mainly on systematics. This evaluation was carried out by R. J. Howerton. The evaluated cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

In the evaluation for this isotope, the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL).

TOTAL CROSS SECTION

There are no experimental data for this cross section. The evaluated total cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As stated above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the

elastic scattering cross sections are obtained by differencing the total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 1 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at the higher energy.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from a threshold of 43 keV, reaching a value of roughly 1.7 barns in the plateau region between 0.6 MeV

Californium-249

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	312	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	38	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	LOCAL ENERGY DEP.	38	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	19	12/01/75	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	16	12/03/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,2N	CROSS SECTION	16	12/01/75	-5.5900+ 0	5.6200+ 0	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	9	12/01/75	-5.5900+ 0	5.6200+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	18	12/03/76	-5.5900+ 0	5.6200+ 0	2.0000+ 1
N,2N	LOCAL ENERGY DEP.	11	12/03/76	-5.5900+ 0	5.6200+ 0	2.0000+ 1
N,3N	CROSS SECTION	11	12/01/75	-1.1780+ 1	1.1830+ 1	2.0000+ 1
N,3N	ENERGY-ANGLE DIST.	6	12/01/75	-1.1780+ 1	1.1830+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	5	12/03/76	-1.1780+ 1	1.1830+ 1	2.0000+ 1
N,3N	LOCAL ENERGY DEP.	5	12/03/76	-1.1780+ 1	1.1830+ 1	2.0000+ 1
N,4N	CROSS SECTION	4	12/01/75	-1.8590+ 1	1.8670+ 1	2.0000+ 1
N,4N	ENERGY-ANGLE DIST.	3	12/01/75	-1.8590+ 1	1.8670+ 1	2.0000+ 1
N,4N	TOTAL ENERGY DEP.	2	12/03/76	-1.8590+ 1	1.8670+ 1	2.0000+ 1
N,4N	LOCAL ENERGY DEP.	2	12/03/76	-1.8590+ 1	1.8670+ 1	2.0000+ 1
N,F	CROSS SECTION	2027	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	ENERGY-ANGLE DIST.	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	NEUTRONS/FISSION	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	G	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	1939	12/01/75	6.6200+ 0	1.0000-10	2.0000+ 1
N,G	ENERGY DIST.	2	12/01/75	6.6200+ 0	1.0000-10	3.0000- 1
N,G	G	3	12/01/75	6.6200+ 0	1.0000-10	3.0000- 1
N,G	MULTIPLICITY	2	11/21/76	6.6200+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.6200+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	16	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1
N,XG	G	15	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1

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and 6 MeV, and then decreases rapidly above 6 MeV due to competition from the $n,2n$ reaction. Above the threshold for the $n,2n$ reaction, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method

used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 5.62 MeV. Since there are no data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises sharply from threshold, reaching a value of roughly 1.1 barns in the plateau region from 9 to 11.5 MeV, and then decreases rapidly due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The n,3n threshold is at 11.8 MeV. The evaluated cross section rises rapidly above threshold to a value of about 0.55 barns in the plateau region between 12.5 to 18 MeV, and then decreases due to competition from the n,4n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,3n REACTION

The angular distribution of secondary neutrons from the n,3n reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the n,2n reaction. The method accounts for the neutron multiplicity and the average neutron energy.

n,4n CROSS SECTION

The n,4n threshold is at 18.67 MeV. The cross section rises from threshold to a value of 0.2 barns, and then remains at this value until it reaches 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,4n REACTION

The angular distribution of secondary neutrons from the n,4n reaction is assumed to be isotropic in the laboratory system. The energy

distribution of the secondary neutrons is obtained as described above for the n,2n and n,3n secondaries.

FISSION CROSS SECTION

The experimental fission data for Cf^{249} are shown graphically on pp. 11-412 to 11-415 of UCRL-50400, Vol. 7, Part B, Rev. 1. These data extend from thermal energies to 7 MeV. As stated above, the evaluated fission cross sections below 1 keV are obtained from the SRL evaluation. The cross sections from 1 keV to 7 MeV are based on the experimental data. The cross sections above 7 MeV are obtained from systematics. The evaluated fission cross sections for Cf^{249} are shown graphically on p. 11-415 of UCRL-50400, Vol. 7, Part B, Rev. 1.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

One measurement of prompt $\bar{\nu}$ at thermal energies has been made. In the absence of other data, the evaluated $\bar{\nu}$ values are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of

the $n,n'f$, $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

For neutron energies below 300 keV, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n,γ) REACTION

The capture cross section measurements consist of a thermal value and

a spectrum-averaged value, plus a resonance integral. As stated above, the capture cross sections below 1 keV are obtained from the SRL evaluation. Above 1 keV, the capture cross sections are obtained from systematics, as described on pp. 29 to 31 of UCRL-50400, Vol. 15, Part A.

PHOTON PRODUCTION FROM (n,γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

$n,X\gamma$ CROSS SECTION

For energies below 45 keV, photon production is assumed to originate only from capture and fission processes. From 45 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton [*Nucl. Sci. Eng.* 57, 1 (1975)]. A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 45 keV
(except for the fission and capture
processes) are calculated with the
NXGAMEL code.

Californium-250

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{250}_{98}\text{Cf}$ are listed in UCRL-50400, Vol. 3. These data include a few capture measurements plus a value for $\bar{\nu}$ for spontaneous fission. Because of the absence of other data, the evaluation is based almost entirely on systematics. This evaluation was carried out by R. J. Howerton. The evaluated cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

In the evaluation for this isotope, the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL).

TOTAL CROSS SECTION

There are no experimental data for this cross section. The evaluated total cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As stated above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the elastic scattering cross sections are

obtained by differencing the total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at the higher energy.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from a threshold of 45 keV, reaching a value of roughly 1.6 barns in the plateau region between 0.7 MeV and 6 MeV, and then decreases rapidly above 6.7 MeV due to the onset of

Californium-250

06/09/78

	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	186	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	40	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	40	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	20	12/01/75	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	14	12/01/75	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	16	12/03/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	13	12/03/76	0.0000+ 0	4.5000- 2	2.0000+ 1
N,2N	CROSS SECTION	18	12/01/75	-5.6100+ 0	6.6400+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	9	12/01/75	-5.6100+ 0	6.6400+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	18	12/03/76	-5.6100+ 0	6.6400+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	12	12/03/76	-5.6100+ 0	6.6400+ 0	2.0000+ 1
N,3N	CROSS SECTION	11	12/01/75	-1.2210+ 1	1.2260+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	6	12/01/75	-1.2210+ 1	1.2260+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.2210+ 1	1.2260+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.2210+ 1	1.2260+ 1	2.0000+ 1
N,4N	CROSS SECTION	4	12/01/75	-1.8590+ 1	1.8670+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	3	12/01/75	-1.8590+ 1	1.8670+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.8590+ 1	1.8670+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.8590+ 1	1.8670+ 1	2.0000+ 1
N,F	CROSS SECTION	22	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	3	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	260	12/01/75	5.1100+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	5.1100+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	5.1100+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	5.1100+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	5.1100+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	4.5000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	4.5000- 2	2.0000+ 1

DELETED

the $n,2n$ reaction. Above the threshold for the $n,2n$ reaction, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the $n,2n$ and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically-

scattered neutrons to be associated with the pre-equilibrium process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 6.64 MeV. Since there are no data for this reaction, the evaluation is based on systematics. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises rapidly above threshold, reaching a value of about 1 barn in the plateau region between 8 and 12 MeV, and then falls off rapidly above 12.5 MeV due to competition from the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The angular distribution of secondary neutrons from the $n,2n$ reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

$n,3n$ CROSS SECTION

The $n,3n$ threshold is at 12.26 MeV.

The evaluated cross section rises rapidly to a value of about 0.55 barns in the plateau region between 13 and 18 MeV, and then falls off due to the onset of the $n,3n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The $n,4n$ threshold is at 18.6 MeV. The cross section rises from threshold to a value of 0.2 barns and then remains at this value to 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

As described above, the SRL evaluated fission cross sections are used below 1 keV. Because of the absence of experimental data, the evaluated fission cross sections above 1 keV are obtained from systematics. The evaluated fission cross sections are shown graphically in UCRL-50400, Vol. 15 Part B.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only $\bar{\nu}$ measurement for Cf^{250} is a prompt $\bar{\nu}$ value for spontaneous fission. Because of the absence of data, the evaluated values for $\bar{\nu}$ are obtained from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the n,n' , $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the

FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} .

CROSS SECTION FOR THE (n,γ) REACTION

The capture cross section measurements consist of a thermal value and a spectrum-averaged value, plus a resonance integral. As stated above, the capture cross sections below 1 keV are obtained from the SRL evaluation. Above 1 keV, the capture cross sections are obtained from

systematics, as described on pp. 29 to 31 of UCRL-50400, Vol. 15, Part A.

PHOTON PRODUCTION FROM (n,γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,γ CROSS SECTION

For energies below 45 keV, photon production is assumed to originate only from capture and fission processes. From 45 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXCAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE $(n, X\gamma)$
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 45 keV
(except for the fission and capture
processes) are calculated with the
NXGAMEL code.

Californium-251

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{98}\text{Cf}^{251}$ are listed in UCRL-50400, Vol. 3. These data are limited to a few capture and fission measurements at thermal-neutron or fission-spectrum energies. Because of the absence of other data, the evaluation is based almost entirely on systematics. The evaluated cross sections are shown graphically in UCRL-50400, Vol. 15, Part B. This evaluation was carried out by R. J. Howerton.

In the evaluation for this isotope, the elastic scattering, fission, and capture cross sections below 1 keV were supplied by F. J. McCrosson of Savannah River Laboratory (SRL).

TOTAL CROSS SECTION

There are no experimental data for this cross section. The evaluated total cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

ELASTIC SCATTERING CROSS SECTION

As stated above, the evaluated elastic scattering cross sections below 1 keV are taken from the SRL evaluation of F. J. McCrosson. For energies between 1 and 150 keV, the elastic scattering cross sections are

obtained by differencing the total and nonelastic cross sections. For energies between 150 keV and 20 MeV, the elastic scattering cross sections are obtained from spherical optical model calculations, using the best-fit optical model parameters of Becchetti and Greenlees [*Phys. Rev.* **182**, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For neutron energies below 10 keV, the elastic scattering is assumed to be isotropic in the center-of-mass system. From 150 keV to 20 MeV, the angular distributions are calculated from a spherical optical model, using the Becchetti and Greenlees parameters. Between 10 and 150 keV, the entries represent a smooth transition from the isotropic distribution at the lower energy to the calculated distribution at the higher energy.

INELASTIC SCATTERING CROSS SECTION

The evaluated inelastic scattering cross section is shown in UCRL-50400, Vol. 15, Part B. It rises from a threshold of 25 keV, reaching a value of roughly 1.75 barns in the plateau region between 0.8 MeV and 5 MeV, and then decreases rapidly above 5.2 MeV due to the onset of the

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	159	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	40	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	LOCAL ENERGY DEP.	40	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	19	12/01/75	0.0000+ 0	2.5000- 2	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	14	12/01/75	0.0000+ 0	2.5000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	2.5000- 2	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	13	12/03/76	0.0000+ 0	2.5000- 2	2.0000+ 1
N,2N	CROSS SECTION	15	12/01/75	-5.1000+ 0	5.1300+ 0	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	10	12/01/75	-5.1000+ 0	5.1300+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	22	12/03/76	-5.1000+ 0	5.1300+ 0	2.0000+ 1
N,2N	LOCAL ENERGY DEP.	12	12/03/76	-5.1000+ 0	5.1300+ 0	2.0000+ 1
N,2N	CROSS SECTION	8	12/01/75	-1.1730+ 1	1.1780+ 1	2.0000+ 1
N,3N	ENERGY-ANGLE DIST.	6	12/01/75	-1.1730+ 1	1.1780+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	3	12/03/76	-1.1730+ 1	1.1780+ 1	2.0000+ 1
N,3N	LOCAL ENERGY DEP.	5	12/03/76	-1.1730+ 1	1.1780+ 1	2.0000+ 1
N,4N	CROSS SECTION	5	12/01/75	-1.7320+ 1	1.7390+ 1	2.0000+ 1
N,4N	ENERGY-ANGLE DIST.	3	12/01/75	-1.7320+ 1	1.7390+ 1	2.0000+ 1
N,4N	TOTAL ENERGY DEP.	3	12/03/76	-1.7320+ 1	1.7390+ 1	2.0000+ 1
N,4N	LOCAL ENERGY DEP.	3	12/03/76	-1.7320+ 1	1.7390+ 1	2.0000+ 1
N,F	CROSS SECTION	203	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	ENERGY-ANGLE DIST.	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	ENERGY DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	206	12/01/75	6.1700+ 0	1.0000-10	2.0000+ 1
N,G	ENERGY-ANGLE DIST.	2	2/17/78	6.1700+ 0	1.0000-10	2.0000+ 1
N,G	MULTIPLICITY	2	2/17/78	6.1700+ 0	1.0000-10	2.0000+ 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.1700+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.1700+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/18/78	0.0000+ 0	2.5000- 2	2.0000+ 1
N,XG	ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	2.5000- 2	2.0000+ 1

OLLAYED

n,2n reaction. Above the threshold for the n,2n reaction, the n,n' cross section is assumed to be the difference between the nonelastic cross section and the sum of the fission cross section plus the n,2n and higher neutron emission cross sections.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for inelastic scattering are assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction portions of the reaction, the uncertainties in the reaction cross section are so large that entering anisotropic angular distributions would be a meaningless procedure. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions of the secondary neutrons are derived from a temperature model. For incident neutron energies above 6 MeV, the energy distributions of the secondary neutrons are characterized by a two-component model — a temperature component plus a pre-equilibrium and unresolved direct-interaction component. The method used in selecting the fraction of the inelastically scattered neutrons to be associated with the pre-equilibrium

process is described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

n,2n CROSS SECTION

The threshold for the n,2n reaction is at 5.13 MeV. Since there are no data for this reaction, the evaluation is based on systematics. The evaluated n,2n cross sections are shown in UCRL-50400, Vol. 15, Part B. The cross section rises rapidly above threshold, reaching a value of about 1.1 barns in the plateau region between 7.5 and 11.5 MeV, and then falls off due to competition from the n,3n reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE n,2n REACTION

The angular distribution of secondary neutrons from the n,2n reaction is assumed to be isotropic in the laboratory system. Energy distributions of the secondary neutrons are presented in tabular form. They are derived from temperature model calculations, with the assigned temperatures consistent with observed systematics (UCRL-50400, Vol. 15, Part A, p. 24).

n,3n CROSS SECTION

The n,3n threshold is at 11.78 MeV. The evaluated cross section rises rapidly above threshold, reaching a

value of about 0.6 barns in the plateau region between 14 and 17.5 MeV, and then falls off due to the onset of the $n,4n$ reaction.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distribution of secondary neutrons from the $n,3n$ reaction is assumed to be isotropic in the laboratory system. The tabular energy distributions of secondaries from this reaction are obtained in a manner similar to the method described above for the $n,2n$ reaction. The method accounts for the neutron multiplicity and the average neutron energy.

$n,4n$ CROSS SECTION

The $n,4n$ threshold is at 17.39 MeV. The cross section rises from threshold to a value of 0.25 barn, and then remains at this value until it reaches 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distribution of secondary neutrons from the $n,4n$ reaction is assumed to be isotropic in the laboratory system. The energy distribution of the secondary neutrons is obtained as described above for the $n,2n$ and $n,3n$ secondaries.

FISSION CROSS SECTION

As described above, the SRL evaluated fission cross sections are used below 1 keV. Since the only fission measurements for Cf^{251} are at thermal neutron energies, the evaluated fission cross sections above 1 keV are obtained entirely from systematics. The evaluated Cf^{251} fission cross sections are shown graphically in UCRL-50400, Vol. 15, Part B.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

There are no experimental measurements for $\bar{\nu}$. The evaluated values for total and delayed $\bar{\nu}$ are shown on p. 449 of UCRL-50400, Vol. 15, Part B. In the absence of data, the evaluated $\bar{\nu}$ values are obtained mainly from systematics, as described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 438 (1977). At the higher energies, the values for $\bar{\nu}$ are obtained with the slope predicted from fission systematics. The method accounts for the onset of the $n,n'f$, $n,2nf$, $n,3nf$, and $n,4nf$ reactions.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics of Howerton and Doyas, as reported in *Nucl. Sci. Eng.* 46, 414 (1971). Above

the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated with the FISPEC code, which assumes temperature model distributions for the prefission neutrons and allows for different fission temperatures for each fission mode. The tabular spectra given in the evaluation are composites, which are weighted for the contributions from the various processes.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total photon energy from fission of 6.2 MeV. This value is divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235}

CROSS SECTION FOR THE (n, γ) REACTION

The capture cross section measurements consist of a thermal value and a spectrum-averaged value, plus a resonance integral. As stated above, the capture cross sections below 1 keV are obtained from the SRL evaluation. Above 1 keV, the capture cross sections are obtained from systematics, as described on

pp. 29 to 31 of UCRL-50400, Vol. 15, Part A.

PHOTON PRODUCTION FROM (n, γ) REACTIONS

Photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reactions are derived by dividing the average photon energy into the total available energy. The spectrum of secondary photons is assumed to be the same as that for the measured U^{238} photon spectrum.

n,X γ CROSS SECTION

For energies below 25 keV, photon production is assumed to originate only from capture and fission processes. From 25 keV to 20 MeV (in the absence of measurements) the photon production cross sections and spectra are calculated with the NXGAMEL code. This code is based on systematics described by Perkins, Haight, and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975). A summary of this method of calculating photon production data is discussed in UCRL-50400, Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS

As stated in the previous section,
the photon spectra associated with

photon production above 25 keV
(except for the fission and capture
processes) are calculated with the
NXGAMEL code.

Californium-252

GENERAL COMMENTS

Experimental data for neutron-induced reactions of ${}_{98}\text{Cf}^{252}$ are extremely sparse. The only measurement, other than at thermal neutron energy, is a fission-cross-section measurement from 20 eV to 5 MeV, in which neutrons from a LASL Physics-8 nuclear explosion were used. These data are reported in ECSIL* Ref. 71-3141. The measurements were done using spectral-averaged thermal neutrons and include: a measurement of the fission cross section; three measurements of the thermal capture cross section; the determination of an absorption cross section and an absorption resonance integral at 0.0253 eV; and a capture cross section and resonance integral for capture at 0.0253 eV. In addition to these neutron-induced measurements, there have been many measurements associated with spontaneous fission phenomenon in Cf^{252} , but these data are of only secondary usefulness in helping to estimate the data for neutron-induced reactions. The experimental data for Cf^{252} are summarized in UCRL-50400, Vol. 3.

*See UCRL-50400, Vol. 2, Rev. 2.

The Savannah River Laboratory (SRL) has developed partial sets of evaluated data for a considerable number of the transuranium isotopes. The present Cf^{252} evaluation is based, in part, on SRL data supplied by F. J. McCrosson. These data are in the form of group-averaged cross sections for elastic scattering, fission and capture reactions. They cover the energy range from sub-thermal energies to a few tens of keV. In addition to background cross sections, the SRL data include resonance parameters for nine resolved resonances from 17 to 157 eV, and for unresolved resonance parameters from 167 eV to 86.5 keV. In the present evaluation, the resonance parameters (both resolved and unresolved) are first expanded into pointwise data and then combined with the group cross sections (by assuming linear interpolability between the nominal energies of the group cross sections). The resulting pointwise set is then modified, as described below.

ELASTIC SCATTERING CROSS SECTION

For energies less than 0.034 MeV, the SRL values are used. From 0.034 to 1 MeV, a smoothly varying cross section is assumed that is consistent with nuclear systematics. From 1 to

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	518	3/15/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N ANGULAR DIST.	13	3/25/75	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	N TOTAL ENERGY DEP.	39	3/29/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N LOCAL ENERGY DEP.	39	3/29/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,N'	CROSS SECTION	27	3/15/75	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	14	3/15/75	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	24	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N LOCAL ENERGY DEP.	18	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	9	3/15/75	-6.1700+ 0	6.2500+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	7	3/15/75	-6.1700+ 0	6.2500+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	14	12/03/76	-6.1700+ 0	6.2500+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	11	12/03/76	-6.1700+ 0	6.2500+ 0	2.0000+ 1
N,3N	CROSS SECTION	8	3/15/75	-1.1280+ 1	1.1400+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	5	3/15/75	-1.1280+ 1	1.1400+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1280+ 1	1.1400+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	4	12/03/76	-1.1280+ 1	1.1400+ 1	2.0000+ 1
N,4N	CROSS SECTION	2	3/15/75	-1.7900+ 1	1.8000+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	3	3/15/75	-1.7900+ 1	1.8000+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.7900+ 1	1.8000+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	2	12/03/76	-1.7900+ 1	1.8000+ 1	2.0000+ 1
N,F	CROSS SECTION	1297	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	6	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	6	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G ENERGY DIST.	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	2/16/78	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	1257	3/15/75	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY-ANGLE DIST.	2	2/17/78	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	G MULTIPLICITY	2	2/17/78	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	N TOTAL ENERGY DEP.	2	11/21/76	4.7900+ 0	1.0000-10	2.0000+ 1
N,G	N LOCAL ENERGY DEP.	2	11/21/76	4.7900+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	20	2/13/78	0.0000+ 0	5.0000- 2	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	20	2/18/78	0.0000+ 0	5.0000- 2	2.0000+ 1

DELAYED

20 MeV, the elastic scattering cross section is calculated from a spherical optical model, using the Becchetti and Greenlees best-fit parameters [Becchetti, *et al.*, *Ann.*, 1190 (1969)].

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

For energies less than 0.04 MeV, the secondary neutrons from elastic scattering are assumed to be isotropic in the center-of-mass system. In the region from 0.04 to 1 MeV, a single entry is made at 0.5 MeV. At 0.5 MeV we assume a four-to-one forward-to-backward elastic scattering ratio. From 1 to 20 MeV, the angular distributions are calculated with a spherical optical model code, using the Becchetti and Greenlees parameters referred to in the previous section.

INELASTIC SCATTERING CROSS SECTION

The inelastic scattering reaction is assumed to have a threshold at 0.05 MeV and to rise in the usual sigmoid shape, reaching half the plateau value at 0.4 MeV, and reaching the plateau region at 0.6 MeV. For energies above 0.6 MeV but below the 6.25 MeV threshold of the $n,2n$ reaction, the inelastic scattering cross section is taken to be the difference between an assumed non-elastic cross section (determined

from systematics) and the fission cross section. For energies above 6.25 MeV, the inelastic scattering cross section is assumed to decrease as competitive processes become energetically possible, falling at high energies to an effectively constant value that represents the direct-interaction plus pre-equilibrium reactions. The cross section for the sum of the two latter reactions is assumed to fall off gradually from a value of 0.25 barns at 7 MeV to a value of 0.15 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distribution of secondary neutrons from inelastic scattering is assumed to be isotropic in the laboratory system for all incident energies. While this assumption is incorrect for the pre-equilibrium and direct-interaction neutrons, which are peaked forward, the uncertainties in the inelastic cross sections are so large that any detailed specification of angular distributions is not justified. For energies below the onset of the pre-equilibrium process, at about 6 MeV, the energy distributions are derived from a temperature model. Above 6 MeV, a steadily increasing fraction of the secondary neutrons is assumed

to be associated with pre-equilibrium and direct-interaction processes.

The temperatures used to derive the energy distributions are determined as described in UCRL-50400, Vol. 15, Part A, pp. 19 to 22.

$n,2n$ CROSS SECTION

The threshold for the $n,2n$ reaction is at 6.19 MeV. The cross section is assumed to rise in a characteristic sigmoid shape, reaching a plateau at about 9 MeV, and to continue at an almost constant value to the onset of the $n,2nf$ and $n,3nf$ reactions, which occur in the neighborhood of 11.5 MeV. For energies above 11.5 MeV, the $n,2n$ cross section is assumed to decrease with the opening of these two new channels, falling to a value of 0.15 barns at 12.25 MeV, and then remaining constant at this value up to 20 MeV. The evaluated $n,2n$ cross sections are shown in UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,2n$ REACTION

The $n,2n$ secondary neutrons are assumed to be isotropic in the laboratory frame of reference. Energy distributions of the secondaries are derived from temperature model calculations, with the assigned temperatures being consistent with

observed systematics as described in UCRL-50400, Vol. 15, Part A, p. 24.

$n,3n$ CROSS SECTIONS

The threshold for the $n,3n$ reaction is at 11.32 MeV. The excitation function is assumed to rise in the usual sigmoid shape to a plateau value obtained by subtracting the sum of the other nonelastic reactions from the total nonelastic cross section. In the evaluation, the $n,3n$ cross section reaches a value of 0.3 barns at 15 MeV, from which it falls gradually to a value of 0.25 barns at 20 MeV.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,3n$ REACTION

The angular distributions at all energies for secondary neutrons from the $n,3n$ reaction are assumed to be isotropic in the laboratory frame of reference. The energy distributions of secondaries from this reaction are obtained from temperature model calculations, taking into account the available energy and the neutron multiplicity, and using temperatures determined as described above for the $n,2n$ reaction.

$n,4n$ CROSS SECTION

The threshold for the $n,4n$ reaction is at 17.97. The assumed excitation function for this reaction rises in

a straight line from threshold to 20 MeV, where it has a value of 0.1 barn.

ANGULAR AND ENERGY DISTRIBUTIONS FOR THE $n,4n$ REACTION

The angular distributions of the secondary neutrons from this reaction are assumed to be isotropic in the laboratory frame of reference. The energy distribution of the secondaries is derived from temperature model calculations, taking into account the available energy and the neutron multiplicity in order to obtain appropriate nuclear temperatures, as described above for the $n,2n$ and $n,3n$ cross sections.

FISSION CROSS SECTION

The SRL evaluation is used for incident neutron energies below 0.06 MeV. A slight modification is made in order to connect the resolved and unresolved resonance regions more smoothly than is permitted by simply summing the background with the resolved resonance and unresolved resonance contributions. From 0.06 MeV to 5 MeV, the evaluation is based on the experimental data of ECSIL Ref. 71-3141. The onset of the n,n' fission process is assumed to take place at 5.5 MeV, and the fission cross section at the higher neutron energies is obtained from systematics.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

There are no measurements of $\bar{\nu}$ for the neutron-induced fission of Cf^{252} . It is necessary, therefore, to rely completely upon the systematic methods described in UCRL-50400, Vol. 15, Part A, p. 54, and in *Nucl. Sci. Eng.* 62, 43 (1977), in order to obtain values for $\bar{\nu}$. Although the low-energy portion of the Cf^{252} fission cross section shows a possible anomalous behavior (that is not characteristic of subthreshold fission, it is nevertheless assumed in the evaluation that the threshold for fission occurs at 0.5 MeV; this value is used to calculate $\bar{\nu}$. The zero neutron energy value obtained for $\bar{\nu}$ is 3.57 neutrons per fission, and the value at 20 MeV, with proper accounting for second and subsequent chance fission, is 8.15 neutrons per fission.

FISSION SPECTRUM

The fission temperature is obtained in accordance with the systematics described by Howerton and Doyas in *Nucl. Sci. Eng.* 46, 414 (1971). For incident neutron energies above the thresholds for second-, third-, and fourth-chance fission, the spectrum is calculated by assuming temperature model distributions for the prefission neutrons and allowing different

fission temperatures for each fission mode. The resulting tabular spectra at the various neutron energies are composites, which are weighted for the contributions from the various processes at each particular neutron energy.

PHOTON PRODUCTION FROM FISSION

The cross section for photon production from fission is entered in the form of a multiplicity applied to the fission cross section. The photon multiplicity is obtained by assuming a total fission photon energy of 6.2 MeV, and then dividing this value by the average energy in the photon spectrum. The spectrum of photons from Cf²⁵² fission is assumed to be identical with the measured spectrum for photons from U²³⁵ neutron-induced fission.

GROSS SECTION FOR THE (n,γ) REACTION

The Q-value for the n,γ reaction is 4.79 MeV. For neutron energies below 0.001 MeV, the SRL (n,γ) evaluation is used, with a small modification made between the upper end of the resolved resonance region and the

onset of the unresolved resonance region in order to provide a smooth cross section transition. From 0.001 MeV to 20 MeV, the capture cross section is derived from systematics, as described on pp. 29 to 31 of UCRL-50400, Vol. 15, Part A.

PHOTON PRODUCTION FROM THE (n,γ) REACTION

The photon production from neutron capture is entered as a multiplicity applied to the capture cross section. The photon multiplicity is obtained by dividing the average photon energy into the total available energy. The spectrum for secondary photons is taken from the measured U²³⁸ photon spectrum.

n,Xγ CROSS SECTION

For incident neutron energies below 50 keV, photon production is assumed to occur only from the capture and fission processes, as described above. From 50 keV to 20 MeV, the n,Xγ cross sections and spectra are calculated with the systematics described by Perkins, Haight and Howerton in *Nucl. Sci. Eng.* 57, 1 (1975).

SPECTRA OF PHOTONS FROM THE (n,Xγ)
PROCESS

As stated in the previous section,
the photon spectra associated with
photon production above 50 keV
(except for the fission and capture

processes) are calculated with the
systematics of Perkins, Haight and
Howerton. The contributions of
fission photons to these spectra are
deduced by using measured U^{235} photon
spectra.