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UCRL-50400 Volume 15
Part D

**An Integrated System for Production of
Neutronics and Photonics Computational Constants
Volume 15 Part D**

**THE LLL EVALUATED NUCLEAR DATA LIBRARY (ENDL):
DESCRIPTIONS OF INDIVIDUAL EVALUATIONS FOR
Z= 90-98**

R. J. Howerton and M. H. MacGregor

June 17, 1977

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Foreword

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

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

The UCRL-50400 series, *An Integrated System for 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*, to be published in 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 LLL 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, *Supplemental Neutron-Induced Interactions ($Z \leq 35$): Graphical, Experimental Data*, July 1976.
- Vol. 8, Rev. 1, Part B, *Supplemental Neutron-Induced Interactions ($Z > 35$): 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, *The LLL Evaluated Nuclear Data Library (ENDL): Descriptions of Individual Evaluations for $Z = 90-98$* , June 1977.
- Vol. 16, *Tabular and Graphical Presentation of 175 Neutron Group Constants Derived from the LLL Evaluated Neutron Data Library (ENDL)*, April 1976.

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THE LLL EVALUATED NUCLEAR DATA LIBRARY (ENDL): DESCRIPTIONS OF INDIVIDUAL EVALUATIONS FOR $Z = 90-98$

Abstract

We have presented evaluated nuclear data for 33 isotopes in the range $Z = 90-98$.

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 the 33 heavy isotopes that fall in the range $Z = 90$ 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.

Thorium-231

DATA SUMMARY AND GENERAL COMMENTS

The only experimental data for $^{231}_{90}\text{Th}$ 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 on pp. 292 to 295 of 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

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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.	19	2/14/76	0.0000+ 0	1.0000- 2	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- 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.	15	12/03/76	0.0000+ 0	5.0000- 2	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	152	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	G ENERGY-ANGLE DIST.	2	2/14/76	1.8000+ 2	1.0000-10	3.0000- 1
N,F	N NEUTRONS/FISSION	5	2/14/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	3	2/14/76	1.8000+ 2	1.0000-10	3.0000- 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	138	2/14/76	6.4300+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	2/14/76	6.4300+ 0	1.0000-10	3.0000- 1
N,G	G MULTIPLICITY	3	2/14/76	6.4300+ 0	1.0000-10	3.0000- 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	16	2/14/76	0.0000+ 0	2.9999- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	14	2/14/76	0.0000+ 0	2.9999- 1	2.0000+ 1

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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 18.5 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

For incident neutron energies below 0.3 MeV, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. For incident neutron energies above 0.3 MeV, the photon production from fission is included in the total photon production 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

For energies below 0.3 MeV, 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. For incident neutron energies above 0.3 MeV, photon production from the capture reactions is subsumed into the total n,X γ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION (n,X γ) FROM 0.3 TO 20 MeV

For energies below 0.3 MeV, photon production is assumed to originate

only from capture and fission processes. This assumption ignores photon production from inelastic scattering below 0.3 MeV, but the uncertainties in the various cross sections and spectra are larger than any reasonably assumed contribution of photon production from inelastic scattering in this range. From 0.3 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 FROM 0.3 TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 0.3 MeV are calculated with the NXGAMEL code. The contribution to these spectra of the photons from fission is obtained by using the measured fission photon spectrum for U²³⁵.

Thorium-232

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{232}_{90}\text{Th}$ are listed on pp. 1-303 to 1-308 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data for Th^{232} are shown graphically on pp. 296 to 300 of 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 Th^{232} 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

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 on p. 298 of 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. Above the $n,2n$ threshold,

Thorium-232

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	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	N ANGULAR DIST.	13	1/03/72	0.0000+ 0	4.0000- 1	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	62	10/20/72	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	15	7/04/77	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,N'	N TOTAL ENERGY DEP.	20	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	17	10/20/72	-6.3400+ 0	6.5000+ 0	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	11	7/04/77	-6.3400+ 0	6.5000+ 0	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	17	12/03/76	-6.3400+ 0	6.5000+ 0	2.0000+ 1	
N,2N	N 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	N ENERGY-ANGLE DIST.	5	10/20/72	-1.1560+ 1	1.1610+ 1	2.0000+ 1	
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1560+ 1	1.1610+ 1	2.0000+ 1	
N,3N	N 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	N ENERGY-ANGLE DIST.	3	10/20/72	-1.8350+ 1	1.8500+ 1	2.0000+ 1	
N,4N	N TOTAL ENERGY DEP.	2	12/03/76	-1.8350+ 1	1.8500+ 1	2.0000+ 1	
N,4N	N 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	N TOTAL ENERGY DEP.	2	12/03/76	1.7000+ 2	1.0000+ 0	2.0000+ 1	
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.7000+ 2	1.0000+ 0	2.0000+ 1	
N,F	N ENERGY-ANGLE DIST.	7	10/20/72	1.7000+ 2	1.0000+ 0	2.0000+ 1	
N,F	N NEUTRONS/FISSION	6	10/20/72	1.7000+ 2	1.0000+ 0	2.0000+ 1	
N,F	N NEUTRONS/FISSION	2	3/01/76	1.7000+ 2	1.0000+ 0	2.0000+ 1	DELAYED
N,G	CROSS SECTION	5535	8/02/74	4.7900+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	12/14/72	4.7900+ 0	1.0000-10	1.0000- 2	
N,G	G MULTIPLICITY	3	12/14/72	4.7900+ 0	1.0000-10	1.0000- 2	
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	4/09/77	0.0000+ 0	9.9000- 3	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	19	4/09/77	0.0000+ 0	9.9000- 3	2.0000+ 1	

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 section is shown on p. 299 of 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

Photon production from fission was subsumed into the total $n, X\gamma$ cross section over the entire range of fission energies.

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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, the photon production from the capture reaction was subsumed into the total $n, X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n, X\gamma)$ FROM 10 keV TO 20 MeV

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 FROM 10 keV TO 20 MeV

The photon spectra associated with total photon production above 10 keV were calculated by using the NXGAMEL code mentioned above. The contribution to these spectra of the photons from fission was obtained by using the measured photon spectrum for U^{235} fission.

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 on p. 1-308 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 301 to 304 of 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.	10	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	G	ENERGY-ANGLE DIST.	2	2/14/76	1.8000+ 2	1.0000-10	3.0000- 1
N,F	N	NEUTRONS/FISSION	5	2/14/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	3	2/14/76	1.8000+ 2	1.0000-10	3.0000- 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 DIST.	2	2/14/76	6.1800+ 0	1.0000-10	3.0000- 1
N,G	G	MULTIPLICITY	3	2/14/76	6.1800+ 0	1.0000-10	3.0000- 1
N,G		TOTAL ENERGY DEP.	2	11/21/76	6.1800+ 0	1.0000-10	2.0000+ 1
N,G		LOCAL ENERGY DEP.	2	11/21/76	6.1800+ 0	1.0000-10	2.0000+ 1
N,XG		CROSS SECTION	16	2/14/76	0.0000+ 0	2.9999- 1	2.0000+ 1
N,XG	G	ENERGY-ANGLE DIST.	15	2/14/76	0.0000+ 0	2.9999- 1	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.* 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

For incident neutron energies below 0.3 MeV, the cross section for photon production from fission was entered as a multiplicity applied to the fission cross section. For incident neutron energies above 0.3 MeV, the photon production from fission was included in the total photon production 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

For energies below 0.3 MeV, 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. For incident neutron energies above 0.3 MeV, photon production from the capture reactions

was subsumed into the total $n, X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION ($n, X\gamma$) FROM 0.3 TO 20 MeV

For energies below 0.3 MeV, photon production was assumed to originate only from capture and fission processes. This assumption ignores photon production from inelastic scattering below 0.3 MeV, but the uncertainties in the various cross sections and spectra are larger than any reasonably assumed contribution of photon production from inelastic scattering in this range. From 0.3 MeV 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 ($n, X\gamma$) PROCESS FROM 0.3 TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 0.3 MeV were calculated by using the NXGAMEL code. The fission photon contribution to these spectra was obtained by using the measured fission photon spectrum for U^{235} .

Uranium-233

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{92}\text{U}^{233}$ are summarized on pp. 1-311 to 1-316 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 305 to 309 of 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 U^{233} 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 on p. 307 of 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	G ENERGY DIST.	2	12/14/72	1.8000+ 2	1.0000-10	2.0000+ 1	
N,F	G MULTIPLICITY	2	12/14/72	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	DELAYED
N,G	CROSS SECTION	1954	6/15/73	6.8400+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	12/14/72	6.8400+ 0	1.0000-10	1.0000- 2	
N,G	G MULTIPLICITY	3	12/14/72	6.8400+ 0	1.0000-10	1.0000- 2	
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	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	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 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 on p. 308 of 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.* 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 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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon

production from capture reactions was absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV TO 20 MeV

For energies below 10 keV, photon production was 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 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 FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production, except for the fission photons, were calculated by using the NXGAMEL code.

Uranium-234

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{234}_{92}\text{U}$ are summarized on p. 1-316 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 310 to 313 of 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 on p. 311 of 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	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	19	11/15/72	0.0000+ 0	4.4000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	13	11/15/72	0.0000+ 0	4.4000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	23	12/03/76	0.0000+ 0	4.4000- 2	2.0000+ 1
N,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	N ENERGY-ANGLE DIST.	7	11/15/72	-6.8400+ 0	6.8700+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	16	12/03/76	-6.8400+ 0	6.8700+ 0	2.0000+ 1
N,2N	N 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	N ENERGY-ANGLE DIST.	4	11/15/72	-1.2590+ 1	1.2650+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	4	12/03/76	-1.2590+ 1	1.2650+ 1	2.0000+ 1
N,3N	N 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	N TOTAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	N LOCAL ENERGY DEP.	2	12/03/76	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	N ENERGY-ANGLE DIST.	6	11/15/72	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	N NEUTRONS/FISSION	7	11/15/72	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	G ENERGY DIST.	2	12/14/72	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	G MULTIPLICITY	2	12/14/72	1.8000+ 2	1.0000- 1	2.0000+ 1
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000- 1	2.0000+ 1
N,G	CROSS SECTION	128	4/03/76	5.3100+ 0	1.0000-10	2.0000+ 1
N,G	G ENERGY DIST.	2	12/14/72	5.3100+ 0	1.0000-10	1.0000- 2
N,G	G MULTIPLICITY	3	12/14/72	5.3100+ 0	1.0000-10	1.0000- 2
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	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	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 on p. 312 of 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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon production from capture reactions was absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV TO 20 MeV

For energies below 10 keV, photon production was assumed to originate only from capture and fission processes. From 10 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 FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV, except for the fission photons, were calculated by using the NXGAMEL code.

Uranium-235

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{235}_{92}\text{U}$ are summarized on pp. 1-316 to 1-325 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 314 to 319 of 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 tabulated in UCRL-50400, Vol. 10, Rev. 2 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 on p. 317 of UCRL-50400, Vol. 15, Part B. This cross section has a threshold at 20

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	28	2/02/76	0.0000+ 0	2.0000- 2	2.0000+ 1
N,N'	N	ENERGY-ANGLE DIST.	17	3/04/72	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	15	2/02/76	-5.2300+ 0	5.2524+ 0	2.0000+ 1
N,2N	N	ENERGY-ANGLE DIST.	7	12/15/71	-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	1/30/73	1.8000+ 2	1.0000-10	1.0900+ 0
N,F	G	MULTIPLICITY	3	1/30/73	1.8000+ 2	1.0000-10	1.0900+ 0
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	1/30/73	6.5500+ 0	1.0000-10	1.0900+ 0
N,G	G	MULTIPLICITY	3	1/30/73	6.5500+ 0	1.0000-10	1.0900+ 0
N,G		TOTAL ENERGY DEP.	2	11/21/76	6.5500+ 0	1.0000-10	2.0000+ 1
N,G		LOCAL ENERGY DEP.	2	11/21/76	6.5500+ 0	1.0000-10	2.0000+ 1
N,XG		CROSS SECTION	20	4/09/77	0.0000+ 0	2.0000- 2	2.0000+ 1
N,XG	G	ENERGY-ANGLE DIST.	18	4/09/77	0.0000+ 0	2.0000- 2	2.0000+ 1

DELAYED

keV 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 on p. 318 of

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. Cierjachs (which were also reported at the ANL conference). The Cierjachs 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 on p. 319 of 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.* 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

For neutron energies below 1.09 MeV, 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} . Above 1.09 MeV, the photons from fission were included in the total $n, X\gamma$ cross section.

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

For energies below 1.09 MeV, 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. For incident energies above 1.09 MeV, photon production from capture is subsumed into the total $n, X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION ($n, X\gamma$) FROM 0.02 MeV to 20 MeV

For energies below 1.09 MeV, photon production from capture and fission processes is handled explicitly, as described above. From 0.02 MeV to 1.09 MeV the ($n, X\gamma$) cross section has as its only component the photons from inelastic scattering. 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 1.09 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 ($n, X\gamma$) PROCESS FROM 1.09 MeV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 1.09 MeV is calculated by using the NXGAMEL code. The contribution to these spectra of the photons from fission is obtained by using the measured photon spectrum for U^{235} fission.

Uranium-236

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{92}\text{U}^{236}$ are summarized on pp. 1-325 and 1-326 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 320 to 324 of 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 on p. 322 of 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

Uranium-236

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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	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	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	12/14/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	2	12/14/72	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 DIST.	2	12/14/72	5.1200+ 0	1.0000-10	1.0000- 2
N,G	G MULTIPLICITY	3	12/14/72	5.1200+ 0	1.0000-10	1.0000- 2
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	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	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 on p. 323 of 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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV to 20 MeV

For energies below 10 keV, photon production is assumed to originate only from capture and fission pro-

cesses. This assumption ignores photon production from inelastic scattering below 10 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 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 $(n,X\gamma)$ PROCESS FROM 10 keV to 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) were calculated by using the NXGAMEL code.

Uranium-237

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{237}_{92}\text{U}$ are summarized on pp. 1-326 and 1-327 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 325 to 328 of 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 ^{237}U are shown graphically on p. 325 of 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 on p. 326 of 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'f 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	48	9/27/75	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.	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	22	11/15/72	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	81	9/27/75	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	12/14/72	1.8000+ 2	1.0000-10	1.0000- 2	
N,F	G MULTIPLICITY	3	12/14/72	1.8000+ 2	1.0000-10	1.0000- 2	
N,F	N NEUTRONS/FISSION	2	3/01/76	1.8000+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G	CROSS SECTION	174	9/27/75	6.1400+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	12/14/72	6.1400+ 0	1.0000-10	1.0000- 2	
N,G	G MULTIPLICITY	3	12/14/72	6.1400+ 0	1.0000-10	1.0000- 2	
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.1400+ 0	1.0000-10	2.0000+ 1	
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.1400+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	16	9/30/75	0.0000+ 0	9.9000- 3	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	15	9/30/75	0.0000+ 0	9.9000- 3	2.0000+ 1	

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 on p. 327 of 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,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 11.72 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

For neutron energies below 0.01 MeV, 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} . Above 0.01 MeV, the photons from fission are included in the total $n,X\gamma$ cross section.

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 B.

PHOTON PRODUCTION FROM (n,γ) REACTIONS

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV to 20 MeV

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 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 FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) are calculated with the NXGAMEL code. The contribution to these spectra of the photons from fission is obtained by using the measured fission photon spectrum for U^{235} .

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DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ^{238}U are summarized on pp. 1-327 to 1-333 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 329 to 334 of 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 ^{238}U 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

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 on pp. 331 and 332 of 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

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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
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'	CROSS SECTION	12	11/05/75	0.0000+ 0	1.1247+ 0	4.0000+ 0	LEVEL = 1.1200+ 0 MEV

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	QUALIFIER
N,N'	N ANGULAR DIST.	2	11/05/75	0.0000+ 0	1.1247+ 0	2.0000+ 1	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,2N	N CROSS SECTION	15	12/15/71	-6.0400+ 0	6.0656+ 0	2.0000+ 1	
N,2N	N ENERGY-ANGLE DIST.	9	2/09/74	-6.0400+ 0	6.0656+ 0	2.0000+ 1	
N,2N	N TOTAL ENERGY DEP.	17	12/03/76	-6.0400+ 0	6.0656+ 0	2.0000+ 1	
N,2N	N LOCAL ENERGY DEP.	11	12/03/76	-6.0400+ 0	6.0656+ 0	2.0000+ 1	
N,3N	N CROSS SECTION	9	2/02/76	-1.1450+ 1	1.1500+ 1	2.0000+ 1	
N,3N	N ENERGY-ANGLE DIST.	6	2/09/74	-1.1450+ 1	1.1500+ 1	2.0000+ 1	
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1450+ 1	1.1500+ 1	2.0000+ 1	
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	

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,4N	N	2	12/03/76	-1.7820+ 1	1.8000+ 1	2.0000+ 1	
N,F		41	2/02/76	1.8000+ 2	4.5000- 1	2.0000+ 1	
N,F	N	2	12/03/76	1.8000+ 2	4.5000- 1	2.0000+ 1	
N,F	N	2	12/03/76	1.8000+ 2	4.5000- 1	2.0000+ 1	
N,F	N	8	1/17/70	1.8000+ 2	4.5000- 1	2.0000+ 1	
N,F	N	5	12/24/74	1.8000+ 2	4.5000- 1	2.0000+ 1	
N,F	G	2	1/29/73	1.8000+ 2	4.5000- 1	1.0900+ 0	
N,F	G	3	1/29/73	1.8000+ 2	4.5000- 1	1.0900+ 0	
N,F	N	4	3/26/71	1.8000+ 2	4.5000- 1	2.0000+ 1	DELAYED
N,G		1473	4/03/76	4.8000+ 0	1.0000-10	2.0000+ 1	
N,G	G	2	1/29/73	4.8000+ 0	1.0000-10	1.0900+ 0	
N,G	G	3	1/29/73	4.8000+ 0	1.0000-10	1.0900+ 0	
N,G		2	11/21/76	4.8000+ 0	1.0000-10	2.0000+ 1	
N,G		2	11/21/76	4.8000+ 0	1.0000-10	2.0000+ 1	
N,XG		15	4/09/77	0.0000+ 0	6.3000- 1	2.0000+ 1	
N,XG	G	15	4/09/77	0.0000+ 0	6.3000- 1	2.0000+ 1	
N,XG		10	1/29/73	0.0000+ 0	5.0000- 2	1.0900+ 0	PHOTON = 5.0000- 2 MEV
N,XG	G	2	5/31/73	0.0000+ 0	5.0000- 2	2.0000+ 1	PHOTON = 5.0000- 2 MEV
N,XG		9	1/29/73	0.0000+ 0	1.5000- 1	1.0900+ 0	PHOTON = 1.0000- 1 MEV
N,XG	G	2	5/31/73	0.0000+ 0	1.5000- 1	2.0000+ 1	PHOTON = 1.0000- 1 MEV
N,XG		9	1/29/73	0.0000+ 0	1.5100- 1	1.0900+ 0	PHOTON = 1.5000- 1 MEV
N,XG	G	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 on p. 333 of 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 on p. 333 of 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 on p. 333 of 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 on p. 334 of 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 on p. 1-332 of UCRL-50400, Vol. 3, Rev. 2. 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

For neutron energies below 1.09 MeV, 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} . Above 1.09 MeV, the photons from fission are included in the total $n, X\gamma$ cross section.

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

For energies below 1.09 MeV, photon production from the neutron capture reaction is handled by using multiplicities and normalized spectra. The photon multiplicities for these reac-

tions 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} . For incident energies above 1.09 MeV, photon production from capture is incorporated into the total $n, X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION ($n, X\gamma$) FROM 0.05 MeV to 20 MeV

Measurements of the partial $n, X\gamma$ 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 $n, X\gamma$ cross section values are used to check energies above 1.09 MeV; but the cross section and spectra are obtained from NXGAMEL. The $n, X\gamma$ cross section is extended down to 0.63 MeV by combining the

photon production data from intermediate inelastic levels into a continuum representation. In addition, 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 ($n, X\gamma$) PROCESS FROM 0.05 MeV to 20 MeV

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 on pp. 335 to 338 of 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 on p. 335 of 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 on p. 336 of 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	33	10/30/75	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.	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	19	11/15/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N	ENERGY-ANGLE DIST.	12	11/15/72	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	N	TOTAL ENERGY DEP.	28	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	14	11/15/72	-4.8000+ 0	4.8300+ 0	2.0000+ 1
N,2N	N	ENERGY-ANGLE DIST.	7	11/15/72	-4.8000+ 0	4.8300+ 0	2.0000+ 1
N,2N	N	TOTAL ENERGY DEP.	17	12/03/76	-4.8000+ 0	4.8300+ 0	2.0000+ 1
N,2N	N	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	N	ENERGY-ANGLE DIST.	5	11/15/72	-1.0950+ 1	1.1000+ 1	2.0000+ 1
N,3N	N	TOTAL ENERGY DEP.	5	12/03/76	-1.0950+ 1	1.1000+ 1	2.0000+ 1
N,3N	N	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	N	ENERGY-ANGLE DIST.	4	11/15/72	-1.6070+ 1	1.6150+ 1	2.0000+ 1
N,4N	N	TOTAL ENERGY DEP.	3	12/03/76	-1.6070+ 1	1.6150+ 1	2.0000+ 1
N,4N	N	LOCAL ENERGY DEP.	3	12/03/76	-1.6070+ 1	1.6150+ 1	2.0000+ 1
N,F		CROSS SECTION	160	6/02/77	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.	4	11/15/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	N	NEUTRONS/FISSION	2	11/15/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G	ENERGY DIST.	2	12/14/72	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	2	12/14/72	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	211	10/30/75	5.9300+ 0	1.0000-10	2.0000+ 1
N,G	G	ENERGY DIST.	2	12/14/72	5.9300+ 0	1.0000-10	1.0000- 2
N,G	G	MULTIPLICITY	3	12/14/72	5.9300+ 0	1.0000-10	1.0000- 2
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	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1
N,XG	G	ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	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 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 on p. 337 of 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 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 B.

PHOTON PRODUCTION FROM (n,γ) REACTIONS

For energies below 10 keV, 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. For incident

neutron energies above 10 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV TO 20 MeV

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 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 FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) are calculated by using the NXGAMEL code.

Uranium-240

DATA SUMMARY AND GENERAL COMMENTS

There are no experimental data for ${}_{92}\text{U}^{240}$. The evaluated data are shown graphically on pp. 339 to 342 of 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 U^{240} are shown on p. 339 of 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 on p. 341 of 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.	29	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	12/14/72	1.8000+ 2	1.0000+ 0	2.0000+ 1	
N,F	G MULTIPLICITY	2	12/14/72	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	DELAYED
N,G	CROSS SECTION	139	2/27/76	6.0800+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	12/14/72	6.0800+ 0	1.0000-10	1.0000- 2	
N,G	G MULTIPLICITY	3	12/14/72	6.0800+ 0	1.0000-10	1.0000- 2	
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.0800+ 0	1.0000-10	2.0000+ 1	
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.0800+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1	

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 on p. 341 of 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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV TO 20 MeV

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 $(n,X\gamma)$ PROCESS FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) are calculated with the NXGAMEL code.

Neptunium-237

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{237}_{93}\text{Np}$ are summarized on pp. 1-334 and 1-335 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 343 to 348 of 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-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 on p. 346 of 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	ANGULAR DIST.	20	5/10/73	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	3/02/77	0.0000+ 0	3.5000- 2	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	12	4/20/73	0.0000+ 0	3.5000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	19	12/03/76	0.0000+ 0	3.5000- 2	2.0000+ 1
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	ENERGY-ANGLE DIST.	8	4/20/73	-6.5370+ 0	6.5700+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	19	12/03/76	-6.5370+ 0	6.5700+ 0	2.0000+ 1
N,2N	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	ENERGY-ANGLE DIST.	5	5/20/73	-1.2310+ 1	1.2400+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	5	12/03/76	-1.2310+ 1	1.2400+ 1	2.0000+ 1
N,3N	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	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.	5	4/20/73	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	NEUTRONS/FISSION	6	7/21/76	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	ENERGY DIST.	2	6/14/73	1.8000+ 2	1.0000-10	2.0000+ 1
N,F	MULTIPLICITY	2	6/14/73	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	1269	4/20/73	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	ENERGY DIST.	2	6/14/73	5.4800+ 0	1.0000-10	1.0000- 2
N,G	MULTIPLICITY	3	6/14/73	5.4800+ 0	1.0000-10	1.0000- 2
N,G	TOTAL ENERGY DEP.	2	11/21/76	5.4800+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	5.4800+ 0	1.0000-10	2.0000+ 1
N,XG	CROSS SECTION	54	6/14/73	0.0000+ 0	9.9000- 3	2.0000+ 1
N,XG	ENERGY-ANGLE DIST.	12	6/14/73	0.0000+ 0	9.9000- 3	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. 15, Part B. For neutron energies below 13.7 MeV and above 15 MeV, the evaluation is based on nuclear sys-

tematics. The evaluated n,2n cross section is shown on p. 347 of UCRL-50400, Vol. 15, Part B, but a new evaluation on March 2, 1977 has changed these values slightly. The n,2n cross section now 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 U²³⁵. 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 Np²³⁷ are some early spectrum-averaged data that are listed on p. 1-334 of UCRL-50400, Vol. 3, Rev. 2. The evaluated values for the total and delayed $\bar{\nu}$ are shown on p. 348 of UCRL-50400, Vol. 15, Part B. In general, the values for $\bar{\nu}$ for Np²³⁷

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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV TO 20 MeV

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 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 FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) are calculated with the NXGAMEL code.

Plutonium-238

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{94}\text{Pu}^{238}$ are summarized on pp. 1-335 and 1-336 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 349 to 353 of 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 on p. 351 of 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	5.0000- 2	2.0000+ 1	
N,N'	N ENERGY-ANGLE DIST.	12	11/15/72	0.0000+ 0	5.0000- 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	12/14/72	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	G MULTIPLICITY	2	12/14/72	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	DELAYED
N,G	CROSS SECTION	629	1/03/75	5.6600+ 0	1.0000-10	2.0000+ 1	
N,G	G ENERGY DIST.	2	12/14/72	5.6600+ 0	1.0000-10	1.0000- 2	
N,G	G MULTIPLICITY	3	12/14/72	5.6600+ 0	1.0000-10	1.0000- 2	
N,G	TOTAL ENERGY DEP.	2	11/21/76	5.6600+ 0	1.0000-10	2.0000+ 1	
N,G	TOTAL ENERGY DEP.	2	11/21/76	5.6600+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1	
N,XG	G ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1	

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 on p. 352 of 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 on p. 11-236 of this same reference. 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

For energies below 10 keV, 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 ^{238}U photon spectrum. For incident neutron energies above 10 keV, photon production from the capture reaction is absorbed into the total n,X γ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION (n,X γ) FROM 10 keV TO 20 MeV

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,X γ) PROCESS FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) are calculated with the NXGAMEL code.

Plutonium-239

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{239}\text{Pu}$ are summarized on pp. 1-336 to 1-344 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 354 to 358 of 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 ${}^{239}\text{Pu}$ 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 listed on p. 1-341 of UCRL-50400, Vol. 3, Rev. 2; the tabulated data points for these measurements are given in UCRL-50400, Vol. 10, Rev. 1. 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 on p. 356 of 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	2/20/76	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	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	25	5/30/77	0.0000+ 0	4.0000- 1	2.0000+ 1	
N,N'	ANGULAR DIST.	4	1/05/71	0.0000+ 0	4.0000- 1	2.0000+ 1	
N,N'	ENERGY-ANGLE DIST.	12	3/18/71	0.0000+ 0	4.0000- 1	2.0000+ 1	
N,N'	TOTAL ENERGY DEP.	20	12/03/76	0.0000+ 0	4.0000- 1	2.0000+ 1	
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'	ANGULAR DIST.	2	5/27/70	0.0000+ 0	5.7241- 2	2.0000+ 1	LEVEL = 5.7000- 2 MEV
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'	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'	ANGULAR DIST.	2	5/27/70	0.0000+ 0	7.6321- 2	2.0000+ 1	LEVEL = 7.6000- 2 MEV
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'	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'	ANGULAR DIST.	2	5/27/70	0.0000+ 0	1.6469- 1	2.0000+ 1	LEVEL = 1.6400- 1 MEV
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'	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'	ANGULAR DIST.	2	5/27/70	0.0000+ 0	2.8721- 1	2.0000+ 1	LEVEL = 2.8600- 1 MEV
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'	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'	ANGULAR DIST.	2	5/27/70	0.0000+ 0	3.3240- 1	2.0000+ 1	LEVEL = 3.3100- 1 MEV
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'	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'	ANGULAR DIST.	2	5/27/70	0.0000+ 0	3.9165- 1	2.0000+ 1	LEVEL = 3.9000- 1 MEV
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'	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	19	5/30/77	-5.6100+ 0	5.6400+ 0	2.0000+ 1	
N,2N	ENERGY-ANGLE DIST.	7	30/47/20	-5.6100+ 0	5.6400+ 0	2.0000+ 1	
N,2N	TOTAL ENERGY DEP.	20	12/03/76	-5.6100+ 0	5.6400+ 0	2.0000+ 1	
N,2N	LOCAL ENERGY DEP.	12	12/03/76	-5.6100+ 0	5.6400+ 0	2.0000+ 1	
N,3N	CROSS SECTION	11	5/30/77	-1.2510+ 1	1.2563+ 1	2.0000+ 1	
N,3N	ENERGY-ANGLE DIST.	4	1/05/71	-1.2510+ 1	1.2563+ 1	2.0000+ 1	
N,3N	TOTAL ENERGY DEP.	4	12/03/76	-1.2510+ 1	1.2563+ 1	2.0000+ 1	
N,3N	LOCAL ENERGY DEP.	4	12/03/76	-1.2510+ 1	1.2563+ 1	2.0000+ 1	
N,4N	CROSS SECTION	2	5/27/70	-1.8550+ 1	1.8628+ 1	2.0000+ 1	
N,4N	ENERGY-ANGLE DIST.	2	1/05/71	-1.8550+ 1	1.8628+ 1	2.0000+ 1	
N,4N	TOTAL ENERGY DEP.	2	12/03/76	-1.8550+ 1	1.8628+ 1	2.0000+ 1	
N,4N	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	TOTAL ENERGY DEP.	2	12/03/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	LOCAL ENERGY DEP.	2	12/03/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	ENERGY-ANGLE DIST.	6	3/05/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	ENERGY-ANGLE DIST.	2	11/30/72	1.8600+ 2	1.0000-10	3.0200- 1	
N,F	NEUTRONS/FISSION	8	5/26/75	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	MULTIPLICITY	3	11/30/72	1.8600+ 2	1.0000-10	3.0200- 1	
N,F	NEUTRONS/FISSION	5	11/27/76	1.8600+ 2	1.0000-10	2.0000+ 1	DELAYED

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,G	CROSS SECTION	1484	2/20/76	6.5300+ 0	1.0000-10	2.0000+ 1	
N,G	ENERGY DIST.	2	11/30/72	6.5300+ 0	1.0000-10	3.0200- 1	
N,G	MULTIPLICITY	3	11/30/72	6.5300+ 0	1.0000-10	3.0200- 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	14	4/09/77	0.0000+ 0	3.0000- 1	2.0000+ 1	
N,XG	ENERGY-ANGLE DIST.	13	4/09/77	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	ANGULAR DIST.	2	5/13/73	0.0000+ 0	6.0000- 2	3.0200- 1	PHOTON = 6.0000- 2 MEV
N,XG	CROSS SECTION	4	11/30/72	0.0000+ 0	8.0000- 2	3.0200- 1	PHOTON = 8.0000- 2 MEV
N,XG	ANGULAR DIST.	2	5/13/73	0.0000+ 0	8.0000- 2	3.0200- 1	PHOTON = 8.0000- 2 MEV
N,XG	CROSS SECTION	4	11/30/72	0.0000+ 0	1.6000- 1	3.0200- 1	PHOTON = 1.6000- 1 MEV
N,XG	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 on p. 357 of UCRL-50400, Vol. 15, Part B. This cross section rises rapidly to a value of 0.6 barns at 7 MeV, falls off slowly above 7 MeV, and falls off rapidly 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 threshold for the n,3n reaction is at 12.71 MeV. The cross section is assumed to rise from threshold to a value of 0.3 barns at 17 MeV. Above this energy it decreases gradually to a value of 0.2 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 0.03 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 on

p. 358 of 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

For neutron energies below 0.3 MeV, 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} . Above 0.3 MeV, the photons from fission are included in the total $n, X\gamma$ cross section.

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

For energies below 0.3 MeV, 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. For incident energies above 0.3 MeV, photon production from capture is subsumed into the total $n, X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n, X\gamma)$ FROM 0.3 MeV TO 20 MeV

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 $n, X\gamma$ 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 $n, X\gamma$ 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, are obtained from calculations with the NXGAMEL code. A summary of this method of calculat-

ing 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 FROM 0.3 MeV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 0.3 MeV are calculated with the NXGAMEL code. The contribution to these spectra of the photons from fission is obtained by using the measured photon spectrum for U^{235} fission.

Plutonium-240

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{240}_{94}\text{Pu}$ are summarized on pp. 1-327 to 1-333 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 359 to 363 of 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 on p. 361 of UCRL-50400, Vol. 15, Part B. It rises from threshold at 50 keV to a plateau value of about 1.5 barns between 2 and 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' reaction is assumed to be the difference between the nonelastic cross section and the

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC	CROSS SECTION	1602	3/15/76	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	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	14	3/15/76	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.	29	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,N'	LOCAL ENERGY DEP.	17	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,2N	CROSS SECTION	10	3/15/76	-6.5300+ 0	6.6000+ 0	2.0000+ 1	
N,2N	ENERGY-ANGLE DIST.	6	11/15/72	-6.5300+ 0	6.6000+ 0	2.0000+ 1	
N,2N	TOTAL ENERGY DEP.	17	12/03/76	-6.5300+ 0	6.6000+ 0	2.0000+ 1	
N,2N	LOCAL ENERGY DEP.	11	12/03/76	-6.5300+ 0	6.6000+ 0	2.0000+ 1	
N,3N	CROSS SECTION	7	3/15/76	-1.2190+ 1	1.2250+ 1	2.0000+ 1	
N,3N	ENERGY-ANGLE DIST.	4	11/15/72	-1.2190+ 1	1.2250+ 1	2.0000+ 1	
N,3N	TOTAL ENERGY DEP.	5	12/03/76	-1.2190+ 1	1.2250+ 1	2.0000+ 1	
N,3N	LOCAL ENERGY DEP.	5	12/03/76	-1.2190+ 1	1.2250+ 1	2.0000+ 1	
N,F	CROSS SECTION	2078	6/22/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	TOTAL ENERGY DEP.	2	12/03/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	LOCAL ENERGY DEP.	2	12/03/76	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	ENERGY-ANGLE DIST.	4	11/15/72	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	NEUTRONS/FISSION	7	11/15/72	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	ENERGY DIST.	2	12/14/72	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	MULTIPLICITY	2	12/14/72	1.8600+ 2	1.0000-10	2.0000+ 1	
N,F	NEUTRONS/FISSION	2	3/01/76	1.8600+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G	CROSS SECTION	3003	/ / 0	5.2400+ 0	1.0000-10	2.0000+ 1	
N,G	ENERGY DIST.	2	12/14/72	5.2400+ 0	1.0000-10	1.0000- 2	
N,G	MULTIPLICITY	3	12/14/72	5.2400+ 0	1.0000-10	1.0000- 2	
N,G	TOTAL ENERGY DEP.	2	11/21/76	5.2400+ 0	1.0000-10	2.0000+ 1	
N,G	LOCAL ENERGY DEP.	2	11/21/76	5.2400+ 0	1.0000-10	2.0000+ 1	
N,XG	CROSS SECTION	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1	
N,XG	ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1	

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 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 on p. 362 of 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 keV 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 ENDL fission cross sections for U^{235} .

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 on p. 363 of 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.* 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

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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV TO 20 MeV

For energies below 10 keV, photon production is assumed to originate only from capture and fission processes. From 10 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.* 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 FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) are calculated with the NXGAMEL code.

Plutonium-241

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{94}\text{Pu}^{241}$ are summarized on pp. 1-346 to 1-348 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are shown graphically on pp. 364 to 368 of 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.* 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 on p. 366 of 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

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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	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	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	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	13	11/15/72	-5.2400+ 0	5.3000+ 0	2.0000+ 1
N,2N	N	ENERGY-ANGLE DIST.	6	11/15/72	-5.2400+ 0	5.3000+ 0	2.0000+ 1
N,2N	N	TOTAL ENERGY DEP.	17	12/03/76	-5.2400+ 0	5.3000+ 0	2.0000+ 1
N,2N	N	LOCAL ENERGY DEP.	10	12/03/76	-5.2400+ 0	5.3000+ 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.	5	12/03/76	-1.1780+ 1	1.1850+ 1	2.0000+ 1
N,3N	N	LOCAL ENERGY DEP.	5	12/03/76	-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	12/03/76	-1.7430+ 1	1.7600+ 1	2.0000+ 1
N,4N	N	LOCAL ENERGY DEP.	2	12/03/76	-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	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	5	11/15/72	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	G	ENERGY DIST.	2	12/14/72	1.8600+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	2	12/14/72	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 DIST.	2	12/14/72	6.3000+ 0	1.0000-10	1.0000- 2
N,G	G	MULTIPLICITY	3	12/14/72	6.3000+ 0	1.0000-10	1.0000- 2
N,G		TOTAL ENERGY DEP.	2	11/21/76	6.3000+ 0	1.0000-10	2.0000+ 1
N,G		LOCAL ENERGY DEP.	2	11/21/76	6.3000+ 0	1.0000-10	2.0000+ 1
N,XG		CROSS SECTION	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1
N,XG	G	ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1

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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 on p. 367 of 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 on p. 368 of 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 on p. 364 of 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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon production from capture reactions is absorbed into the total n,X γ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION (n,X γ) FROM 10 keV TO 20 MeV

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,X γ) PROCESS FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) are calculated with the NXGAMEL code.

Plutonium-242

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{242}_{94}\text{Pu}$ are summarized on pp. 1-348 and 1-349 of UCRL-50400, Vol. 3, Rev. 2. The evaluated data are displayed graphically on pp. 369 to 373 of 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 Pu^{242} 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 on p. 371 of UCRL-50400, Vol. 15, Part B. It rises from threshold at 45 keV to a plateau value of about 2 barns at 1 MeV, then falls gradually to a value of 1.7 barns at 6 MeV, and then falls off rapidly above 6 MeV due to competition

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC		CROSS SECTION	758	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	22	3/15/76	0.0000+ 0	4.4000- 2	2.0000+ 1
N,N'	N	ENERGY-ANGLE DIST.	17	12/01/75	0.0000+ 0	4.4000- 2	2.0000+ 1
N,N'	N	TOTAL ENERGY DEP.	24	12/03/76	0.0000+ 0	4.4000- 2	2.0000+ 1
N,N'	N	LOCAL ENERGY DEP.	16	12/03/76	0.0000+ 0	4.4000- 2	2.0000+ 1
N,2N		CROSS SECTION	11	3/15/76	-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	12/03/76	-6.3000+ 0	6.3300+ 0	2.0000+ 1
N,2N	N	LOCAL ENERGY DEP.	10	12/03/76	-6.3000+ 0	6.3300+ 0	2.0000+ 1
N,3N		CROSS SECTION	9	3/15/76	-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	12/03/76	-1.1540+ 1	1.1590+ 1	2.0000+ 1
N,3N	N	LOCAL ENERGY DEP.	5	12/03/76	-1.1540+ 1	1.1590+ 1	2.0000+ 1
N,4N		CROSS SECTION	2	12/01/75	-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	12/03/76	-1.8070+ 1	1.8150+ 1	2.0000+ 1
N,4N	N	LOCAL ENERGY DEP.	2	12/03/76	-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	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.	4	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	NEUTRONS/FISSION	4	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G		CROSS SECTION	1271	12/01/75	5.0400+ 0	1.0000-10	2.0000+ 1
N,G	G	ENERGY DIST.	2	12/01/75	5.0400+ 0	1.0000-10	3.0000- 1
N,G	G	MULTIPLICITY	3	12/01/75	5.0400+ 0	1.0000-10	3.0000- 1
N,G		TOTAL ENERGY DEP.	2	11/21/76	5.0400+ 0	1.0000-10	2.0000+ 1
N,G		LOCAL ENERGY DEP.	2	11/21/76	5.0400+ 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	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1

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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 6.33 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 on p. 372 of 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 on p. 373 of 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

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 then divided by the average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} . Above 300 keV, the photons from fission are included in the total $n, X\gamma$ cross section.

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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n, X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n, X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This means that the photons from the $nn'\gamma$ process are neglected. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission; in short, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV (except for the fission photons) are calculated with the NXGAMEL code.

Plutonium-243

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{243}\text{Pu}$ 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 on p. 1-349 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 374 to 378 of 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 on pp. 374 and 375 of 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

09/07/77

	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- 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	25	12/01/75	0.0000+ 0	6.0000- 2	2.0000+ 1
N,N'	N ENERGY-ANGLE DIST.	17	12/01/75	0.0000+ 0	6.0000- 2	2.0000+ 1
N,N'	N TOTAL ENERGY DEP.	22	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	20	12/01/75	-5.0392+ 0	5.0600+ 0	2.0000+ 1
N,2N	N ENERGY-ANGLE DIST.	10	12/01/75	-5.0392+ 0	5.0600+ 0	2.0000+ 1
N,2N	N TOTAL ENERGY DEP.	19	12/03/76	-5.0392+ 0	5.0601+ 0	2.0000+ 1
N,2N	N LOCAL ENERGY DEP.	13	12/03/76	-5.0392+ 0	5.0601+ 0	2.0000+ 1
N,3N	CROSS SECTION	14	12/01/75	-1.1333+ 1	1.1380+ 1	2.0000+ 1
N,3N	N ENERGY-ANGLE DIST.	6	12/01/75	-1.1333+ 1	1.1380+ 1	2.0000+ 1
N,3N	N TOTAL ENERGY DEP.	5	12/03/76	-1.1333+ 1	1.1380+ 1	2.0000+ 1
N,3N	N LOCAL ENERGY DEP.	5	12/03/76	-1.1333+ 1	1.1380+ 1	2.0000+ 1
N,4N	CROSS SECTION	7	12/01/75	-1.6581+ 1	1.6650+ 1	2.0000+ 1
N,4N	N ENERGY-ANGLE DIST.	4	12/01/75	-1.6581+ 1	1.6650+ 1	2.0000+ 1
N,4N	N TOTAL ENERGY DEP.	3	12/03/76	-1.6581+ 1	1.6650+ 1	2.0000+ 1
N,4N	N LOCAL ENERGY DEP.	3	12/03/76	-1.6581+ 1	1.6650+ 1	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	G ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 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 DIST.	2	12/01/75	6.0200+ 0	1.0000-10	3.0000- 1
N,G	G MULTIPLICITY	3	12/01/75	6.0200+ 0	1.0000-10	3.0000- 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.0200+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.0200+ 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 ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1

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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 on p. 376 of 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 on p. 377 of 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, 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

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 then divided by the

average energy in the photon spectrum, using the measured fission photon spectrum for U^{235} . Above 300 keV, the photons from fission are included in the total $n, X\gamma$ cross section.

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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n, X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS
SECTION (n,X γ) FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the n' γ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission; in short, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV to 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV (except for the fission 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 on pp. 1-350 and 1-351 of UCRL-50400, Vol. 3, Rev. 2.

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 on pp. 379 to 384 of 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

09/07/77

		REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX	
N,ELASTIC		CROSS SECTION	199	4/03/76	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	22	8/15/75	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,N'	N	ENERGY-ANGLE DIST.	14	8/15/75	0.0000+ 0	5.0000- 2	2.0000+ 1	
N,N'	N	TOTAL ENERGY DEP.	20	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	13	8/15/75	-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	4	8/15/75	-1.2600+ 1	1.2650+ 1	2.0000+ 1	
N,3N	N	ENERGY-ANGLE DIST.	6	8/15/75	-1.2600+ 1	1.2650+ 1	2.0000+ 1	
N,3N	N	TOTAL ENERGY DEP.	4	12/03/76	-1.2600+ 1	1.2653+ 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+ 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	8/15/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	G	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1	
N,F	N	NEUTRONS/FISSION	6	8/15/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	G	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1	
N,F	N	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G		CROSS SECTION	656	6/02/77	5.4800+ 0	1.0000-10	2.0000+ 1	
N,G	G	ENERGY DIST.	2	8/15/75	5.4800+ 0	1.0000-10	3.0000- 1	
N,G	G	MULTIPLICITY	3	8/15/75	5.4800+ 0	1.0000-10	3.0000- 1	
N,G		TOTAL ENERGY DEP.	2	11/21/76	5.4800+ 0	1.0000-10	2.0000+ 1	
N,G		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 DIST.	2	8/15/75	5.5280+ 0	1.0000-10	3.0000- 1	
N,G	G	MULTIPLICITY	3	8/15/75	5.5280+ 0	1.0000-10	3.0000- 1	
N,G		TOTAL ENERGY DEP.	2	11/21/76	5.5280+ 0	1.0000-10	2.0000+ 1	
N,G		LOCAL ENERGY DEP.	2	11/21/76	5.5280+ 0	1.0000-10	2.0000+ 1	
N,XG		CROSS SECTION	11	8/15/75	0.0000+ 0	2.9999- 1	2.0000+ 1	
N,XG	G	ENERGY-ANGLE DIST.	10	8/15/75	0.0000+ 0	2.9999- 1	2.0000+ 1	

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 $n, n'f$ 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, 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 (see UCRL-50400, Vol. 15, Part A, p. 23). 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 U²³⁵ fission cross section data. The latter are based on the experimental U²³⁵ fission data of Czirr and Sidhu.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only measurements of $\bar{\nu}$ for Am²⁴¹ 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 U²³⁵ (to which these measurements are

normalized), a value of 3.11 is selected for the low-energy $\bar{\nu}$ value of Am²⁴¹. 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

For incident neutron energies below 0.3 MeV, the cross section for photon production from fission is entered as a multiplicity applied to

the fission cross section. For incident neutron energies above 0.3 MeV, the photon production from fission is included in the total photon production cross section. The photon multiplicity 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

For energies below 0.3 MeV, 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. For incident neutron energies above 0.3 MeV, photon production from the capture reactions is subsumed into the total n,X γ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION (n,X γ) FROM 0.3 TO 20 MeV

For energies below 0.3 MeV, photon production is assumed to

originate only from capture and fission processes. This assumption ignores photon production from inelastic scattering below 0.3 MeV. However, the uncertainties in the various cross sections and spectra are larger than any reasonably assumed contribution of photon production from inelastic scattering in this range. From 0.3 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 FROM 0.3 TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 0.3 MeV are calculated with the NXGAMEL code. The contribution to these spectra of the photons from fission is obtained with the measured photon spectrum for U^{235} .

Americium-242M

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{95}\text{Am}^{242\text{m}}$ are summarized on p. 1-351 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 385 to 389 of UCRL-50400, Vol. 15, Part B.

TOTAL CROSS SECTION

The evaluated total cross sections for $\text{Am}^{242\text{m}}$ are displayed graphically on pp. 385 and 386 of 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 on p. 387 of UCRL-50400, Vol. 15, Part B.

ANGULAR AND ENERGY DISTRIBUTIONS FOR INELASTIC SCATTERING

The angular distributions for

Americium-242M

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		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	11/15/72	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	10	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	4	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	491	11/15/72	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	12/14/72	1.9200+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	2	12/14/72	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 DIST.	2	12/14/72	6.3800+ 0	1.0000-10	1.0000- 2
N,G	G	MULTIPLICITY	3	12/14/72	6.3800+ 0	1.0000-10	1.0000- 2
N,G		TOTAL ENERGY DEP.	2	11/21/76	6.3800+ 0	1.0000-10	2.0000+ 1
N,G		LOCAL ENERGY DEP.	2	11/21/76	6.3800+ 0	1.0000-10	2.0000+ 1
N,XG		CROSS SECTION	54	12/14/72	0.0000+ 0	9.9000- 3	2.0000+ 1
N,XG	G	ENERGY-ANGLE DIST.	12	12/14/72	0.0000+ 0	9.9000- 3	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 on p. 388 of 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 on p. 389 of 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

For energies below 10 keV, 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. For incident neutron energies above 10 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 10 keV TO 20 MeV

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 $(n,X\gamma)$ PROCESS FROM 10 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 10 keV (except for the fission photons) are calculated with the NXGAMEL code.

Americium-243

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{243}_{95}\text{Am}$ are listed on pp. 1-351 and 1-352 of UCRL-50400, Vol. 3, Rev. 2. The evaluated cross sections are shown graphically on pp. 390 to 394 of 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 on p. 392 of 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	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	26	12/01/75	0.0000+ 0	8.0000- 2	2.0000+ 1
N,N'	N	ENERGY-ANGLE DIST.	14	12/01/75	0.0000+ 0	8.0000- 2	2.0000+ 1
N,N'	N	TOTAL ENERGY DEP.	24	12/03/76	0.0000+ 0	8.0000- 2	2.0000+ 1
N,N'	N	LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	8.0000- 2	2.0000+ 1
N,2N		CROSS SECTION	18	12/01/75	-6.3738+ 0	6.4100+ 0	2.0000+ 1
N,2N	N	ENERGY-ANGLE DIST.	9	12/01/75	-6.3738+ 0	6.4100+ 0	2.0000+ 1
N,2N	N	TOTAL ENERGY DEP.	16	12/03/76	-6.3738+ 0	6.4100+ 0	2.0000+ 1
N,2N	N	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	N	ENERGY-ANGLE DIST.	6	12/01/75	-1.1901+ 1	1.1950+ 1	2.0000+ 1
N,3N	N	TOTAL ENERGY DEP.	5	12/03/76	-1.1901+ 1	1.1950+ 1	2.0000+ 1
N,3N	N	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	N	ENERGY-ANGLE DIST.	3	12/01/75	-1.8424+ 1	1.8500+ 1	2.0000+ 1
N,4N	N	TOTAL ENERGY DEP.	2	12/03/76	-1.8424+ 1	1.8500+ 1	2.0000+ 1
N,4N	N	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	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	G	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	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	G	ENERGY DIST.	2	12/01/75	5.3600+ 0	1.0000-10	3.0000- 1
N,G	G	MULTIPLICITY	3	12/01/75	5.3600+ 0	1.0000-10	3.0000- 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	16	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1
N,XG	G	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	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 on p. 393 of 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

For incident neutron energies below 0.3 MeV, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. For incident neutron energies above 0.3 MeV, the photon production from fission is included in the total photon production 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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the

uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. In short, it is felt to be a trivial omission in the energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV (except for the fission photons) are calculated with the NXGAMEL code.

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DATA SUMMARY AND GENERAL COMMENTS

The few data points that exist for $^{96}_{\text{Cm}}^{242}$ are listed on p. 1-352 of UCRL-50400, Vol. 3, Rev. 2. 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 Cm^{242} , 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^{242} 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 on p. 395 of 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 on p. 397 of 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	G ENERGY-ANGLE DIST.	2	2/02/76	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N NEUTRONS/FISSION	5	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	3	2/02/76	2.0000+ 2	1.0000-10	3.0000- 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 DIST.	2	2/02/76	5.7000+ 0	1.0000-10	3.0000- 1
N,G	G MULTIPLICITY	3	2/02/76	5.7000+ 0	1.0000-10	3.0000- 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	16	2/02/76	0.0000+ 0	2.9999- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	2/02/76	0.0000+ 0	2.9999- 1	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 on p. 399 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 $n, n'f$, $n, 2nf$, 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

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 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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total n,X γ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION (n,X γ) FROM 300 keV TO 20 MeV

For energies below 300 keV, photon

production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the nn' γ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. In short, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV are calculated with the NXGAMEL code.

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DATA SUMMARY AND GENERAL COMMENTS

The few data points that have been measured for ${}_{96}\text{Cm}^{243}$ are listed on p. 1-352 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 400 to 404 of 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 on p. 400 of 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 on p. 402 of 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	N	ANGULAR DIST.	19	2/02/76	0.0000+ 0	1.0000- 2	2.0000+ 1
N,ELASTIC	N	TOTAL ENERGY DEP.	38	2/02/76	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	N	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'	N	ENERGY-ANGLE DIST.	14	2/02/76	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	2/02/76	-5.6900+ 0	5.7200+ 0	2.0000+ 1
N,2N	N	ENERGY-ANGLE DIST.	7	2/02/76	-5.6900+ 0	5.7200+ 0	2.0000+ 1
N,2N	N	TOTAL ENERGY DEP.	19	12/03/76	-5.6900+ 0	5.7200+ 0	2.0000+ 1
N,2N	N	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	N	ENERGY-ANGLE DIST.	5	2/02/76	-1.2660+ 1	1.2720+ 1	2.0000+ 1
N,3N	N	TOTAL ENERGY DEP.	4	12/03/76	-1.2660+ 1	1.2720+ 1	2.0000+ 1
N,3N	N	LOCAL ENERGY DEP.	4	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	N	ENERGY-ANGLE DIST.	2	2/02/76	-1.8740+ 1	1.8820+ 1	2.0000+ 1
N,4N	N	TOTAL ENERGY DEP.	2	12/03/76	-1.8740+ 1	1.8820+ 1	2.0000+ 1
N,4N	N	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	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	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G	ENERGY-ANGLE DIST.	2	2/02/76	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	NEUTRONS/FISSION	5	2/02/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	3	2/02/76	2.0000+ 2	1.0000-10	3.0000- 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 DIST.	2	2/02/76	6.8000+ 0	1.0000-10	3.0000- 1
N,G	G	MULTIPLICITY	3	2/02/76	6.8000+ 0	1.0000-10	3.0000- 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	16	2/02/76	0.0000+ 0	2.9999- 1	2.0000+ 1
N,XG	G	ENERGY-ANGLE DIST.	15	2/02/76	0.0000+ 0	2.9999- 1	2.0000+ 1

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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 on p. 403 of 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.* 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

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} . Above 300 keV, the photons from fission are included in the total $n, X\gamma$ cross section.

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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n, X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n, X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. Thus, it is felt to be a trivial omission in this energy range. From 300 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 produc-
tion data is discussed in UCRL-50400,
Vol. 15, Part A, pp. 38 to 41.

SPECTRA OF PHOTONS FROM THE (n,X γ)
PROCESS FROM 300 keV TO 20 MeV

As stated in the previous section,
the photon spectra associated with
total photon production above 300 keV
are calculated with the NXGAMEL code.

Curium-244

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{96}\text{Cm}^{244}$ are listed on pp. 1-352 and 1-353 of UCRL-50400, Vol. 3, Rev. 2. The evaluated cross sections are shown graphically on pp. 405 to 409 of 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 Cm^{244} 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 on p. 407 of 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	-6.8000+ 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	G ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 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 DIST.	2	12/01/75	5.5200+ 0	1.0000-10	3.0000- 1
N,G	G MULTIPLICITY	3	12/01/75	5.5200+ 0	1.0000-10	3.0000- 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	16	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1
N,XG	G ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	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 on p. 408 of 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

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} . Above 300 keV, the photons from fission are included in the total $n,X\gamma$ cross section.

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. Be-

tween 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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this

omission. Thus, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV are calculated with the NXGAMEL code.

Curium-245

DATA SUMMARY AND GENERAL COMMENTS

There are very few cross section measurements for ${}_{96}\text{Cm}^{245}$. 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 on pp. 1-353 and 1-354 of UCRL-50400, Vol. 3, Rev. 2. 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	G	ENERGY-ANGLE DIST.	2	3/15/75	2.0000+ 2	1.0000-10	3.0200- 1
N,F	N	NEUTRONS/FISSION	6	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	3	3/15/75	2.0000+ 2	1.0000-10	3.0200- 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 DIST.	2	3/15/75	6.4500+ 0	1.0000-10	3.0200- 1
N,G	G	MULTIPLICITY	3	3/15/75	6.4500+ 0	1.0000-10	3.0200- 1
N,G		TOTAL ENERGY DEP.	2	11/21/76	6.4500+ 0	1.0000-10	2.0000+ 1
N,G		LOCAL ENERGY DEP.	2	11/21/76	6.4500+ 0	1.0000-10	2.0000+ 1
N,XG		CROSS SECTION	12	3/15/75	0.0000+ 0	3.0000- 1	2.0000+ 1
N,XG	G	ENERGY-ANGLE DIST.	11	3/15/75	0.0000+ 0	3.0000- 1	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

For energies less than 0.3 MeV, the cross section for photon production from fission is entered as a multiplicity applied to the fission cross section. Above 0.3 MeV, the photon production from fission is included in the total photon production 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

For neutron energies below 0.3 MeV, 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 U²³⁸ photon spectrum. The use of a multiplicity and associated spectra is only for energies below 0.3 MeV; for incident neutron energies above 0.3 MeV, the photons from the capture reaction are subsumed into the total n,X γ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION (n,X γ) FROM 0.3 TO 20 MeV

For energies less than 0.3 MeV,

photon production is assumed to occur only from the capture and fission processes. This ignores the photon production from inelastic scattering below 0.3 MeV, but the uncertainties in the various cross sections and spectra are larger than any reasonably assumed contribution of photon production from inelastic scattering in this range. From 0.3 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 FROM 0.3 TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 0.3 MeV are calculated with the NXGAMEL code. The contribution of photons from fission to these spectra is obtained by using the measured photon spectrum for U²³⁵ fission.

Curium-246

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{246}_{96}\text{Cm}$ are listed on p. 1-354 of UCRL-50400, Vol. 3, Rev. 2. 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 on p. 415 of 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 on p. 417 of 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						
N,ELASTIC	N	CROSS SECTION	276	12/01/75	0.0000+ 0	1.0000-10
N,ELASTIC	N	ANGULAR DIST.	19	12/01/75	0.0000+ 0	1.0000- 2
N,ELASTIC	N	TOTAL ENERGY DEP.	38	12/01/75	0.0000+ 0	1.0000-10
N,ELASTIC	N	LOCAL ENERGY DEP.	38	12/01/75	0.0000+ 0	1.0000-10
N,N'		CROSS SECTION	20	12/01/75	0.0000+ 0	4.3000- 2
N,N'	N	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	4.3000- 2
N,N'	N	TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	4.3000- 2
N,N'	N	LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	4.3000- 2
N,2N		CROSS SECTION	17	12/01/75	-6.4500+ 0	6.4800+ 0
N,2N	N	ENERGY-ANGLE DIST.	9	12/01/75	-6.4500+ 0	6.4800+ 0
N,2N	N	TOTAL ENERGY DEP.	13	12/03/76	-6.4500+ 0	6.4800+ 0
N,2N	N	LOCAL ENERGY DEP.	9	12/03/76	-6.4500+ 0	6.4800+ 0
N,3N		CROSS SECTION	11	12/01/75	-1.1970+ 1	1.2020+ 1
N,3N	N	ENERGY-ANGLE DIST.	6	12/01/75	-1.1970+ 1	1.2020+ 1
N,3N	N	TOTAL ENERGY DEP.	5	12/03/76	-1.1970+ 1	1.2020+ 1
N,3N	N	LOCAL ENERGY DEP.	4	12/03/76	-1.1970+ 1	1.2020+ 1
N,4N		CROSS SECTION	3	12/01/75	-1.8760+ 1	1.8840+ 1
N,4N	N	ENERGY-ANGLE DIST.	3	12/01/75	-1.8760+ 1	1.8840+ 1
N,4N	N	TOTAL ENERGY DEP.	2	12/03/76	-1.8760+ 1	1.8840+ 1
N,4N	N	LOCAL ENERGY DEP.	2	12/03/76	-1.8760+ 1	1.8840+ 1
N,F		CROSS SECTION	305	12/01/75	2.0000+ 2	1.0000-10
N,F	N	TOTAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10
N,F	N	LOCAL ENERGY DEP.	2	12/03/76	2.0000+ 2	1.0000-10
N,F	N	ENERGY-ANGLE DIST.	5	12/01/75	2.0000+ 2	1.0000-10
N,F	G	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10
N,F	N	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10
N,F	G	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10
N,F	N	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10
N,G		CROSS SECTION	433	12/01/75	5.1600+ 0	1.0000-10
N,G	G	ENERGY DIST.	2	12/01/75	5.1600+ 0	1.0000-10
N,G	G	MULTIPLICITY	3	12/01/75	5.1600+ 0	1.0000-10
N,G		TOTAL ENERGY DEP.	2	11/21/76	5.1600+ 0	1.0000-10
N,G		LOCAL ENERGY DEP.	2	11/21/76	5.1600+ 0	1.0000-10
N,XG		CROSS SECTION	16	12/01/75	0.0000+ 0	2.9999- 1
N,XG	G	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 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 on p. 418 of 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 on p. 419 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

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 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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. Thus, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV TO 20 MeV.

As stated in the previous section, the photon spectra associated with total photon production above 300 keV are calculated with the NXGAMEL code.

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DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{247}_{96}\text{Cm}$ are listed on p. 1-354 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 420 to 424 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 on p. 420 of 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 on p. 422 of 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

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	REACTION	POINTS	DATE	Q-VALUE	E-MIN	E-MAX
N,ELASTIC	CROSS SECTION	217	12/01/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	ANGULAR DIST.	28	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	19	12/01/75	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	LOCAL ENERGY DEP.	15	12/03/76	0.0000+ 0	5.0000- 2	2.0000+ 1
N,2N	CROSS SECTION	17	12/01/75	-5.1500+ 0	5.1800+ 0	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	10	12/01/75	-5.1500+ 0	5.1800+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	20	12/03/76	-5.1500+ 0	5.1800+ 0	2.0000+ 1
N,2N	LOCAL ENERGY DEP.	15	12/03/76	-5.1500+ 0	5.1800+ 0	2.0000+ 1
N,3N	CROSS SECTION	10	12/01/75	-1.1600+ 1	1.1650+ 1	2.0000+ 1
N,3N	ENERGY-ANGLE DIST.	6	12/01/75	-1.1600+ 1	1.1650+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	5	12/03/76	-1.1600+ 1	1.1650+ 1	2.0000+ 1
N,3N	LOCAL ENERGY DEP.	5	12/03/76	-1.1600+ 1	1.1650+ 1	2.0000+ 1
N,4N	CROSS SECTION	4	12/01/75	-1.7100+ 1	1.7200+ 1	2.0000+ 1
N,4N	ENERGY-ANGLE DIST.	3	12/01/75	-1.7100+ 1	1.7200+ 1	2.0000+ 1
N,4N	TOTAL ENERGY DEP.	3	12/03/76	-1.7100+ 1	1.7200+ 1	2.0000+ 1
N,4N	LOCAL ENERGY DEP.	3	12/03/76	-1.7100+ 1	1.7200+ 1	2.0000+ 1
N,F	CROSS SECTION	1170	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	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	NEUTRONS/FISSION	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	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1
N,G	CROSS SECTION	1268	12/01/75	6.2100+ 0	1.0000-10	2.0000+ 1
N,G	ENERGY DIST.	2	12/01/75	6.2100+ 0	1.0000-10	3.0000- 1
N,G	MULTIPLICITY	3	12/01/75	6.2100+ 0	1.0000-10	3.0000- 1
N,G	TOTAL ENERGY DEP.	2	11/21/76	6.2100+ 0	1.0000-10	2.0000+ 1
N,G	LOCAL ENERGY DEP.	2	11/21/76	6.2100+ 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	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1

DELAYED

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 on p. 423 of 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 on p. 424 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

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

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 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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total n,X γ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION (n,X γ) FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the nn' γ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. In short, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV are calculated with the NXGAMEL code.

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DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{248}_{96}\text{Cm}$ are listed on p. 1-354 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 425 to 429 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 on p. 425 of 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 on p. 427 of 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

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		REACTION	POINTS	DATE	Q-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	600	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	G	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1	
N,F	N	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	G	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1	
N,F	N	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G		CROSS SECTION	966	12/01/75	4.7100+ 0	1.0000-10	2.0000+ 1	
N,G	G	ENERGY DIST.	2	12/01/75	4.7100+ 0	1.0000-10	3.0000- 1	
N,G	G	MULTIPLICITY	3	12/01/75	4.7100+ 0	1.0000-10	3.0000- 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	16	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1	
N,XG	G	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1	

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 on p. 428 of 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

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 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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. Thus, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV are calculated with the NXGAMEL code.

Berkelium-249

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{97}\text{Bk}^{249}$ are listed on p. 1-355 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 430 to 434 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 on p. 430 of 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 on p. 432 of 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

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		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+ 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	G	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1	
N,F	N	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	G	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1	
N,F	N	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G		CROSS SECTION	368	12/01/75	4.9700+ 0	1.0000-10	2.0000+ 1	
N,G	G	ENERGY DIST.	2	12/01/75	4.9700+ 0	1.0000-10	3.0000- 1	
N,G	G	MULTIPLICITY	3	12/01/75	4.9700+ 0	1.0000-10	3.0000- 1	
N,G		TOTAL ENERGY DEP.	2	11/21/76	4.9700+ 0	1.0000-10	2.0000+ 1	
N,G		LOCAL ENERGY DEP.	2	11/21/76	4.9700+ 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	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1	

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 on p. 433 of 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 on p. 430 of 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 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 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 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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. In short, it is felt to be a trivial omission in the energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV are calculated with the NXGAMEL code.

Californium-249

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}^{249}_{98}\text{Cf}$ are listed on p. 1-355 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 435 to 439 of 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 on p. 435 of 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 on p. 437 of 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	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	16	12/01/75	-5.5900+ 0	5.6200+ 0	2.0000+ 1
N,2N	N	ENERGY-ANGLE DIST.	9	12/01/75	-5.5900+ 0	5.6200+ 0	2.0000+ 1
N,2N	N	TOTAL ENERGY DEP.	18	12/03/76	-5.5900+ 0	5.6200+ 0	2.0000+ 1
N,2N	N	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	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	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	2027	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	G	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	NEUTRONS/FISSION	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	G	ENERGY DIST.	2	12/01/75	6.6200+ 0	1.0000-10	3.0000- 1
N,G	G	MULTIPLICITY	3	12/01/75	6.6200+ 0	1.0000-10	3.0000- 1
N,G		TOTAL ENERGY DEP.	2	11/21/76	6.6200+ 0	1.0000-10	2.0000+ 1
N,G		LOCAL 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	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1

DELAYED

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 on p. 438 of 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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured

inelastic scattering cross section combine to mitigate the effects of this omission. Thus, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV are calculated with the NXGAMEL code.

Californium-250

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for $^{250}_{98}\text{Cf}$ are listed on p. 1-355 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 440 to 444 of 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 on p. 440 of 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 on p. 442 of 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

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		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	-6.6100+ 0	6.6400+ 0	2.0000+ 1
N,2N	N	ENERGY-ANGLE DIST.	9	12/01/75	-6.6100+ 0	6.6400+ 0	2.0000+ 1
N,2N	N	TOTAL ENERGY DEP.	18	12/03/76	-6.6100+ 0	6.6400+ 0	2.0000+ 1
N,2N	N	LOCAL ENERGY DEP.	12	12/03/76	-6.6100+ 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.	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	G	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1
N,F	N	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	G	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 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 DIST.	2	12/01/75	5.1100+ 0	1.0000-10	3.0000- 1
N,G	G	MULTIPLICITY	3	12/01/75	5.1100+ 0	1.0000-10	3.0000- 1
N,G		TOTAL ENERGY DEP.	2	11/21/76	5.1100+ 0	1.0000-10	2.0000+ 1
N,G		LOCAL ENERGY DEP.	2	11/21/76	5.1100+ 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	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	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 6.64 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. 443 of 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,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 18.6 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 on p. 440 of UCRL-50400, Vol. 15, Part B.

AVERAGE NUMBER OF NEUTRONS PER FISSION ($\bar{\nu}$)

The only $\bar{\nu}$ measurement for Cf²⁵⁰ 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'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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. Hence, it is felt to be a trivial omission in this energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV are calculated with the NXGAMEL code.

Californium-251

DATA SUMMARY AND GENERAL COMMENTS

The experimental data for ${}_{98}\text{Cf}^{251}$ are listed on p. 1-355 of UCRL-50400, Vol. 3, Rev. 2. 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 on pp. 445 to 449 of 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 on p. 445 of 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 on p. 447 of 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

Californium-251

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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	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	19	12/01/75	0.0000+ 0	2.5000- 2	2.0000+ 1	
N,N'	N						
	ENERGY-ANGLE DIST.	14	12/01/75	0.0000+ 0	2.5000- 2	2.0000+ 1	
N,N'	N						
	TOTAL ENERGY DEP.	17	12/03/76	0.0000+ 0	2.5000- 2	2.0000+ 1	
N,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	N						
	ENERGY-ANGLE DIST.	10	12/01/75	-5.1000+ 0	5.1300+ 0	2.0000+ 1	
N,2N	N						
	TOTAL ENERGY DEP.	22	12/03/76	-5.1000+ 0	5.1300+ 0	2.0000+ 1	
N,2N	N						
	LOCAL ENERGY DEP.	12	12/03/76	-5.1000+ 0	5.1300+ 0	2.0000+ 1	
N,3N							
	CROSS SECTION	8	12/01/75	-1.1730+ 1	1.1780+ 1	2.0000+ 1	
N,3N	N						
	ENERGY-ANGLE DIST.	6	12/01/75	-1.1730+ 1	1.1780+ 1	2.0000+ 1	
N,3N	N						
	TOTAL ENERGY DEP.	5	12/03/76	-1.1730+ 1	1.1780+ 1	2.0000+ 1	
N,3N	N						
	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	N						
	ENERGY-ANGLE DIST.	3	12/01/75	-1.7320+ 1	1.7390+ 1	2.0000+ 1	
N,4N	N						
	TOTAL ENERGY DEP.	3	12/03/76	-1.7320+ 1	1.7390+ 1	2.0000+ 1	
N,4N	N						
	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	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	G						
	ENERGY-ANGLE DIST.	2	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1	
N,F	N						
	NEUTRONS/FISSION	5	12/01/75	2.0000+ 2	1.0000-10	2.0000+ 1	
N,F	G						
	MULTIPLICITY	3	12/01/75	2.0000+ 2	1.0000-10	3.0000- 1	
N,F	N						
	NEUTRONS/FISSION	2	3/01/76	2.0000+ 2	1.0000-10	2.0000+ 1	DELAYED
N,G							
	CROSS SECTION	206	12/01/75	6.1700+ 0	1.0000-10	2.0000+ 1	
N,G	G						
	ENERGY DIST.	2	12/01/75	6.1700+ 0	1.0000-10	3.0000- 1	
N,G	G						
	MULTIPLICITY	3	12/01/75	6.1700+ 0	1.0000-10	3.0000- 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	16	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1	
N,XG	G						
	ENERGY-ANGLE DIST.	15	12/01/75	0.0000+ 0	2.9999- 1	2.0000+ 1	

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 on p. 448 of 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 Cf²⁵¹ are at thermal neutron energies, the evaluated fission cross sections above 1 keV are obtained entirely from systematics. The evaluated Cf²⁵¹ fission cross sections are shown graphically on p. 445 of 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

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

For energies below 300 keV, 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. For incident neutron energies above 300 keV, photon production from capture reactions is absorbed into the total $n,X\gamma$ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION $(n,X\gamma)$ FROM 300 keV TO 20 MeV

For energies below 300 keV, photon production is assumed to originate only from capture and fission processes. This ignores the photons emitted during the $nn'\gamma$ process. While this is a technical deficiency, the softness of the photons and the uncertainty of the unmeasured inelastic scattering cross section combine to mitigate the effects of this omission. In short, it is felt to be a trivial omission in the energy range. From 300 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 FROM 300 keV TO 20 MeV

As stated in the previous section, the photon spectra associated with total photon production above 300 keV 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 on pp. 1-355 and 1-356 of UCRL-50400, Vol. 3, Rev. 2.

*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 kV. 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	ANGULAR DIST.	13	3/25/75	0.0000+ 0	4.0000- 2	2.0000+ 1
N,ELASTIC	TOTAL ENERGY DEP.	39	3/29/75	0.0000+ 0	1.0000-10	2.0000+ 1
N,ELASTIC	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'	ENERGY-ANGLE DIST.	14	3/15/75	0.0000+ 0	5.0000- 2	2.0000+ 1
N,N'	TOTAL ENERGY DEP.	24	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	9	3/15/75	-6.1700+ 0	6.2500+ 0	2.0000+ 1
N,2N	ENERGY-ANGLE DIST.	7	3/15/75	-6.1700+ 0	6.2500+ 0	2.0000+ 1
N,2N	TOTAL ENERGY DEP.	14	12/03/76	-6.1700+ 0	6.2500+ 0	2.0000+ 1
N,2N	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	ENERGY-ANGLE DIST.	5	3/15/75	-1.1280+ 1	1.1400+ 1	2.0000+ 1
N,3N	TOTAL ENERGY DEP.	5	12/03/76	-1.1280+ 1	1.1400+ 1	2.0000+ 1
N,3N	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	ENERGY-ANGLE DIST.	3	3/15/75	-1.7900+ 1	1.8000+ 1	2.0000+ 1
N,4N	TOTAL ENERGY DEP.	2	12/03/76	-1.7900+ 1	1.8000+ 1	2.0000+ 1
N,4N	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	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	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	ENERGY-ANGLE DIST.	2	3/15/75	2.0000+ 2	1.0000-10	3.0200- 1
N,F	NEUTRONS/FISSION	6	3/15/75	2.0000+ 2	1.0000-10	2.0000+ 1
N,F	MULTIPLICITY	3	3/15/75	2.0000+ 2	1.0000-10	3.0200- 1
N,F	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	ENERGY DIST.	2	3/15/75	4.7900+ 0	1.0000-10	3.0200- 1
N,G	MULTIPLICITY	3	3/15/75	4.7900+ 0	1.0000-10	3.0200- 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	12	3/15/75	0.0000+ 0	3.0000- 1	2.0000+ 1
N,XG	ENERGY-ANGLE DIST.	12	3/15/75	0.0000+ 0	3.0000- 1	2.0000+ 1

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20 MeV, the elastic scattering cross section is calculated from a spherical optical model, using the Becchetti and Greenlees best-fit parameters [*Phys. Rev.* 182, 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 on p. 453 of 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

For incident neutron energies below 0.3 MeV, the cross section for photon production from fission is entered in the form of a multiplicity applied to the fission cross section. Above 0.3 MeV, the photon production from fission is incorporated into the total photon production cross section. In the energy range below 0.3 MeV, 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.

CROSS 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

For energies below 0.3 MeV, 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. For neutron energies above 0.3 MeV, the photons from the capture reaction are subsumed into the total n,Xγ reaction.

TOTAL PHOTON PRODUCTION CROSS SECTION (n,Xγ) FROM 0.3 TO 20 MeV

For incident neutron energies below 0.3 MeV, photon production is assumed to occur only from the capture and fission processes, as described above. This assumption ignores the photon production from inelastic scattering below 0.3 MeV, but the uncertainties in the various

cross sections and spectra are considerably larger than any reasonably assumed contribution to photon production from inelastic scattering in this energy range. From 0.3 to 20 MeV, the $n,X\gamma$ 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 $(n,X\gamma)$ PROCESS FROM 0.3 TO 20 MeV

As stated in the previous section, the photon spectra associated with the total photon production above 0.3 MeV 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.

MSG/gw