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SURVEY OF EXPERIMENTALLY DETERMINED NEUTRON CROSS SECTIONS OF THE ACTINIDES

R. W. Benjamin

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Savannah River Laboratory

Aiken, South Carolina

PREPARED FOR THE U. S. ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(07-2)-1

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SURVEY OF EXPERIMENTALLY DETERMINED NEUTRON CROSS SECTIONS OF THE ACTINIDES

by

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ABSTRACT

Experimentally determined neutron cross section data for heavy actinides involved in the reactor production chains leading to ^{238}Pu and ^{252}Cf have been examined. The neutron energy region below one kilovolt is emphasized because these cross sections and reactions are important for thermal and near-thermal reactors. Included with the data summaries are brief descriptions of pertinent measurements in progress or planned for the near future at United States and European laboratories. Additional measurements that are needed are suggested. Of most immediate interest are: $\sigma_{n\gamma}$ for ^{248}Cm below 1 keV, σ_{nf} for ^{245}Cm below 40 eV, σ_{nf} for ^{247}Cm below 40 eV, and σ_{nf} for ^{251}Cf below 1 keV. Data were gathered for the survey through January 1973.

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INTRODUCTION

The Savannah River Laboratory has a strong interest in the development of techniques for the accurate calculation of reactor production rates for the heavy actinides. The isotopes ^{238}Pu and ^{252}Cf are of special interest because of their unique and beneficial properties.

The successful calculation of reactor production rates for the heavy actinides requires as input the product of two energy-dependent quantities, the neutron flux $\phi(E)$ and the cross sections $\sigma_i(E)$. The neutron cross sections are fundamental physical quantities which must be determined experimentally, although in some instances approximations based on nuclear systematics and nuclear theory may be used. The purpose of this survey is to examine the available heavy actinide cross section data with the object of directing attention to key nuclides in the production chains for which more experimental data are needed. Particular emphasis is placed on the energy region below one keV, which is most important for thermal reactors.

The cross section data are in two categories, integral and differential, which derive from fundamentally different measurement techniques. Differential cross sections, i.e., specific reaction probabilities as a function of incident neutron energy, are useful for most calculations; however, because enriched isotopic sample material is not always readily available, such data for many of the higher actinides are fragmentary or nonexistent. Integral measurements require only small quantities of sample material and relatively simple experimental techniques and are used to fill in the gaps as much as possible. Integral cross section measurements are reaction-rate measurements and thus involve the product $\phi(E) \cdot \sigma_i(E)$. The flux as a function of energy $\phi(E)$ and the cross section of the isotope as a function of energy interact; therefore, certain simplifying assumptions and standard conditions are conventionally used: the cross section in the thermal region varies inversely with the neutron velocity, and the neutron flux in the reactor above the thermal Maxwellian is inversely proportional to the neutron energy. The integral values obtained must be adjusted for any deviations from the assumptions or the conditions.

The nuclides involved in three production chains, one leading to ^{252}Cf and two leading to ^{238}Pu, have been studied. The ^{238}Pu chains are shown in Figure 1 and the ^{252}Cf chain is shown in

Figure 2. The isotopes surveyed are those cross sections significant to the production process and are enclosed in solid lines. Appreciable fission, which removes a nucleus from the chain, is denoted by bold vertical arrows; neutron capture is denoted by an arrow to the right; the γ,n or n,2n reactions are denoted by an arrow to the left; and alpha decay, beta decay, and electron capture are denoted by arrows in the appropriate directions. Best estimates for thermal cross sections (above the line) and resonance integrals (below the line) are given where experimental values are available.

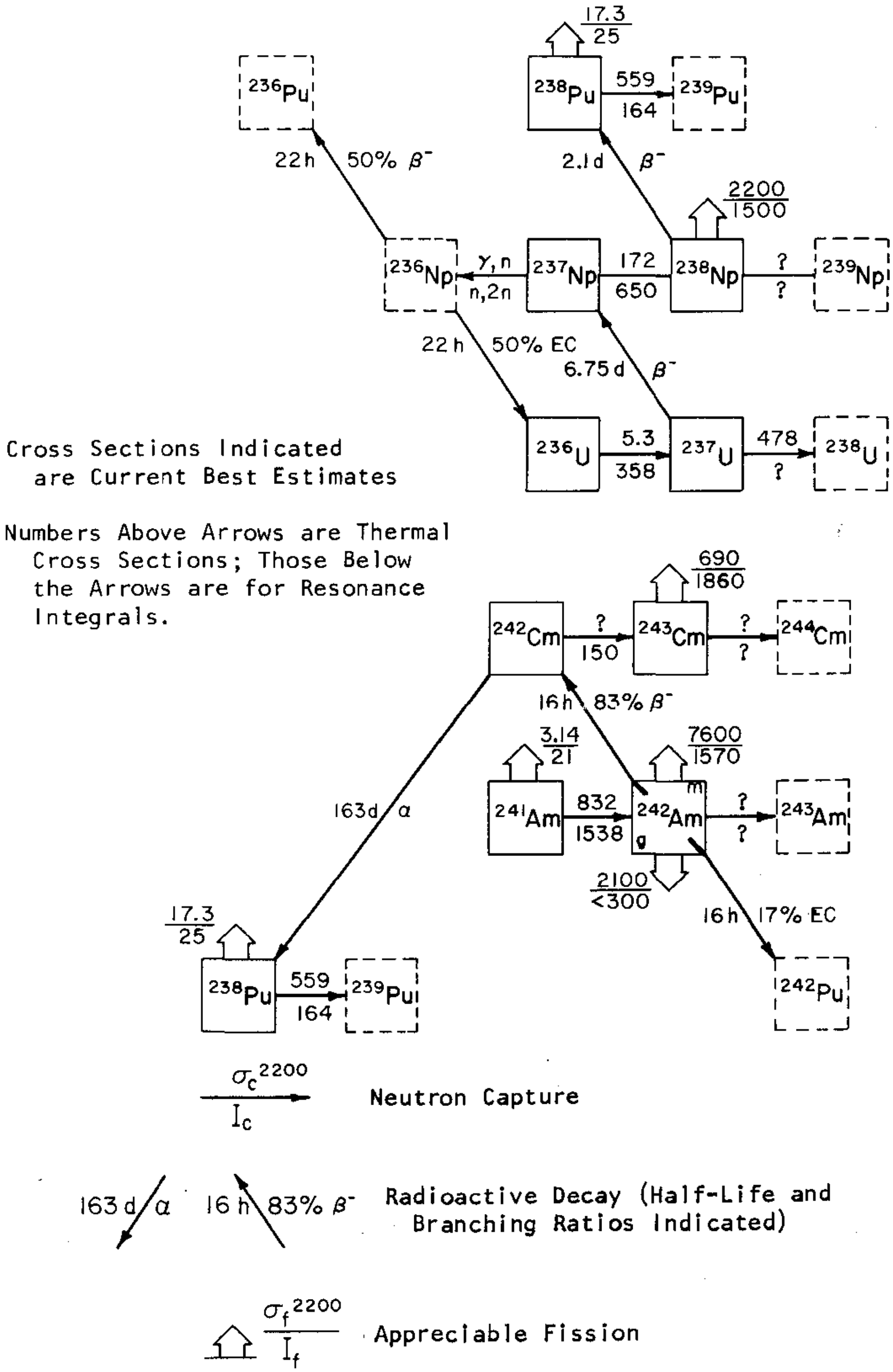
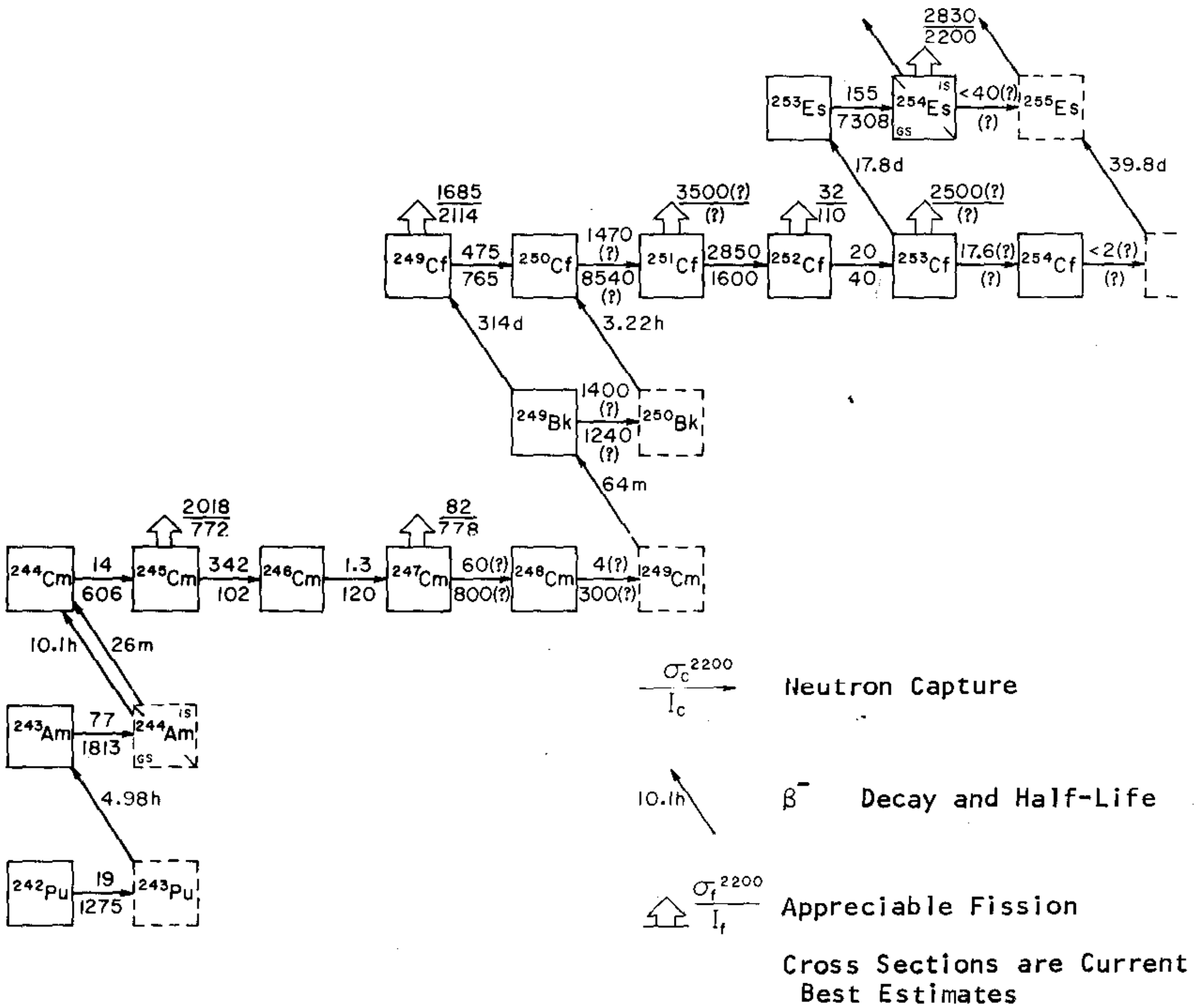


FIGURE 1. The ^{238}Pu Production Chains



Numbers above arrows are thermal cross sections;
those below the arrows are for resonance integrals.

FIGURE 2. The ^{252}Cf Production Chain

CROSS SECTION DATA

In this section, the elements are discussed in order of increasing atomic number with the isotopes of each element in order of increasing atomic weight. Currently significant measurements are summarized; questionable measurements are included only if they represent a significant portion of the available data. An effort has been made to include all planned or current measurements on isotopes in the chains. Information concerning any omissions or errors would be most welcome.

The cross section notation used in the following summaries conforms with that of H. Goldstein (*Fast Neutron Physics*, Vol. II, p. 2227, Interscience, New York, 1963) with minor changes. The symbols used are:

$\sigma(E)$	The differential cross section as a function of energy
σ^{2200}	The 2200 m/sec thermal cross section
I	The resonance integral $I = \sigma\ (E)/E\ dE$
σ_{nn}	The elastic scattering cross section
σ_{nf}	The fission cross section
$\sigma_{n\gamma}$	The capture cross section
σ_{nT}	The total cross section
σ_{na}	The absorption cross section

Terms mentioned in the discussion of the references are from the single-level resonance Breit-Wigner formula for neutron absorption.

URANIUM-236

Substantial differential and integral data are available for ^{236}U. The differential data are especially good and adequate for valid evaluations. Data of higher precision would be desirable but are not crucial to current requirements.

Differential Measurements

$\sigma_{n\gamma}(E)$ A. D. Carlson, S. J. Friesenhahn, W. M. Lopez, and M. P. Fricke, "The ^{236}U Neutron Capture Cross Section." *Nucl. Phys. A141,* 577 (1970). Capture measurements were made with Gulf General Atomic (GGA) linac on highly enriched samples for 0.01 eV $<E_n<$ 20 keV. Thermal data are good. 29 resonances were analyzed for E_o, Γ_n, and 12 for E_o, Γ_n, and Γ_γ up to 415 eV. One bound level was added to fit thermal data. $\sigma_{n\gamma}^{2200} = 5.1 \pm 0.25$ b; $I_{n\gamma}$ ($E > 0.5$ eV) = 350 ±25 b.

$\sigma_{nf}(E)$ J. D. Cramer and D. W. Bergen, *Fission Cross Section from Pommard.* USAEC Report LA-4420, Los Alamos Scientific Laboratory, Los Alamos, N. M. p 74 (1970) Los Alamos Scientific Laboratory (LASL) bomb shot fission data were obtained from highly enriched samples. Cross section curves were obtained for 35 eV $<E_n<$ 3 MeV with no parametric analysis and low precision.

$\sigma_{nT}(E)$ R. A. Harlan. Report to the AEC Nuclear Cross Sections Advisory Committee, Oak Ridge, April 1969. USAEC Report WASH-1127, Oak Ridge National Laboratory, Oak Ridge, Tenn. p 60 (1969). Materials Testing Reactor (MTR) fast chopper transmission measurements were made for 0.01 eV $<E_n<$ 1000 eV. 13 resonances were analyzed for Γ_n assuming one bound level and Γ_γ = 25 mV to 400 eV.

$\sigma_{nT}(E)$ G. J. McCallum. "The Neutron Total Cross-Sections of Uranium-234 and Uranium-236." *J. Nucl. Energy 6* 181 (1958). Harwell fast chopper transmission measurements were made with small samples enriched to ~95% for 0.01 $<E_n<$ 20 eV. Small-angle scattering in the thermal region created problems. Parameters were determined for the 5.48-eV resonance. Thermal cross sections: $\sigma_{nT}^{2200} = 18.7 \pm 1.7$ b, $\sigma_{n\gamma}^{2200} = 8.1 \pm 1.8$ b, $\sigma_{nn}^{2200} = 10.6 \pm 0.4$ b.

$\sigma_{nT}(E)$ J. A. Harvey and D. J. Hughes. "Spacing of Nuclear Energy Levels." *Phys. Rev. 109*, 471 (1958). Brookhaven fast chopper transmission measurements were made for samples enriched to ∿95%. 15 resonances were analyzed below 400 eV for E_o and Γ_n assuming Γ_γ = 25 mV. No thermal data were given.

Integral Measurements

$\sigma_{n\gamma}$ M. J. Cabell and M. Wilkins. *Thermal Neutron Capture Cross Sections of ^{234}U and ^{236}U.* British Report AERE-R6761, Atomic Energy Research Establishment, Harwell, England (1971). Mass spectrometric analysis was made after a two year reactor irradiation in Maxwellian spectrum at T = 119 ±9°C. $\bar{\sigma}_{n\gamma}$ = 8.47 ±4.00 b.

$\sigma_{n\gamma}$ R. P. Schuman and J. R. Berreth. *Resonance Integral Measurements.* USAEC Report IN-1296, Idaho Nuclear Corporation, Idaho Falls p 11 (1969). Samples enriched to 97.5%, both bare and cadmium-covered, received reactor irradiation. 0.208-meV gamma counting was performed after ion exchange purification. $\sigma_{n\gamma}^{2200}$ = 5.4 ±1.5 b, $I_{n\gamma}$ (no cutoff given) = 381 ±20 b.

$\sigma_{n\sigma}$ N. P. Baumann, J. D. Halford, and D. J. Pellarin. "Resonance Parameters for ^{236}U from Integral Measurements." *Nucl. Sci. Eng. 32*, 265 (1968). Reactor activation measurements were made for samples with composition ^{236}U-11.56 wt %, ^{235}U-2.22 wt %, ^{27}Al-86.22 wt %. Monitors were ^{235}U, ^{238}U, Au, and W. $I_{n\gamma}$ (E_n >0.5 eV) = 417 ±25 b. Resonance parameters for the first resonance were adjusted to give this value. Revised values (N. P. Baumann, private communication, 6/73) are $I_{n\gamma}$ = 5.3 ±0.2 b and $I_{n\gamma}$ (E_n >0.625 eV) = 375 ±10.

$\sigma_{n\gamma}$ M. J. Cabell, T. A. Eastwood, and D. J. Campion. "The Thermal Neutron Capture Cross Sections and Resonance Capture Integral of ^{236}U." *J. Nucl. Energy 7*, 81 (1958). Reactor activation measurements were made for bare and cadmium-covered samples enriched to ∿95%. A ^{59}Co monitor was used (assumed $\sigma_{n\gamma}^{2200}$ = 36.5 b, $I_{n\gamma}$ = 48.6 b). $\sigma_{n\gamma}^{2200}$ = 5.5 ±0.3 b, $I_{n\gamma}$ (E_n >0.5 eV) = 257 ±22 b.

Measurements in Progress or Planned

K. H. Böckhoff, private communication. GEEL has in progress a program to measure σ_{nT}, σ_{nn}, and $\sigma_{n\gamma}$ (resonance parameters) from about 1 eV to about 3 keV.

URANIUM-237

Both the differential and integral data for ^{237}U are very limited because of its short half-life of 6.75 days; for the same reason this isotope is not crucial. Additional measurements, however, would be useful.

Differential Data

$\sigma_{nf}(E)$ J. H. McNally, J. W. Barnes, B. J. Dropsky, P. A. Seeger, and K. Wolfsberg in *Fission Cross Sections from Pommard.* USAEC Report LA-4420 p 91 (1970). LASL bomb shot fission measurements were made for samples containing 18.1 ±0.5 μg ^{237}U with ∿38% ^{237}Np contaminant. $\sigma_{nf}(E)$ was measured for 35 eV $<E_n<$1.8 MeV. No parametric analysis was made.

Integral Data

$\sigma_{n\gamma}$ W. R. Cornman, E. J. Hennelly, and C. J. Banick. "Neutron Absorption Cross Section of ^{237}U." *Nucl. Sci. Eng. 31,* 149 (1968). Samples enriched to 73.08% ^{236}U were irradiated in an SRL reactor. After chemical separation and α-counting, the effective cross section was $\sigma_{n\gamma}$ = 370 ±124 b and the inferred cross section was $\sigma_{n\gamma}^{2200}$ = 378 ±160 b.

Measurements

None known.

NEPTUNIUM-237

Substantial differential and integral data are available for ^{237}Np, a key nuclide in the ^{238}Pu chain. The lower-energy neutron cross sections for capture, scattering, and fission seem well described by the differential data, and no further data are required. The integral data for ^{237}Np are, however, not very useful because the first resonance is at 0.489 eV, directly in the cadmium-cutoff region. Small uncertainties in the precise cadmium-cutoff lead to large differences in the resonance integral. Recent calculations made by F. J. McCrosson at Savannah River Laboratory using ENDF/B Version II resonance parameters determined the effects of the cutoff on the resonance integral. The results are listed below:

Low Energy Cutoff, eV	$I_{n\gamma}$, barns
0.625	550
0.525	582
0.500	635
0.475	733
0.450	788
0.400	817

If the cadmium-difference technique is used, the thermal cross section is difficult to determine. Thus, with ^{237}Np, only the differential data are measurable and integral data are estimated.

Two high-energy reactions lead to ^{236}Pu, which is a very undesirable contaminant in the ^{238}Pu product. These reactions, both having a Q-value of about 6.8 MeV, are the n,2n and γ,n reactions, which are initiated by the high-energy fission neutron tail and by capture gammas from structural elements (such as aluminum and iron), respectively. There are only a few measurements of the γ,n and n,2n cross sections for ^{237}Np in the energy regions of interest, and further measurements would be worthwhile.

Differential Data

σ_{nf} R. J. Jiacoletti, W. K. Brown, and H. G. Olson. "Fission Cross Sections of Neptunium-237 from 20 eV to 7 MeV Determined from a Nuclear Explosive Experiment." *Nucl. Sci. Eng. 48*, 412 (1972). LASL measurements of σ_{nf} were obtained for 20 eV $<E_n<$ 7 MeV from the Physics 8 bomb shot. The oxide was isotopically pure (contaminants <0.1%). Cross sections were presented, and only a rudimentary parametric comparison was made.

$\sigma_{nf}(E)$ W. Kolar, J. P. Theobald, and G. Lanzano. "Fission of $^{237}Np + n$ through a Double Humped Fission Barrier." *Z. Physik 248*, 355 (1971). At the Euratom linac at Geel Belguim, fission measurements were made with a very highly enriched sample for 20 eV $<E_n<$60 eV. 28 resonances were analyzed for E_o and Γ_f, assuming the values of Paya *et al.* for $2g\,\Gamma_n$ and Γ.

$\sigma_{nT}(E)$ $\sigma_{nn}(E)$ F. Poortmans, H. Ceulemans, J. Theobald, and E. Migneco in *Proceedings of the Third Conference on Neutron Cross Sections and Technology*. CONF-710301, 667 (1971). Geel linac scattering and transmission measurements were made for samples enriched to about 99.9%. 14 resonances were analyzed for E_o, $2g\Gamma_n$, Γ_γ, and J from 5 to 51 eV.

$\sigma_{nf}(E)$ W. K. Brown, D. R. Dixon, and D. M. Drake. "Fission Cross Sections of ^{237}Np from Pommard." *Nucl. Phys. A156*, 609 (1970). LASL bomb shot fission measurements were made for highly enriched samples for 35 eV $<E_n<$3 MeV. Only cross section curves were made. No parametric analysis was made.

$\sigma_{nf}(E)$ K. A. Gavrilov, K. K. Koshaeva, S. N. Kraitor, and L. B. Pikel'ner. "The Cross Section for Fission of ^{237}Np by Slow Neutrons." *Soviet Atomic Energy 28*(4), 464 (1970). Pulsed reactor time-of-flight measurements were made for 0.02 eV $<E_n<$800 eV. 7 resonances were analyzed for E_o, σ_o, Γ_f, and Γ from 0.49 to 7.5 eV. Thermal data are very good.

$\sigma_{nf}(E)$ $\sigma_{nT}(E)$ D. Paya, H. Derrien, A. Fubini, A. Michaudon, and P. Ribon. International Atomic Energy Agency Report INDC/156, paper 69 (1966). SACLAY transmission and fission linac measurements were made for 0.4 eV $<E_n$ $<$100 eV. Many resonances were analyzed for E_o, Γ_f, and Γ from 0.489 to 107.2 eV.

$\sigma_{nT}(E)$ I. V. Adamchuk, S. S. Moskalev, and M. I. Pevzner. "The Total Neutron Cross-Section of ^{237}Np between 2 and 10,000 eV." *J. Nucl. En. A13*, 72 (1960). Fast chopper transmission measurements were made for samples enriched to about 88% for 2.5 eV $<E_n<$10 keV. Only E_o was analyzed, and no parametric analysis was made. I was determined to be $\int\sigma_T\,dE/E = 360$ b for 2.7 to 12 keV.

$\sigma_{nT}(E)$ J. A. Harvey, R. C. Block, and G. G. Slaughter. *Reports to the AEC Nuclear Cross Sections Advisory Group, Oak Ridge, November 1958.* USAEC Report WASH-1013, p 50 (1958). Oak Ridge National Laboratory (ORNL) fast-chopper, time-of-flight transmission measurements were made for 0.40 eV $<E_n<$36 eV. 32 resonances were analyzed for 2g and Γ_n assuming Γ_γ = 32 meV.

$\sigma_{nT}(E)$ M. S. Smith, R. R. Smith, E. G. Joki, and J. E. Evans. "Neutron Total Cross Section of ^{237}Np from 0.02 to 2.8 eV." *Phys. Rev. 107*, 525 (1957). MTR crystal spectrometer transmission measurements were made. Cross section curves are given. Thermal data are good (σ_{nT}^{2200} = 170 ±22 b). Three resonances were analyzed for E_o and $\sigma_o\Gamma$.

Integral Data

$\sigma_{\gamma n}$ C. E. Ahlfeld and N. P. Baumann. "Measurement of (α,n) Cross Sections of ^{232}Th, ^{233}U, and ^{237}Np with Aluminum Capture Gamma Rays." *Trans. Amer. Nucl. Soc. 14*, 807 (1971). Reactor irradiations in the thermal spectrum were made with cadmium-covered foils in large aluminum cylinders (to produce n,γ reaction in aluminum). ^{59}Co monitors were used to measure $I_{\gamma n}$ = 12.2 ±1.4 b.

$\sigma_{n\gamma}$ S. H. Eberle, H. J. Bleyl, E. Gantner, J. Reinhardt, and C. Kruckeberger. *Actinide Project: First Semi-Annual Report.* KFK-1456, Karlsruhe, West Germany, p 51 (1971). Reactor irradiations were made for bare and cadmium-covered samples. $\sigma_{n\gamma}^{2200}$ = 184 ±6 b, $I_{n\gamma}$ (no cutoff given) = 805 ±10 b.

$\sigma_{n\gamma}$ E. Hellstrand, J. Phelps, and C. Sastre. *Studies of the Capture Cross Section of ^{237}Np and ^{241}Am in Different Reactor Spectrum.* USAEC Report BNL-50242, Brookhaven National Laboratory, Upton, NY (1970). Pile oscillator techniques were used to study capture cross sections. Independent values were not obtained. Assuming $\sigma_{n\gamma}^{2200}$ = 169 ±5 b, $I_{n\gamma}$ (>0.55 eV) = 640 ±50 b. Cutoff problem was well discussed.

$\sigma_{n,2n}$ J. Halperin, L. E. Idom, C. R. Baldock, and R. W. Stoughton. *Chemistry Division Annual Progress Report for Period Ending May 20, 1968.* USAEC Report ORNL-4306, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 1 (1968). Reactor irradiations were made in an approximately Maxwellian neutron flux for foils in cadmium covers. The preliminary value of $I_{n,2n}$ is 1.2 mb.

$\sigma_{n\gamma}$ R. P. Schuman. *Reports to the AEC Nuclear Cross Sections Committee, New York, October 1968.* USAEC Report WASH-1124, p. 74 (1968). Reactor irradiations were made for cadmium-covered samples. ^{197}Au and ^{56}Co monitors were used. $I_{n\gamma}$ (no cutoff given) = 807 ±60 b.

$\sigma_{n\gamma}$ J. W. Rogers and J. J. Scoville. "Resonance Absorption. Integrals Measured by Reactivity Techniques." *Trans. Amer. Nucl. Soc. 10,* 259 (1967). Activation measurements were made in cadmium-shielded reactor positions. $I_{n\gamma}$ (corrected to E_n >0.5) = 905 ±28 b.

$\sigma_{n,2n}$ J. L. Perkin and R. F. Coleman. "Cross-Sections for the (n,2n) Reactions of ^{232}Th, ^{238}U, and ^{237}Np with 14 MeV Neutrons." *J. Nucl. Energy AB14,* 69 (1961). Activation measurements were made with 14.5-MeV neutrons from a neutron generator. $\sigma_{n,2n}$ (at 14.5 ±0.4 MeV) = 0.39 ±0.07 b.

$\sigma_{n\gamma}$ R. B. Tattersall, H. Rose, S. K. Pattenden, and D. Jowitt. "Pile Oscillator Measurements of Resonance Absorption Integrals." *J. Nucl. Energy A12,* 32 (1960). Pile oscillator measurements were made of thermal cross sections and resonance integrals. $\sigma_{n\gamma}^{2200}$ = 169 ±3 b, $I_{n\gamma}$ (no cutoff given) = 870 ±130 b.

Measurements in Progress and Planned

R. S. Caswell, private communication. The National Bureau of Standards (NBS) Van de Graaff group plans a poor-resolution fission cross section measurement from 100 keV to 2 MeV relative to ^{235}U. The measurement is estimated to be completed in 1974.

G. A. Keyworth, private communication. A Los Alamos Scientific Laboratory - Oak Ridge National Laboratory measurement at ORELA of the resonance parameters and spins from 1 eV to 1 keV has been completed and will be submitted for publication shortly.

K. H. Böckhoff, private communication. A Geel linac measurement of σ_{nn} and the resonance spin assignments above 70 eV are planned.

J. Blons, private communication. SACLAY linac measurements of σ_{nf} to 30 keV and σ_{nT} in the resonance region are planned.

NEPTUNIUM-238

Very little cross section data are available for ^{238}Np because of its relatively brief half-life, 2.1 days. More information, though very useful, would be difficult to obtain experimentally.

Differential Data

None known.

Integral Data

σ_{na} σ_{nf} E. J. Hennelly, W. R. Cornman, and N. P. Baumann, in *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, DC, March 4-7, 1968.* NBS Special Publication 299, p 1271 (1968). Reactor irradiations were made for samples made from high-purity ^{237}Np with cadmium and boron filters. Results were obtained from high-flux activation studies and low-flux fission chamber measurements. High flux: σ_{na}^{eff} = 1620 ±100 b; σ_{nf}^{eff} = 1520 ±100 b; low flux: σ_{nf}^{eff} = 1640 ±150 b; σ_{nf}^{2200} = 2200 ±200 b; I_{nf} (no cutoff given) = 1500 ±500 b.

Measurements in Progress or Planned

None known.

PLUTONIUM-238

There are extensive differential data and a limited amount of integral data for ^{238}Pu. The differential data are adequate for a good evaluation, and more experimental measurements are not required at present.

Differential Data

$\sigma_{nf}(E)$ $\sigma_{n\gamma}(E)$ M. G. Silbert, A. Moat, and T. E. Young. *Reports to the National Cross Section Advisory Committee, Chicago, May 1970*, NCSAC-31, pp 70, 129 (1970). Fission and capture measurements were made from the LASL bomb shot "Persimmon" for 15 eV $<E_n<$ 500 eV. Many resonances were analyzed for E_o, Γ_n°, and Γ_f/Γ, and some, for E_o, Γ_f, and Γ_n. A Γ_γ of 34 mV was assumed (to be published in *Nucl. Sci. Eng.*).

$\sigma_{nT}(E)$ T. E. Young, F. B. Simpson, and J. R. Berreth. "Neutron Total and Absorption Cross Sections of ^{238}Pu." *Nucl. Sci. Eng. 30*, 355 (1967). MTR transmission measurements were made for highly enriched samples for 0.008 $<E_n<$ 6500 eV with multiple inverse sample thicknesses from 288 to 2520 b/atom. $\sigma_{n\gamma}^{2200}$ (measured) = 559 ±20 b, $\sigma_{n\gamma}^{2200}$ (effective, 1/v) = 532 b, $I_{n\gamma}$ (E_n > 0.5 eV) = 164 ±15 b. 14 positive energy resonances were analyzed for E_o and Γ_n°, with Γ_γ determined from the first 3 resonances. Thermal data were good.

$\sigma_{nf}(E)$ W. F. Stubbins, C. D. Bowman, G. F. Auchampaugh, and M. S. Coops. "Neutron-Induced Resonance Fission Cross Sections of ^{238}Pu." *Phys. Rev. 154*, 1111 (1967). Lawrence Livermore Laboratory (LLL) linac time-of-flight fission chamber measurements were made for samples enriched to 99.88% and plated on both sides of 3 foils (125 $\mu g/cm^2$ on each side) for 2 eV $<E_n<$ 300 eV. 16 resonances were analyzed for E_o, Γ_n°, and Γ_f/Γ.

$\sigma_{nf}(E)$ V. F. Gerasimov, in *Nuclear Data for Reactors, Conference Proceedings, Paris, 17-21, October 1966, Vol. II*, p 129 (in Russian). Fission cross sections were measured from 0.02 to 100 eV. The first 5 resonances were analyzed for E_o and $\sigma_o\Gamma$. Γ_f was determined for the first 3 resonances. Thermal data were good.

Integral Data

σ_{nf} T. A. Eastwood et al. in *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva 16*, 54 (1958). Thermal neutron beam experiments were made with the Chalk River National Research Experiment (NRX) reactor. $\sigma_{nf}^{2200} = 17.1 \pm 0.4$ b; I_{nf} ($E_n > 0.6$ eV) = 25 ±5 b.

$\sigma_{n\gamma}$ J. P. Butler, M. Lounsbury, and J. S. Merritt. "The Neutron Capture Cross Sections for ^{238}Pu, ^{242}Pu, and ^{243}Am in the Thermal and Epicadmium Regions." *Can. J. Phys. 35*, 147 (1957). Reactor irradiations were made on bare and cadmium-covered samples, followed by chemical separation and mass spectrometry. $\sigma_{n\gamma}^{2200} = 403 \pm 8$ b; $I_{n\gamma}$ ($E_n > 0.5$ eV) = 3260 ±280 b (this seems very much too high).

σ_{nf} E. K. Hulet, R. W. Hoff, H. R. Bowman, and M. C. Michel. "Thermal-Neutron Fission Cross Sections for Isotopes of Plutonium, Americium, and Curium." *Phys. Rev. 107*, 1294 (1957). Reactor thermal column fission chamber measurements were made on bare samples enriched to 99.71%. $\sigma_{nf}^{2200} = 18.4 \pm 0.9$ b.

Measurements in Progress or Planned

None known.

PLUTONIUM-242

There is an abundance of both differential and integral data on ^{242}Pu and some very good, high-precision recent measurements. No further work on this nuclide is required in the near future.

Differential Data

$\sigma_{nf}(E)$ G. F. Auchampaugh and C. D. Bowman. "Parameters of the Subthreshold Fission Structure in ^{242}Pu." *Phys. Rev. C7*, 2085 (1973). Transmission measurements were made at the Lawrence Livermore Laboratory over the energy range 600 eV $< E_n <$ 81 keV, and resonances with significant fission widths below 4 keV were analyzed for Γ_n and Γ_f, with Γ_γ assumed to be 30 mV. Parameters are given for 72 resonances.

$\sigma_{nT}(E)$ T. E. Young, F. B. Simpson, and R. E. Tate. "The Low-Energy Total Neutron Cross Section of Plutonium-242." *Nucl. Sci. Eng. 43*, 341 (1971). MTR fast-chopper transmission measurements were made for 99.9% enriched metallic ^{242}Pu samples for 0.0015 eV $< E_n <$ 1 eV. Careful thermal measurements were made.

$\sigma_{nT}(E)$ F. B. Simpson, O. D. Simpson, J. A. Harvey, and N. W. Hill. Private communication (to be published). Oak Ridge Electron Linear Accelerator (ORELA) transmission measurements were made for 15 eV $< E_n <$ 30 keV on the same samples described in the preceeding reference. The samples were cooled to liquid N_2 temperature. Resolved resonances were analyzed to about 500 eV.

$\sigma_{nT}(E)$ T. E. Young and S. D. Reeder. "Total Neutron Cross Section of ^{242}Pu." *Nucl. Sci. Eng. 40*, 389 (1970). MTR fast-chopper transmission measurements were made on $^{242}PuO_2$ samples for 0.0015 eV $< E_n <$ 8 keV. 8 resonances were analyzed for E_o and Γ_n for 2 eV $< E_n <$ 150 eV, and some, for Γ_γ.

$\sigma_{nf}(E)$ G. F. Auchampaugh, J. A. Farrell, and D. W. Bergen. "Neutron-Induced Fission Cross Sections of ^{242}Pu and ^{244}Pu." *Nucl. Phys. A171*, 31 (1971). LASL bomb shot measurements were made on samples enriched to 99.9% in ^{242}Pu with ^6Li and ^{235}U monitors for 20 eV $< E_n <$ 4 MeV. Below 300 eV, fission strength is so weak that fission fragments cannot be seen over capture gammas from the same resonance. Data above 300 eV are very good.

$\sigma_{nT}(E)$ G. F. Auchampaugh, C. D. Bowman, M. S. Coops, and S. C. Fultz. "Neutron Total Cross Section of ^{242}Pu." *Phys. Rev. 146*, 840 (1966). Linac transmission measurements were made for 99.9% enriched $^{242}Pu_2O_3$ samples for 0.02 eV $<E_n<$ 400 eV. 14 resonances were analyzed at <400 eV for E_o and Γ_n.

$\sigma_{nT}(E)$ N. J. Pattenden. *Nuclear Physics Division Progress Report for the Period March 1, 1965 to October 31, 1965.* British Report AERE-PR/NP9, Atomic Energy Research Establishment, Harwell, England, p 10 (1966). Time-of-flight transmission measurements were made for samples enriched to 91% in ^{242}Pu for 4 eV $<E_n<$ 2000 eV. Data were analyzed for E_o and Γ_n° for 17 resonances from 14.6 to 311 eV.

Integral Data

$\sigma_{n\gamma}$ R. W. Durham and F. Molson. "Capture Cross Section of ^{242}Pu." *Can. J. Phys. 48*, 716 (1970). Reactor irradiations were made on bare samples enriched to ∿90% ^{242}Pu. ^{59}Co monitors were used. $\sigma_{n\gamma}^{2200}$ = 18.7 ±0.7 b.

$\sigma_{n\gamma}$ R. L. Folger, J. A. Smith, L. C. Brown, R. F. Overman, and H. P. Holcomb. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, DC, 1968.* NBS Special Publication 299, p 1297 (1968). Reactor activations were made for bare and cadmium-covered samples. ^{59}Co monitors were used. $\bar{\sigma}_a$ = 28 b, I_a (no cutoff given) = 1180 b; inferred σ_a^{2200} = 20 b.

$\sigma_{n\gamma}$ J. Halperin and J. H. Oliver. *Chemistry Division Annual Progress Report for Period Ending June 20, 1964.* USAEC Report ORNL-3679, Oak Ridge National Laboratory, Oak Ridge, Tenn. p 13 (1964). Reactor irradiations were made for 99.9% enriched bare and cadmium-covered ^{242}Pu samples. $\sigma_{n\gamma}^{2200}$ = 24.9 ±4 b; $I_{n\gamma}$ (no cutoff given) = 1280 ±60 b.

$\sigma_{n\gamma}$ J. P. Butler, M. Lounsbury, and J. S. Merritt. "The Neutron Capture Cross Sections of ^{238}Pu, ^{242}Pu, and ^{243}Am in the Thermal and Epicadmium Regions." *Can. J. Phys. 35*, 147 (1957). Reactor irradiations were made for bare and cadmium-covered samples enriched to 90% in ^{242}Pu. $\sigma_{n\gamma}$ = 18.6 ±0.8 b; $I_{n\gamma}$ (E >0.5 eV) = 1275 ±30 b.

Measurements in Progress or Planned

K. H. Böckhoff, private communication. GEEL is currently measuring σ_{nn} and $\sigma_{n\gamma}$ (resonance parameters) to about 3 keV.

R. C. Block, private communication. Renssalear Polytechnic Institute plans a total cross section measurement on ^{242}Pu for 1 eV $<E_n<$ 3 keV and fission and capture cross section measurements for 100 eV $<E_n<$ 60 keV.

AMERICIUM-241

Extensive data, both integral and differential, are available for ^{241}Am, but further work on this isotope would be worthwhile. There are some problems in determining the integral cross sections because of large resonances in the cadmium-cutoff region, a particularly troublesome problem when trying to determine the capture branching ratio to ^{242}Am and its metastable state ^{242m}Am. A desirable measurement would be the determination of the branching ratio as a function of energy. This measurement, however, is beyond the capabilities of current experimental techniques.

Differential Data

$\sigma_{nf}(E)$ P. A. Seeger, A. Hemmendinger, and B. C. Diven. "Fission Cross Sections of ^{241}Am and ^{242m}Am." *Nucl. Phys. A96*, 605 (1967). After a LASL nuclear detonation, time-of-flight measurements were made for 20 eV $< E_n <$ 1 MeV on samples enriched to 98.7%. Cross section curves are given and integrated over resonances. No parametric analysis is given.

$\sigma_{nf}(E)$ V. F. Gerasimov. *Nuclear Data for Reactors, Conference Proceedings, Paris, 17-21 October 1966, Vol. II*, p 129 (1966). Linac fission measurements were made for 0.02 eV $< E_n <$ 50 eV. 15 resonances were analyzed for E_o and Γ_f/Γ. Thermal data are good.

$\sigma_{nf}(E)$ C. D. Bowman, M. S. Coops, G. F. Auchampaugh, and S. C. Fultz. "Subthreshold Neutron-Induced Fission Cross Section of ^{241}Am." *Phys. Rev. 137*, B326 (1965). Lawrence Livermore Laboratory (LLL) linac fission measurements were made for samples enriched to 99.95%. 11 resonances were analyzed for E_o and Γ_f/Γ. One negative resonance was required.

$\sigma_{nT}(E)$ J. A. Harvey, R. C. Block, and G. G. Slaughter. *Physics Division Annual Progress Reports for Periods Ending March 10, 1959, and February 10, 1961.* USAEC Reports ORNL-2718 p 29 (1959) and ORNL-3085 p 42 (1961). ORNL fast-chopper, time-of-flight transmission measurements were made for highly enriched samples of ^{241}AmF (solid) and $^{241}Am(NO_3)_2$ (liquid) for 0.2 eV $< E_n <$ 45 eV. Cross section curves were obtained. Many resonances were analyzed for E_o and $g\Gamma_n^{\circ}$ and some shapes were analyzed for Γ_γ.

$\sigma_{nT}(E)$ Y. B. Adamchuk, et al. *United Nations Conference on Peaceful Uses of Atomic Energy, Geneva, 4,* 216 (1955). Early chopper transmission measurements were made for 0.006 eV $<E_n<$100 eV. Thermal are good. No parametric analysis is given.

Integral Measurements

$\sigma_{n\gamma}$ K. W. MacMurdo, R. M. Harbour, and F. J. McCrosson. *Nucl. Sci. Eng. 50,* 364 (1973). Reactor irradiations were made for highly enriched bare and cadmium-covered samples. $\sigma_{n\gamma}^{2200}$ (to ^{242m}Am) = 83.8 ±2.6 b; $\sigma_{n\gamma}^{2200}$ (to ^{242}Am) = 748 ±20 b; $I_{n\gamma}$ (to ^{242m}Am) (E_n >0.369 eV) = 208 ±18 b; $I_{n\gamma}$ (to ^{242}Am) (E_n >0.369 eV) = 1330 ±117 b.

σ_{nf} M. A. Bak, K. A. Petrzhak, Yu. G. Petrov, Yu. F. Romanov, and E. A. Schlyamin. "Resonance Fission Integrals for Uranium, Plutonium, and Americium Isotopes." *Soviet Atomic Energy 28,* 460 (1970). Reactor dual fission chamber measurements were made for cadmium-covered-enriched samples. ^{235}U monitors were used. I_{nf} (no cutoff given) = 21 ±2 b.

$\sigma_{n\gamma}$ R. P. Schuman. *Reports to the AEC National Cross Section Advisory Committee, Rice Univ., September 1969.* USAEC Report WASH-1136, p 53 (1969). High-flux, cadmium-shielded reactor irradiations were made for enriched samples. ^{59}Co monitors were used (assumed $I_{n\gamma}$ = 74.6 b). $I_{n\gamma}$ (to ^{242m}Am, no cutoff given) = 250 ±40 b; $I_{n\gamma}$ (to ^{242}Am, no cutoff given) = 850 ±60 b.

$\sigma_{n\gamma}$ σ_{nf} M. A. Bak, A. S. Krivokhatskii, Yu. F. Romanov, A. V. Sarokina, and E. A. Shlyamin. *Soviet Atomic Energy 24,* 300 (1968). Reactor burnup measurements were made for enriched samples. Alpha counting was done with ^{147}Au monitors (assumed $\sigma_{n\gamma}^{2200}$ = 98.8 ±0.3 b and $I_{n\gamma}$ = 2300 ±200 b). $\sigma_{n\gamma}^{2200}$ (to ^{242m}Am) = 70 ±5 b, $\sigma_{n\gamma}^{2200}$ (to ^{242}Am) = 670 ±60 b; $I_{n\gamma}$ (to ^{242m}Am, no cutoff given) = 300 ±30 b; $I_{n\gamma}$ (to ^{242}Am, no cutoff given) = 2100 ±200 b; σ_{nf}^{2200} = 3.15 ±0.10 b; I_{nf} (no cutoff given) = 21 ±2 b.

σ_{nf} E. K. Hulet, R. W. Hoff, H. R. Bowman, and M. C. Michel. "Thermal-Neutron Fission Cross Sections for Isotopes of Plutonium, Americium, and Curium." *Phys. Rev. 107,* 1294 (1957). Thermal column measurements were made in the MTR with mixed isotopic samples. σ_{nf}^{2200} = 3.13 ±0.15 b.

Measurements Planned or in Progress

K. M. Böckhoff, private communication. Measurements of σ_{nf} from 1 eV to 2 keV are in progress at the Geel linac.

J. Blons, private communication. Measurements of σ_{nT} in the resonance region and σ_{nf} from 1 eV to several keV are planned at the SACLAY linac.

J. E. Lynn, private communication. Measurements of $\sigma_{n\gamma}$ for 100 eV $<E_n<$100 keV (M. C. Moxon and M. S. Coates) and σ_{nf} for 1 keV $<E_n<$1 MeV (D. B. Gayther) are planned at Harwell.

AMERICIUM-242

Substantial differential and integral data exist for ^{242}Am, but mostly for the fission cross sections of the long-lived (433 yr) isomeric state. The ground state of ^{242}Am decays by beta emission and electron capture with a half-life of 16.02 hours. The isomeric state has the largest fission cross section known and is, therefore, of considerable interest. The data available are reasonably good, but information on the capture cross sections of both states and the fission cross section of the ground state would be valuable.

Differential Measurements

$\sigma_{nf}(E)$ C. D. Bowman, G. F. Auchampaugh, S. C. Fultz, and R. W. Hoff. "Neutron-Induced Fission Cross Section of ^{242m}Am." *Phys. Rev. 166*, 1219 (1968). LLL fission chamber linac measurements were made for samples enriched to 19.8% ^{242m}Am, 79.5% ^{241}Am, and 0.7% ^{243}Am for 0.02 eV $<E_n<$ 6 MeV. Data were normalized to a thermal value of 6600 b at 0.0253 eV. Thermal data were good. 6 resonances were analyzed for E_o, Γ_n, and Γ_f, assuming I_γ = 50 MeV.

$\sigma_{nf}(E)$ S. T. Perkins, G. F. Auchampaugh, R. W. Hoff, and C. D. Bowman. "Average Cross Sections and Resonance Integrals of ^{242m}Am." *Nucl. Sci. Eng. 32*, 131 (1968). LLL linac fission chamber measurements were made on ^{242m}Am, with the same composition as in the reference above. I_{nf} (E_n >0.5 eV) = 1570 ±110 b.

$\sigma_{nf}(E)$ P. A. Seeger, A. Hemmendinger, and B. C. Diven. "Fission Cross Sections of ^{241}Am and ^{242m}Am." *Nucl. Phys. A96*, 605 (1967). LASL Nuclear detonation, time-of-flight measurements were made on enriched samples with 25% ^{242m}Am for 20 eV $<E_n<$ 1 MeV. Cross section curves were obtained for E_o and were analyzed and integrated over resonances. No parametric analysis was given.

Integral Data

σ_{nf} K. Wolfsberg and G. P. Ford. "Thermal-Neutron Fission of ^{242m}Am: Mass and Charge Distribution." *Phys. Rev. C3*, 1333 (1971). Reference below (Wolfsberg, et al.) was revised because of half-life refinement. $T_{½}$ changed from 457.7 yr to 432.7 yr. σ_{nf}^{2200} = 7600 ±300 b.

σ_{nf} R. P. Schuman. *Reports to the AEC Nuclear Cross Sections Advisory Committee, Rice Univ., September 1969.* USAEC Report WASH-1136, p 53 (1969). High-flux, cadmium-shielded reactor irradiations were made for ^{241}Am samples. ^{59}Co monitors were used (assumed $I_{n\gamma}$ = 74.6 b). I_{nf} (^{242m}Am to total destruction) = 7000 ±2000 b.

σ_{nf} M. A. Bak, A. S. Krivokhatskii, K. A. Petrzhak, Yu. G. Petrov, Yu. F. Romana, and E. A. Schlyamin. "Cross Sections and Resonance Integrals for Capture and Fission in Long-Lived Americium Isotopes." *Soviet Atomic Energy 23*, 1059 (1967). Reactor irradiations were made for ^{241}Am and ^{243}Am mixtures; alpha-counting was used. σ_{nf}^{2200} (for ^{242}Am) = 2100 ±200 b; I_{nf} (no cutoff given) = <300 b.

σ_{nf} K. Wolfsberg, G. P. Ford, and H. L. Smith. "Thermal Neutron-Induced Fission Cross Section of ^{242m}Am." *J. Nucl. Energy AB20*, 588 (1966). Dual fission chamber reactor measurements were made of samples of 0.16% ^{242}Cm, 79.44% ^{241}Am, 19.70% ^{242m}Am, and 0.7% ^{243}Am. ^{235}U monitor was used (assumed σ_{nf}^{2200} = 582 ±4 b, f = 0.977). σ_{nf}^{2200} = 7200 ±300 b. (Revised, see reference above.)

Measurements in Progress or Planned

J. C. Browne, private communication. Lawrence Livermore Laboratory plans new fission cross section measurements with ^{242m}Am from thermal energies to the MeV range with the LLL linac.

AMERICIUM-243

The necessary differential and integral data for ^{243}Am are available, and no further work is required at present.

Differential Data

$\sigma_{nT}(E)$ O. D. Simpson, F. B. Simpson, J. A. Harvey, G. G. Slaughter, R. W. Benjamin, and C. E. Ahlfeld. USAEC Report ANCR-1060, Aerojet Nuclear Company, Idaho Falls (1972). ORELA transmission measurements were made for multiple high-purity samples from the cadmium-cutoff to 1000 eV. 238 resonances were analyzed for E_o, Γ_n, and Γ_γ from 0.5 to 250 eV.

$\sigma_{nf}(E)$ P. A. Seeger in: *Fission Cross Sections from Pommard.* USAEC Report LA-4420, Los Alamos Scientific Laboratory, Los Alamos, N. M., p 138 (1970). LASL bomb shot fission data were obtained with a highly purified sample and a ^{235}U monitor for 50 eV $<E_n<$ 3 MeV. Cross section data are presented; no parametric analysis is given.

$\sigma_{nT}(E)$ J. R. Berreth and F. B. Simpson. USAEC Report IN-1407, Idaho Nuclear Corp., Idaho Falls (1970). MTR fast chopper transmission measurements were made on multiple high-purity nuclear samples for 0.01 eV $<E_n<$ 1000 eV. 36 resonances were analyzed for E_o and Γ_n, and some for Γ_γ from -2.00 eV (bound level) to 25 eV.

$\sigma_{nT}(E)$ R. E. Coté, L. M. Bollinger, R. F. Barnes, and H. Diamond. "Slow Neutron Cross Sections of ^{240}Pu, ^{242}Pu, and ^{243}Am." *Phys. Rev. 114,* 505 (1959). Argonne fast chopper transmission measurements were made on samples enriched to ∿99.5% ^{243}Am for 0 eV $<E_n<$ 16 eV. 11 resonances were analyzed for E_o, Γ_n, and some for Γ_γ from 0.9 to 15.3 eV.

Integral Data

$\sigma_{n\gamma}$ S. H. Eberle, H. J. Bleyl, E. Gantner, J. Reinhard, and C. Kruckeberg. KFK-1456, Karlsruhe, West Germany, p 51 (1971). Reactor irradiations were made. $\sigma_{n\gamma}^{2200}$ = 77 ±2 b; $I_{n\gamma}$ (no cutoff given) = 1930 ±50 b.

$\sigma_{n\gamma}$ R. P. Schuman. *Report to the AEC Nuclear Cross Sections Advisory Committee, New York, October 1968.* USAEC Report WASH-1124, p 72 (1968). Reactor irradiations were made for cadmium-covered samples. ^{197}Au and ^{59}Co monitors were used. $I_{n\gamma}$ (total capture, no cutoff given) = 2160 ±100 b; $I_{n\gamma}$ (to 10.1 hr ^{244}Am, no cutoff given) 111 ±15 b.

σ_a R. L. Folger, J. A. Smith, L. C. Brown, R. F. Overman, and H. P. Holcomb in: *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, DC, 1968.* NBS Special Publication 299, Vol. II (1968) p 1279. Reactor activations were made with bare and cadmium-covered samples. σ_a^{eff} = 90 b, I_a (no cutoff given) = 2250 b, inferred σ_a^{2200} = 78 b.

σ_a M. A. Bak, A. S. Krivokhatskii, K. A. Petrzak, Yu. G. Petrov., Yu. F. Romanov, and E. A. Shlyamin. *Atomnaya Energija 23,* 316 (1967). Reactor irradiation studies were made of buildup from ^{241,243}Am samples, both bare and cadmium-covered. The monitor ^{197}Au was used. σ_a^{2200} = 73 ±6 b; $I_{n\gamma}$ (no cutoff given) = 2300 ±200 b.

Measurements in Progress or Planned

None known.

CURIUM-242

Very little data are available for ^{242}Cm, the alpha decay precursor to ^{238}Pu. Only two integral measurements have been performed, and considerably more data on this isotope would be desirable. Measurements will be difficult because of limited sample availability. The half-life, 163 days, is short, and the methods of obtaining a reasonably pure sample are fairly complex. Improved measurements of the ^{243}Cm cross sections might also be required to properly interpret these data.

Differential Data

None available.

Integral Data

$\sigma_{n\gamma}$ R. P. Schuman. *Reports to the AEC Nuclear Cross Sections Advisory Committee, Rice Univ., September 1969*. USAEC Report WASH-1136, p 53 (1969). High-flux, cadmium-shielded ^{241}Am reactor irradiations were made followed by alpha pulse height and mass analysis. $I_{n\gamma}$ (to 32 y ^{243}Cm, no cutoff given) = 150 ±40 b.

σ_{nf} G. C. Hanna, B. G. Harvey, N. Moss, and P. R. Tunnicliffe. "Fission in ^{242}Am." *Phys. Rev. 81,* 893 (1951). Reactor irradiations were made of purified ^{241}Am. $\sigma_{nf}^{2200} \leq 5$ b.

Measurements in Progress or Planned

None known.

CURIUM-243

The isotope ^{243}Cm is not an important participant in either the ^{252}Cf chain or the ^{238}Pu chain; therefore, its cross sections are considerably less important than the other isotopes included in the survey. Both limited integral and differential data exist, however, and there is sufficient information on ^{243}Cm for present requirements. A good measurement of the ^{242}Cm cross sections would probably require more data on ^{243}Cm.

Differential Data

$\sigma_{nf}(E)$ R. R. Fullwood, private communication. LASL bomb shot fission data were obtained for samples enriched to 89% ^{243}Cm for 20 eV $< E_n <$ 1 MeV. Data were converted to cross sections versus energy curves, but the curves have not been analyzed.

$\sigma_{nT}(E)$ J. R. Berreth, F. B. Simpson, and B. C. Rusche. "The Total Neutron Cross Sections of the Curium Isotopes from 0.01 to 30 eV." *Nucl. Sci. Eng. 49*, 145 (1972). Fast-chopper transmission data were obtained for multiple mixed samples. 15 resonances were analyzed for E_0, Γ_n, and Γ_f, assuming Γ_γ = 40 mV, for 1 eV $< E_n <$ 26 eV.

Integral Data

σ_{nf} M. C. Thompson, M. L. Hyder, and R. J. Reuland. "Thermal Neutron Cross Sections and Resonance Integrals for ^{244}Cm through ^{248}Cm." *J. Inorg. Nucl. Chem. 33*, 1553 (1971). Reactor irradiations and radiochemical and mass spectrometry techniques were used for bare and cadmium-covered multiple mixed samples. ^{235}U and ^{59}Co monitors were used. I_{nf} (no cutoff given) = 1860 ±400 b.

σ_{nf} E. K. Hulet, R. W. Hoff, H. R. Bowman, and M. C. Michel. "Thermal Neutron Fission Cross Sections for Isotopes of Plutonium, Americium, and Curium." *Phys. Rev. 107*, 1294 (1957). MTR thermal column fission chamber measurements were made for low enrichment samples. A ^{239}Pu monitor was used. σ_{nf}^{th} = 690 ±50 b.

Work in Progress or Planned

J. C. Browne, private communication. LLL plans fission cross section measurements using the linac with very highly enriched samples if and when sample material becomes available. The measurements are planned over the energy region 0.01 $<E_n<$ 14 MeV but will emphasize the region below 30 eV.

CURIUM-244

Both integral and differential data for ^{244}Cm are abundant and in good agreement. No further work on ^{244}Cm is required at present.

Differential Data

$\sigma_{nT}(E)$ — O. D. Simpson, F. B. Simpson, T. E. Young, J. A. Harvey, and R. W. Benjamin. Private communication (to be published). ORELA transmission measurements were made with highly enriched samples from thermal energies to 530 eV. 36 resonances were analyzed for E_o, Γ_n, Γ_γ, and Γ_f from 0 to 520 eV using, in addition, the data from the reference below.

$\sigma_{nf}(E)$, $\sigma_{n\gamma}(E)$ — M. S. Moore and G. A. Keyworth. "Analysis of the Fission and Capture Cross Sections of the Curium Isotopes." *Phys. Rev. C3*, 1656 (1971). LASL bomb shot capture and fission data were obtained with 98.5% enriched fission samples and 79.2% enriched capture samples for 20 eV $<E_n<$ 3 MeV. Data were analyzed for E_o, Γ_γ, Γ_f, and Γ_n. 67 resonances were analyzed for 22 eV $<E_n<$ 975 eV.

$\sigma_{nT}(E)$ — J. R. Berreth, F. B. Simpson, and B. C. Rusche. "The Total Neutron Cross Sections of the Curium Isotopes from 0.01 to 30 eV." *Nucl. Sci. Eng. 49*, 145 (1972). Fast chopper transmission data were obtained for multiple mixed samples of up to ∿94% ^{244}Cm. 3 resonances were analyzed for E_o, Γ_γ, and Γ_n for 0 $<E_n<$ 30 eV.

$\sigma_{nT}(E)$ — R. E. Coté, R. F. Barnes, and H. Diamond. "Total Neutron Cross Section of ^{244}Cm." *Phys. Rev. 134*, B1281 (1964). Fast chopper transmission data were obtained for multiple mixed samples up to 96.5% ^{244}Cm. Γ_n and Γ_γ were analyzed for 3 resonances; Γ_n, for 12 more assuming Γ_γ = 37 mV. 0 $<E_n<$ 900 eV.

Integral Data

σ_{nf} R. W. Benjamin, K. W. MacMurdo, and J. D. Spencer. "Fission Cross Sections for Five Isotopes of Curium and Californium-249." *Nucl. Sci. Eng. 47*, 203 (1972). Reactor fission chamber measurements were made with multiple bare and cadmium-covered multiple mixed samples of up to 99% enrichment in ^{244}Cm. ^{235}U monitors were used. σ_{nf}^{2200} = 1.1 ±0.5 b; I_{nf} (E_n >0.625 eV) = 18.0 ±1.0 b.

σ_{nf} $\sigma_{n\gamma}$ M. C. Thompson, M. L. Hyder, and R. J. Reuland. "Thermal Neutron Cross Sections and Resonance Integrals for ^{244}Cm through ^{248}Cm." *J. Inorg. Nucl. Chem. 33*, 1553 (1971). Reactor irradiations and radiochemical and mass spectrometry techniques were used for bare and cadmium-covered multiple enriched samples. ^{235}U and Co monitors were used. $\sigma_{n\gamma}^{2200}$ = 14 ±4 b; $I_{n\gamma}$ (E_n >0.625 eV) = 650 ±50 b; σ_{nf}^{2200} = 1.5 ±1.0 b; I_{nf} (E >0.625 eV) = 12.5 ±2.5 b.

$\sigma_{n\gamma}$ R. P. Schuman. *Report to the AEC Nuclear Cross Sections Advisory Committee, Houston, September 1969.* USAEC Report WASH-1136, p 54 (1969). Reactor activations were made for mixed samples with cadmium. I_{nf} (no cutoff given) = 650 ±50 b.

Work in Progress or Planned

None known.

CURIUM-245

Several integral cross section values and two sets of differential data are available for ^{245}Cm. The only limitation is good differential fission data in the thermal and low resonance region. These data could probably be obtained with the quantities of ^{245}Cm now available through measurements at one of the linac facilities.

Differential Measurements

$\sigma_{nf}(E)$ M. S. Moore and G. A. Keyworth. "Analysis of the Fission and Capture Cross Sections of the Curium Isotopes." *Phys. Rev. C3*, 1656 (1971). LASL bomb shot capture and fission data were obtained with fission samples enriched to ∿77% for 20 eV $<E_n<$ 3 MeV. Data were analyzed for E_o, 2 $g\Gamma_n{}^\circ$, and Γ_f with Γ_γ assumed to be 40 eV. 26 resonances were analyzed for 20 eV $<E_o<$ 60 eV.

$\sigma_{nT}(E)$ J. R. Berreth, F. B. Simpson, and B. C. Rusche. "The Total Neutron Cross Sections of the Curium Isotopes from 0.01 to 30 eV." *Nucl. Sci. Eng. 49*, 145 (1972). Fast chopper transmission data were obtained for multiple mixed samples of low ^{245}Cm enrichment. 10 resonances below 30 eV were analyzed for E_o, Γ_n, and Γ_f assuming Γ_γ = 40 mV.

Integral Measurements

σ_{nf} R. W. Benjamin, K. W. MacMurdo, and J. D. Spencer. "Fission Cross Sections for Five Isotopes of Curium and Californium-249." *Nucl. Sci. Eng. 47*, 203 (1972). Reactor fission chamber and track counter measurements were made for multiple bare and cadmium-covered samples of 77% enrichment ^{245}Cm. ^{235}U monitors were used. σ_{nf}^{2200} = 2018 ±37 b, I_{nf} (E_n >0.625 eV) = 772 ±40 b.

$\sigma_{n\gamma}$
σ_{nf} M. C. Thompson, M. L. Hyder, and R. J. Reuland. "Thermal Neutron Cross Sections and Resonance Integrals for ^{244}Cm through ^{248}Cm." *J. Inorg. Nucl. Chem. 33*, 1553 (1971). Reactor irradiations and radiochemical and mass spectrometry techniques were used for bare and cadmium-covered multiple enriched samples. ^{235}U and Co monitors were used. $\sigma_{n\gamma}^{2200}$ = 360 ±50 b. $I_{n\gamma}$ (E_n >0.625 eV) = 110 ±20 b. σ_{nf}^{2200} = 2030 ±200 b. I_{nf} (E_n >0.625 eV) = 750 ±150 b.

σ_{nf} J. Halperin, J. H. Oliver, and R. W. Stoughton. *Chemistry Division Annual Progress Report for Period Ending May 20, 1970.* USAEC Report ORNL-4581, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 37 (1970). Reactor irradiations were made for bare and cadmium-covered mixed samples of ∿77% ^{245}Cm and 23% ^{244}Cm. ^{197}Au monitors were used. σ_{nf}^{2200} = 1920 ±180 b; I_{nf} = 1100 ±100 b. Note: I is incorrect because the sample holder under the cadmium covers was hydrogenous.

$\sigma_{n\gamma}$ J. Halperin, R. E. Druschel, and R. E. Eby. *Chemistry Division Annual Progress Report for Period Ending May 20, 1969.* USAEC Report ORNL-4437, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 20 (1969). Reactor activations were made for bare and cadmium-covered samples enriched to ∿77% ^{245}Cm. ^{59}Co monitors were used. $\sigma_{n\gamma}^{2200}$ = 340 ±20 b; $I_{n\gamma}$ (E >0.54 eV) = 101 ±8 b.

σ_{nf} H. Diamond, J. J. Hines, R. K. Sjoblom, R. F. Barnes, D. N. Metta, J. L. Lerner, and P. R. Fields. "Fission Cross-Sections for ^{243}Pu, ^{250}Bk, ^{247}Cm, ^{245}Cm, ^{254m}Es, and ^{254}Es, and Odd-Odd Systematics." *J. Inorg. Nucl. Chem. 30,* 2553 (1968). Reactor thermal column fission chamber measurements were made for samples with an enrichment purity of ∿13%. ^{235}U monitors were used. No account was taken of epithermal neutrons. σ_{nf}^{th} = 2040 ±80 b.

σ_{nf} E. K. Hulet, R. W. Hoff, H. R. Bowman, and M. C. Michel. "Thermal-Neutron Fission Cross Sections for Isotopes of Plutonium, Americium, and Curium." *Phys. Rev. 107,* 1294 (1957). MTR thermal column fission chamber measurements were made for samples enriched to 1.62 ±0.01%. ^{239}Pu monitors were used. σ_{nf} = 1880 ±150 b.

Measurements in Progress or Planned

J. C. Browne, private communication. LLL plans fission cross section measurements using the linac with very highly enriched samples if and when sample material becomes available. The measurements are planned over the energy region 0.01 eV $<E_n<$14 MeV but will emphasize the region below 30 eV.

CURIUM-246

Both differential and integral data are available for ^{246}Cm, and the quality of the data is sufficient for a reasonable evaluation. The known details of the cross section, although very limited in the thermal region, are well described by the Breit-Wigner single-level formula using the available resonance parameters. More data in the thermal and resonance regions below 20 eV would be useful, but will be difficult to measure because of the very limited amount of material available and the small cross section in the thermal region.

Differential Data

$\sigma_{nf}(E)$
$\sigma_{n\gamma}(E)$ M. S. Moore and G. A. Keyworth. "Analyses of the Fission and Capture Cross Sections of the Curium Isotopes." *Phys. Rev. C3*, 1656 (1971). LASL bomb shot fission and capture data were obtained for 95% enriched fission samples and 16% enriched capture samples for 20 eV <E <3 MeV. Data were analyzed for E_o, Γ_n, and Γ_f, with Γ_γ assumed = 37 meV; 8 resonances were analyzed for 80 eV $<E_o$ <390 eV.

$\sigma_{nT}(E)$ J. R. Berreth, F. B. Simpson, and B. C. Rusche. "The Total Neutron Cross Sections of the Curium Isotopes from 0.01 to 30 eV." *Nucl. Sci. Eng. 49*, 145 (1972). MTR fast chopper transmission data were obtained for multiple mixed samples of low enrichment. Two resonances were analyzed for Γ_n assuming Γ_γ = 35 meV for E_n below 30 eV.

$\sigma_{nT}(E)$ R. E. Coté, R. F. Barnes, and H. Diamond. "Total Neutron Cross Section of ^{244}Cm." *Phys. Rev. 134*, B1281 (1964). Argonne fast chopper transmission data were obtained for mixed samples (mostly ^{244}Cm). 3 resonances were resolved and analyzed for Γ_n.

Integral Data

σ_{nf} R. W. Benjamin, K. W. MacMurdo, and J. D. Spencer. "Fission Cross Sections for Five Isotopes of Curium and Californium-249." *Nucl. Sci. Eng. 47*, 203 (1972). Reactor fission chamber measurements were made for multiple bare and cadmium-covered samples of ^{246}Cm (enrichments to 95%). ^{235}U monitors were used. σ_{nf}^{2200} = 0.17 ±0.10 b; I_{nf} (E_n >0.625 eV) = 10.0 ±0.4 b.

$\sigma_{n\gamma}$ σ_{nf} M. C. Thompson, M. L. Hyder, and R. J. Reuland. "Thermal Neutron Cross Sections and Resonance Integrals for ^{244}Cm through ^{248}Cm." *J. Inorg. Nucl. Chem. 33*, 1553 (1971). Reactor irradiations, bare and cadmium-covered radiochemical and mass spectrometry techniques were used on multiple samples of up to 94.66% enrichment. ^{235}U and ^{59}Co monitors were used. $\sigma_{n\gamma}^{2200}$ = 1.5 ±0.5 b; $I_{n\gamma}$ (no cutoff given) = 84 ±15 b. σ_{nf}^{2200} and I_{nf} are low.

$\sigma_{n\gamma}$ J. Halperin, R. E. Druschel, and R. E. Eby. *Chemistry Division Annual Progress Report for Period Ending May 20, 1969.* USAEC Report ORNL-4437, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 20 (1969). Reactor activations were made for bare and cadmium-covered highly enriched (∿97%) samples. ^{235}U and ^{59}Co monitors were used. $\sigma_{n\gamma}^{2200}$ = 1.2 ±0.4 b; $I_{n\gamma}$ (E_n >0.54 eV) = 121 ±7 b.

$\sigma_{n\gamma}$ R. P. Schuman. *Report to the AEC Nuclear Cross Sections Advisory Committee, Houston, September 1969.* USAEC Report WASH-1136 p 54 (1969). Reactor activations were made for cadmium-covered, low-enrichment mixed samples. $I_{n\gamma}$ (no cutoff given) = 110 ±40 b.

Measurements in Progress or Planned

None known.

CURIUM-247

Limited differential and integral data are available for ^{247}Cm. More data, particularly below 30 eV, would be desirable, but this isotope is available in such small quantities and such low enrichments that new measurements will be very difficult. Fission data should be attainable below about 30 to 40 eV, however, and these measurements are planned for the LLL linac if sufficient high-purity sample becomes available.

Differential Data

$\sigma_{nf}(E)$ M. S. Moore and G. A. Keyworth. "Analyses of the Fission and Capture Cross Sections of the Curium Isotopes." *Phys. Rev. C3*, 1656 (1971). LASL bomb shot fission and capture data were obtained for 21% enriched fission samples and mixed capture samples (predominantly ^{244,246}Cm) for 20 eV $<E<$ 3 MeV. No capture resonances were observed; fission data were analyzed for Γ_f and Γ_n assuming Γ_γ. 29 resonances were resolved for 20 eV $<E_o<$ 60 eV.

Integral Data

σ_{nf} R. W. Benjamin, K. W. MacMurdo, and J. D. Spencer. "Fission Cross Sections for Five Isotopes of Curium and Californium-249." *Nucl. Sci. Eng. 47*, 203 (1972). Reactor fission chamber and track counter measurements were made for bare and cadmium-covered multiple samples enriched to ∿22%. ^{235}U monitors were used. σ_{nf}^{2200} = 82 ±5 b; I_{nf} (E >0.625 eV) = 778 ±50 b.

σ_{nf} $\sigma_{n\gamma}$ M. C. Thompson, M. L. Hyder, and R. J. Reuland. "Thermal Neutron Cross Sections and Resonance Integrals for ^{244}Cm through ^{248}Cm." *J. Inorg. Nucl. Chem. 33*, 1553 (1971). Reactor irradiations and bare and cadmium-covered radiochemical and mass spectrometry techniques were used for multiple enriched samples. ^{235}U and ^{59}Co monitors were used. $\sigma_{n\gamma}^{2200}$ = 60 ±30 b; I_c (no cutoff given) = 800 ±400 b; σ_{nf}^{2200} = 100 ±50 b; I_{nf} (no cutoff given) = 935 ±190 b.

σ_{nf} J. Halperin, J. H. Oliver, and R. W. Stoughton. *Chemistry Division Annual Progress Report for Period Ending May 20, 1970*. USAEC Report ORNL-4581, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 37 (1970). Reactor irradiations and track counting were used for mixed curium samples enriched to 22% ^{247}Cm. Au monitors were used. σ_{nf}^{2200} = 120 ±12 b; I_{nf} (no cutoff given) = 1060 ±110 b. Note: I is incorrect because the sample positioned under the cadmium covers was hydrogenous.

σ_{nf} H. Diamond, J. J. Hines, R. K. Sjoblom, R. F. Barnes, D. N. Metta, J. L. Lerner, and P. R. Fields. "Fission Cross-Sections for ^{243}Pu, ^{250}Bk, ^{247}Cm, ^{245}Cm, ^{254m}Es, and ^{254}Es, and Odd-Odd Systematics." *J. Inorg. Nucl. Chem. 30*, 2553 (1968). Reactor thermal column fission chamber measurements were made for samples of 14% enrichment. ^{235}U monitors were used. No account was taken of epithermal neutrons. σ_{nf}^{th} = 108 ±5 b.

σ_{nf} J. A. Smith, C. J. Banick, R. L. Folger, H. P. Holcomb, and I. B. Richter. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1285 (1968). A reactor production study was made using a ^{242}Pu sample in a highly thermalized spectrum. $\bar{\sigma}_a$ = 457 b; $\bar{\sigma}_{nf}$ = 409 b

Measurements in Progress or Planned

J. C. Browne, private communication. LLL plans fission cross section measurements on the linac using highly purified samples, if and when sample material becomes available. These measurements will be for 0.01 eV <E_n <14 MeV, but will emphasize the region below 20 eV.

CURIUM-248

Limited differential and integral data are available for ^{248}Cm, a very important link in the ^{252}Cf chain. Capture data for this nuclide are of particular interest because it precedes ^{249}Cm, which is the precursor of the beta decay link to the californium isotopes. Differential fission and limited capture data exist from a LASL bomb shot for $E_n > \sim 20$ eV; a cooperative total cross section measurement by SRL and ORNL has been completed, and the data are being analyzed. Good integral fission data have been taken, but the integral capture data are sparse and not consistent. Of all the isotopes in the ^{252}Cf chain, ^{248}Cm is the most important for precision thermal and resonance cross section measurements at this time.

Differential Measurements

$\sigma_{nT}(E)$ R. W. Benjamin, C. E. Ahlfeld, J. A. Harvey, and N. W. Hill. "The Neutron Total Cross Section of ^{248}Cm." (to be submitted for publication). ORELA transmission measurements were made for multiple 97% enriched samples cooled to liquid nitrogen temperatures from thermal energies to 3 keV. Resonances are being analyzed for the E_o, Γ_γ, and Γ_n from the first resonance at 7.25 eV to $\sim$1.5 keV.

$\sigma_{n\gamma}(E)$
$\sigma_{nf}(E)$ M. S. Moore and G. A. Keyworth. "Analyses of the Fission and Capture Cross Sections of the Curium Isotopes." *Phys. Rev. C3*, 1656 (1971). LASL bomb shot fission and capture data were obtained for high-purity fission samples and mixed ^{244,246}Cm capture samples for 20 eV $<E<$ 3 MeV. 8 resonances were analyzed for fission; 3 resonances were analyzed for capture. Capture data were not very useful.

Integral Data

σ_{nf} R. W. Benjamin, K. W. MacMurdo, and J. D. Spencer. "Fission Cross Sections for Five Isotopes of Curium and Californium-249." *Nucl. Sci. Eng. 47*, 203 (1972). Reactor fission chamber and track-counter measurements were obtained for bare and cadmium-covered multiple samples of up to 96% enrichment. ^{235}U monitors were used. $\sigma_{nf}^{2200} = 0.34 \pm 0.07$ b; I_{nf} ($E > 0.625$ eV) = 13.2 ± 0.8 b.

$\sigma_{n\gamma}$ σ_{nf} M. C. Thompson, M. L. Hyder, and R. J. Reuland. "Thermal Neutron Cross Sections and Resonance Integrals for ^{244}Cm through ^{248}Cm." *J. Inorg. Nucl. Chem.* *33*, 1553 (1971). Reactor irradiations and bare and cadmium-covered radiochemical and mass spectrometry techniques were used for multiple enriched samples. ^{235}U and Co monitors were used. $\sigma_{n\gamma}^{2200} = 3 \pm 1$ b; $I_{n\gamma}$ (no cutoff given) = 275 ±75 b. σ_{nf}^{2200} and I_{nf} are low.

σ_a J. A. Smith, C. J. Banick, R. L. Folger, H. P. Holcomb, and I. B. Richter. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1285 (1968). A reactor production study was made using a ^{242}Pu sample in a highly thermalized spectrum. $\bar{\sigma}_a = 5.4$ b.

$\sigma_{n\gamma}$ A. Chetham-Strode, R. E. Druschel, J. Halperin, and R. J. Silva. *Chemistry Division Annual Report for Period Ending May 20, 1965.* USAEC Report ORNL-3832, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 1 (1965). Reactor irradiations were made for bare and cadmium-covered enriched samples (∿95%). ^{56}Mn monitors and beta counting were used. $\sigma_{n\gamma}^{2200} = 7.2 \pm 2$ b; $I_{n\gamma}$ (E >0.54 eV) = 350 ±40 b.

$\sigma_{n\gamma}$ T. A. Eastwood and R. P. Schuman. "Curium-249." *J. Inorg. Nucl. Chem.* *6*, 261 (1958). Reactor irradiations were made of mixed curium for half-life measurements. $\sigma_{n\gamma}^{eff} \simeq 6$ b.

$\sigma_{n\gamma}$ K. W. MacMurdo. "The Thermal Neutron Capture Cross Section and Capture Resonance Integral of ^{248}Cm." (submitted to *Nucl. Sci. Eng.*). Reactor activation measurements have been made at SRL using 97.64% enriched sample material and the cadmium difference technique. ^{59}Co monitors were used.

Measurements in Progress or Planned

J. Halperin, private communication. Corroboration of the Chetham-Strode integral results is planned for the near future.

BERKELIUM-249

Very limited integral data are available for ^{249}Bk. Bomb-shot measurements have been made by LASL, but the data are not yet available. These cross sections are relatively less important for production forecasts because the capture cross section is very large.

Differential Data

$\sigma_{n\gamma}$ M. E. Ennis, private communication. LASL bomb-shot fission data for $E_n \geq 20$ eV may be analyzed in the future. Data will be available in the near future.

Integral Data

σ_a R. L. Folger, J. A. Smith, L. C. Brown, R. F. Overman, and H. P. Holcomb. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1279 (1968). Reactor activations were made for bare and cadmium-covered samples. ^{59}Co monitors were used. $\sigma_a^{eff} = 1150$ b; I_a ($>\sim 0.5$ eV) = 1240 b; inferred $\sigma_a^{2200} = 1400$ b.

$\sigma_{n\gamma}$ L. B. Magnusson, M. H. Studier, P. R. Fields, C. M. Stevens, J. F. Mech, A. M. Friedman, H. Diamond, and J. R. Huizenga. "Berkelium and Californium Isotopes Produced in Neutron Irradiation of Plutonium." *Phys. Rev. 96*, 1576 (1954). Reactor irradiations were made in MTR to provide rough cross sections. $\sigma_{n\gamma}^{Pile} \cong 350$ b.

$\sigma_{n\gamma}$ B. G. Harvey, H. P. Robinson, S. G. Thompson, A. Ghiorso, and G. R. Choppin. "Some Pile Neutron Cross Sections of Isotopes of Americium, Berkelium, Californium, and Element 99." *Phys. Rev. 95*, 581 (1954). Crude, early burn-up measurements were made at MTR. $\sigma_{n\gamma}^{Pile} = 1100 \pm 300$ b.

Measurements in Progress or Planned

J. C. Browne, private communication. LLL plans fission cross section measurements on the linac using highly purified samples if and when sample material becomes available. Measurements are to range 0.01 eV $< E_n <$ 14 MeV, but the region below 20 eV will be emphasized.

CALIFORNIUM-249

Considerable effort has been put into cross section measurements on ^{249}Cf, and both differential and integral measurements are available. Upon completion of the analysis of the most recent ORNL data, any requirement for future measurements will be clearer. This nuclide is not directly in the ^{252}Cf chain and is significant only to the extent of the ^{249}Bk beta decay.

Differential Data

$\sigma_{nf}(E)$ J. T. Dabbs, private communication. Electron linac measurements have been made of $\sigma_f(E)$ for 0.3 eV $<E_n$ <1.5 MeV. See "Measurements in Progress or Planned" and preliminary report in ORNL-4791, p 27. Final results are expected about mid-1973.

$\sigma_{nf}(E)$ M. G. Silbert, private communication. (to be published in *Phys. Rev. C*). Nuclear detonation measurements were made of $\sigma_{nf}(E)$ for 13 eV $<E_n<3$ MeV on a 101-μg sample of ∿100% ^{249}Cf. Reich-Moore fitting of cross section data was used to extract E_o, Γ_n°, and Γ_f for 3 resonances from 16 eV to 70 eV.

Integral Data

σ_{nf} R. W. Benjamin, K. W. MacMurdo, and J. D. Spencer. "Fission Cross Sections for Five Isotopes of Curium and Californium-249." *Nucl. Sci. Eng. 47*, 203 (1972). Reactor fission chamber and track-counter measurements were made for high-purity, bare, and cadmium-covered samples. σ_{nf}^{2200} = 1660 ±50 b; I_{nf} (E >0.625 eV) = 2114 ±70 b.

$\sigma_{n\gamma}$ J. Halperin, C. E. Bemis, Jr., R. E. Druschel, and R. E. Eby. *Chemistry Division Annual Progress Report for Period Ending May 20, 1971.* USAEC Report ORNL-4706, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 47 (1971). Reactor irradiations were made of pure $^{249,250}Cf$. Mass spectrometric isotopic ratio determinations were made for bare and cadmium-covered samples. ^{59}Co monitors were used. $\sigma_{n\gamma}^{2200}$ = 478 ±25 b; $I_{n\gamma}$ (>∿0.5 eV) = 765 ±35 b.

σ_{nf} J. Halperin, J. H. Oliver, and R. W. Stoughton. *Chemistry Division Annual Report for Period Ending May 20, 1970.* USAEC Report ORNL-4581, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 37 (1970). Reactor irradiations and track counting were used for bare and cadmium-covered samples of high purity. ^{197}Au monitors were used. σ_{nf}^{2200} = 1690 ±160 b; I_{nf} (no cut-off given) = 2940 ±280 b. The resonance integral is incorrect because moderating polyethylene foil holders were used inside the cadmium covers.

σ_{nf} D. Metta, H. Diamond, R. F. Barnes, J. Milsted, J. Gray, Jr., D. J. Henderson, and C. M. Stevens. "Nuclear Constants of Nine Transplutonium Nuclides." *J. Inorg. Nucl. Chem. 27,* 33 (1965). Fission chamber measurements in CP-5 thermal column were made for pure ^{249}Cf samples, normalized to ^{233}U. σ_{nf}^{2200} = 1735 ±70 b.

Measurements in Progress or Planned

J. T. Dabbs, private communication. John Dabbs and others at ORNL have recently completed measurements of $\sigma_{nf}(E)$ for 0.3 eV $<E<$1.5 MeV at ORELA. These data are currently being analyzed and should provide substantial information in the low energy region. Initial results indicate that the first resonance is at about 0.7 eV, is very large ($\Gamma_f \gtrsim$150 mV), and absorbs ∿75% of the total events. The peak cross section σ_f is 5000 b.

CALIFORNIUM-250

Only limited integral and burn-up data are available for ^{250}Cf, and these data are inconsistent. Additional careful cadmium-difference measurements would be useful. These measurements would be difficult, however, because of the very limited amount of material available.

Differential Data

None.

Integral Data

$\sigma_{n\gamma}$ J. Halperin, C. E. Bemis, Jr., R. E. Druschel, and R. E. Eby. *Chemistry Division Annual Report for Period Ending May 20, 1971.* USAEC Report ORNL-4706, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 47 (1971). Reactor irradiations were made for samples of pure $^{249,250}Cf$. Mass spectrometric isotopic ratio determinations were made on bare and cadmium-covered samples. ^{59}Co monitors were used. $\sigma_{n\gamma}^{th} = 2030 \pm 200$ b; $I_{n\gamma}$ ($>\sim 0.5$ eV) = 11,600 ±500 b.

σ_a J. A. Smith, C. J. Banick, R. L. Folger, H. P. Holcomb, and I. B. Richter. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1285 (1968). Reactor production studies were made with a ^{242}Pu sample in a highly thermalized spectrum. $\bar{\sigma}_a = 1090$ b.

σ_a R. L. Folger, J. A. Smith, L. C. Brown, R. F. Overman, and H. P. Holcomb. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1279 (1968). Reactor activations were made for bare and cadmium-covered samples. $\sigma_a^{eff} = 1250$ b; I_a (>0.5 eV) = 5300 b; inferred $\sigma_a^{2200} = 1250$ b.

$\sigma_{n\gamma}$ L. B. Magnusson, M. H. Studier, P. R. Fields, C. M. Stevens, J. F. Mech, A. M. Friedman, H. Diamond, and J. R. Huizenga. "Berkelium and Californium Isotopes Produced in Neutron Irradiation of Plutonium." *Phys. Rev. 96*, 1576 (1954). Reactor irradiations were made in the MTR to provide rough values. $\sigma_{n\gamma}^{Pile} = 1500$ b.

Measurements in Progress or Planned

None known.

CALIFORNIUM-251

Only integral and burn-up data exist for ^{251}Cf, and these data are contradictory. In spite of the relatively long half-life of ^{251}Cf (892 y), only a very small quantity (around 10 μg) of reasonably pure material is available.

Differential Data

None.

Integral Data

$\sigma_{n\gamma}$ J. Halperin, C. E. Bemis, Jr., R. E. Druschel, R. D. Baybarz, and R. E. Eby. *Chemistry Division Annual Report for Period Ending May 20, 1971.* USAEC Report ORNL-4706, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 46 (1971). Reactor irradiations were made of pure ^{249,250}Cf. Mass spectrometric isotopic ratio determinations were made for bare and cadmium-covered samples. ^{59}Co monitors were used. $\sigma_{n\gamma}^{th}$ = 2850 ±150 b and $I_{n\gamma}$ (>∼0.5 eV) = 1600 ±30 b. Also, σ_a^{eff} ≃6900 ±1380 b and $\sigma_{n\gamma}^{eff}$ = 3022 ±150 b, with activation measurement, chemical separation, and alpha counting, I_a ≅7000 b ±50%, $I_{n\gamma}$ = 1620 ±100 b.

σ_{nf} D. Metta, H. Diamond, R. F. Barnes, J. Milsted, J. Gray, Jr., D. J. Henderson, and C. M. Stevens. "Nuclear Constants of Nine Transplutonium Nuclides." *J. Inorg. Nucl. Chem. 27*, 33 (1965). Fission chamber measurements were made in the CP-5 thermal column for mixed californium samples. Data were normalized to ^{239}Pu. σ_{nf}^{2200} = 3000 ±260 b.

$\sigma_{n\gamma}$ σ_{nf} J. A. Smith, C. J. Banick, R. L. Folger, H. P. Holcomb, and I. B. Richter. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1285 (1968). Reactor production study was made in a highly thermalized spectrum with a bare ^{242}Pu sample. $\bar{\sigma}_a$ = 4970 b; $\bar{\sigma}_{nf}$ = 3550 b.

σ_a R. L. Folger, J. A. Smith, L. C. Brown, R. F. Overman, and H. P. Holcomb. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1279 (1968). Reactor activations were made for bare and cadmium-covered samples. σ_a^{eff} = 5300 b; I_a (>∼0.5 eV) = 980 b; inferred σ_a^{2200} = 6600 b.

$\sigma_{n\gamma}$ L. B. Magnusson, M. H. Studier, P. R. Fields, C. M. Stevens, J. F. Mech, A. M. Friedman, H. Diamond, and J. R. Huizenga. "Berkelium and Californium Isotopes Produced in Neutron Irradiation of Plutonium." *Phys. Rev. 96*, 1576 (1954). Reactor irradiations were made in the MTR to provide rough values. $\sigma_{n\gamma}^{Pile} = 3000$ b.

Measurements in Progress or Planned

G. A. Keyworth, private communication. In the Spring of 1974, G. A. Keyworth and C. E. Bemis, Jr., plan to make differential fission measurements on ^{251}Cf with a LASL nuclear detonation from about 5 eV to several keV. The measurements will be made in a downhole location to permit such a low initial energy.

CALIFORNIUM-252

There are good differential fission data from 20 eV to 5 MeV from which fission resonance parameters have been extracted in the energy region from 20 to 984 eV. Integral thermal and resonance measurements include one preliminary fission measurement and two consistent capture measurements. No measurements are known to be in progress or planned. Low-energy differential measurements would be useful but are not crucial. These measurements would be difficult because of the spontaneous fission background.

Differential Data

$\sigma_{nf}(E)$ M. S. Moore, J. H. McNally, and R. D. Baybarz. "Neutron-Induced Fission Cross Section of ^{252}Cf." *Phys. Rev. C4*, 273 (1971). Bomb shot measurements were made of $\sigma_f(E)$ for 20 eV to 5 MeV; $\frac{1}{2}\pi\sigma_o\Gamma_f$ was deduced from 24 eV to 984 eV (35 resonances), I_{nf} (>20 eV) = 65 ±6 b.

Integral Data

σ_{nf} J. Halperin, J. H. Oliver, and R. W. Stoughton. *Chemistry Division Annual Report for Period Ending May 20, 1971.* USAEC Report ORNL-4706, Oak Ridge National Laboratory, Oak Ridge, Tenn., p 53 (1971). Fission-track measurements were made in the ORNL Research Reactor (ORR) for bare and cadmium-covered samples. Data were normalized to ^{197}Au and ^{56}Mn. σ_{nf}^{eff} = 35 ±4 b; I_{nf} = 110 ±30 b; inferred σ_{nf}^{2200} = 32 ±4 b.

$\sigma_{n\gamma}$ S. H. Eberle, J. Reinhardt, E. Gantner, Ch. Kruckeberg. KFK-1338, Karlsruhe, West Germany (1971). Reactor activations were made for bare and cadmium-covered samples. $\sigma_{n\gamma}^{2200}$ = 20 ±1.5 b. $I_{n\gamma}$ (no cutoff given) = 40 ±4 b.

$\sigma_{n\gamma}$ J. Halperin, C. E. Bemis, Jr., R. E. Druschel, and J. R. Stokely. "The Thermal-Neutron Capture Cross Section and Resonance Integral of ^{252}Cf." *Nucl. Sci. Eng. 37*, 228 (1969). Reactor activations were made for bare and cadmium-covered samples. $\sigma_{n\gamma}^{2200}$ = 20.4 ±2 b; $I_{n\gamma}$ (>0.54 eV) = 43.5 ±3 b.

$\sigma_{n\gamma}$ R. L. Folger, J. A. Smith, L. C. Brown, R. F. Overman, and H. P. Holcomb. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1279 (1968). Reactor activations were made for bare and cadmium-covered samples. $\sigma_a^{eff} = 7.4$ b; I_a (no cutoff given) = 42 b; inferred $\sigma_a^{2200} = 8.6$ b.

Measurements in Progress or Planned

None known.

CALIFORNIUM-253

Only two cross section measurements of ^{253}Cf have been reported. The more reliable is the measurement of Bemis, et al., which established reasonable effective absorption and capture cross sections. Integral measurements of the thermal cross section and the resonance integral would be very desirable. Material availability may be a serious problem since the half-life of ^{253}Cf is only 17.8 days.

Differential Measurements

None.

Integral Measurements

$\sigma_{n\gamma}$ C. E. Bemis, Jr., R. E. Druschel, and J. Halperin. "Effective Capture and Fission Cross Sections for Californium-253." *Nucl. Sci. Eng. 41,* 146 (1970). Reactor irradiations were made in the ORR for mixed samples of 40% ^{253}Cf and 60% ^{252}Cf. Determined $\sigma_{n\gamma}^{eff} = 17.6 \pm 1.8$ b; implied $\sigma_{abs}^{eff} = 2550 \pm 400$ b.

σ_a J. A. Smith, C. J. Banick, R. L. Folger, H. P. Holcomb, and I. B. Richter. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1285 (1968). Reactor production studies were made for a highly thermalized spectrum from a bare ^{242}Pu sample. $\sigma_{abs} = 165$ b.

Measurements in Progress or Planned

None.

CALIFORNIUM-254

Only one integral experiment has been done on this nuclide, and it was a very early measurement. More extensive data would be interesting, although not crucial, and the material is available only in very small quantities.

Differential Data

None.

Integral Data

$\sigma_{n\gamma}$ B. G. Harvey, H. P. Robinson, S. G. Thompson, A. Ghiorso, and G. R. Choppin. "Some Pile Neutron Cross Sections of Isotopes of Americium, Berkelium, Californium, and Element 99." *Phys. Rev. 95*, 581 (1954). Crude, early burn-up measurements were made at the MTR. $\sigma_{n\gamma}^{Pile}$ <2 b.

Measurements in Progress or Planned

None known.

EINSTEINIUM-253

Only integral data are available for ^{253}Es, and all are capture measurements. More extensive data are not crucial and would be difficult to obtain because of the very small amount of material available.

Differential Data

None.

Integral Data

$\sigma_{n\gamma}$ R. M. Harbour and K. W. MacMurdo. Submitted to *J. Inorg. Nucl. Chem.* Reactor activations were made with bare and cadmium-covered samples. Data were normalized to ^{59}Co. $\sigma_{n\gamma}^{2200}$ (to ^{254}Es) = 155 ±20 b; $\sigma_{n\gamma}^{2200}$ (to ^{254g}Es) <3 b; $I_{n\gamma}$ (to ^{254m}Es, >0.421 eV) = 3009 ±168 b; $I_{n\gamma}$ (to ^{254g}Es, >0.421 eV) = 4299 ±218 b.

σ_a R. L. Folger, J. A. Smith, L. C. Brown, R. F. Overman, and H. P. Holcomb. *Neutron Cross Sections and Technology, Proceedings of a Conference, Washington, D. C., 1968.* NBS Special Publication 299, Vol. II, p 1279 (1968). Reactor activations were made for bare and cadmium-covered samples. Data were normalized to ^{59}Co. σ_a^{eff} = 200 b. I_a (no cutoff given) = 3600 b; inferred σ_a^{2200} = 130 b.

$\sigma_{n\gamma}$ P. R. Fields, H. Diamond, A. M. Friedman, J. Milsted, J. L. Lerner, R. F. Barnes, R. K. Sjoblom, D. N. Metta, and E. P. Horwitz. "Some New Properties of ^{254}Es and ^{255}Es." *Nucl. Phys. A96*, 440 (1967). Reactor activations were made for bare samples. Data were normalized to ^{59}Co. $\sigma_{n\gamma}^{Pile}$ (to ^{254g}Es) = 13 b.

Measurements in Progress or Planned

None known.

EINSTEINIUM-254

Only integral data are available for ^{254}Es, and all are fission measurements. The useful measurements include two consistent thermal cross sections, one thermal cross section for ^{254m}Es, and one resonance integral. Further data are not crucial and would be difficult to obtain because of the very small amount of ^{254}Es available.

Differential Data

None.

Integral Data

σ_{nf} K. W. MacMurdo and R. M. Harbour. *J. Inorg. Nucl. Chem.*, *34*, 449 (1972). Fission-track measurements were made in the Savannah River Standard Pile (SP) reactor for bare and cadmium-covered samples. Data were normalized to ^{249}Cf. σ_{nf}^{2200} = 2830 ±130 b; I_{nf} (>0.421 eV) = 2200 ±90 b.

σ_{nf} H. Diamond, J. J. Hines, K. K. Sjoblom, R. F. Barnes, D. N. Metta, J. L. Lerner, and P. R. Fields. "Fission Cross Sections for ^{243}Pu, ^{250}Bk, ^{247}Cm, ^{245}Cm, ^{254m}Es, and Odd-Odd Systematics." *J. Inorg. Nucl. Chem. 30*, 2553 (1968). Fission chamber measurements were made in a reactor thermal column with bare and cadmium-covered samples. Data were normalized to ^{235}U. σ_{nf}^{2200} (^{254}Es) = 3060 ±180 b. σ_{nf}^{2200} (^{254m}Es) = 1840 ±80 b.

σ_{nf} σ_n R. P. Schuman, T. A. Eastwood, H. G. Jackson, and J. P. Butler. "The Half-Life, Neutron Capture, and Fission Cross Sections of Long-Lived Einsteinium-254." *J. Inorg. Nucl. Chem. 6*, 1 (1958). Reactor burnup measurements were made with low precision. σ_{nf}^{eff} (^{254}Es) = 2700 ±600 b; $\sigma_{n\gamma}^{eff} \leq 40$ b.

$\sigma_{n\gamma}$ B. G. Harvey, H. P. Robinson, S. G. Thompson, A. Ghiorso, and G. R. Choppin. "Some Pile Neutron Cross Sections of Isotopes of Americium, Berkelium, Californium, and Element 99." *Phys. Rev. 95*, 581 (1954). Crude, early burn-up measurements were made at the MTR. $\sigma_{n\gamma}^{Pile} \leq 15$ b.

Measurements in Progress or Planned

None known.

CONCLUSIONS

PLUTONIUM-238

Cross sections for isotopes in the ^{238}Pu chain leading from ^{236}U are reasonably well described at present. Good, detailed differential data are available for all but the shorter half-lived isotopes ^{237}U and ^{238}Np, for which more data would be very helpful although difficult to measure. The serious problems lie in the lack of differential γ,n and n,2n measurements on ^{237}Np: both reactions have the same threshold, 6.8 MeV, and lead to ^{236}Pu, a very undesirable plutonium contaminant in ^{238}Pu.

There are only three important isotopes other than ^{238}Pu in the chain leading from ^{241}Am, and problems exist with each of them. The first, ^{241}Am, captures neutrons to produce two different isomeric states in ^{242}Am: the ground state, which has a spin of 1^- and decays by β^- emission and electron capture with a 16.02-hr half-life, and the metastable state which has a spin of 5^- and decays to the ground state by an E4 isomeric transition with a half-life of 152 yr. Both states are important: the ground state originates the decay chain to ^{238}Pu and the metastable state has the largest fission cross section known. Good differential data exist for ^{241}Am, and there are a few inconsistent integral measurements. The differential data show considerable resonance structure in the thermal cutoff region so that small differences in the cutoff lead to large cross section discrepancies (a not uncommon problem in both ^{238}Pu production chains). This problem is exacerbated by the need to determine accurately the branching ratio to the isomeric states of ^{242}Am, a measurement that must be done as an integral measurement because as a differential measurement it is beyond the present technology. Thus, the assumption must be made that an integrally measured branching ratio is valid over the entire energy span of interest, a fairly reasonable assumption in this case. The capture cross sections for both isomeric states of ^{242}Am remain unknown, as does the thermal capture cross section for ^{242}Cm. The circumstances which permit reasonable calculations of ^{238}Pu production are as follows: (1) the ^{241}Am cross sections and branching ratios are reasonably well known, (2) approximately 90% of the ^{241}Am capture goes to the ground state of ^{242}Am where it subsequently decays to ^{242}Cm, and (3) the capture and fission cross sections of ^{242}Cm, although not known, must be relatively small.

The experimentally derived integral cross sections are listed in Table I, and the recommendations for each nuclide are summarized in Table II.

TABLE I

Current Best Experimental Cross Section Values, barns

(Resonance Integrals Nominally for E_n $\geq$0.5 eV)

Isotope	$\sigma_{n\gamma}^{2200}$	σ_{nf}^{2200}	$I_{n\gamma}$	I_{nf}	$I_{\gamma n}$	$I_{n,2n}$
^{236}U	5.3 ± 0.2	*a*	358 ± 20	*a*		
^{237}U	478 ±160	*a*	*b*	*a*		
^{237}Np	172 ± 3	*a*	819[c]	*a*	12.2 ±1.4	0.0012
^{238}Np	*b*	2200 ±200	*b*	1500 ±500		
^{238}Pu	559 ± 20	17.3 ± 0.4	164 ± 15	25 ± 5		
^{241}Am to ^{242}Am	748 ± 20	3.14 ± 0.10	1330 ±117	21 ± 2		
to ^{242m}Am	83.8 ± 6		208 ± 18			
^{242}Am	*b*	2100 ±200	*b*	<300		
^{242m}Am	*b*	7600 ±300	*b*	1570 ±110		
^{242}Cm	*b*	5	*b*	150 ± 40		
^{243}Cm	*b*	690 ± 50	*b*	1860 ±400		

a. Unknown cross sections but probably quite small.

b. Unknown values required but probably appreciable.

c. This value is a mean of the integral experimental values. It seems much too high for a 0.5 eV cutoff when compared with the differential results. For a discussion of this problem, see the section on ^{237}Np.

TABLE II

^{238}Pu Chain Cross Sections Summary

Nuclide	Status	Low Energy Shape	First Resonance, eV	Comments	Recommendations
^{236}U	Good	1/v ≤0.05 eV	5.49 eV	Good differential measurements	Higher precision resonance parameters (planned), thermal value
^{237}U	Very Poor	Unknown	Unknown	Differential fission >20 eV, one integral measurement	Not crucial at present
^{237}Np	Good	1/v <0.15 eV	0.489 eV	Good differential data, fairly good integral data, little γn or n,2n data	Higher precision resonance parameters (planned), need more γn and n,2n data
^{238}Np	Very Poor	Unknown	Unknown	One integral measurement	Not crucial at present
^{241}Am	Good	1/v <0.06 eV	0.308 eV	Good differential data and reasonable integral data, one good branching ratio measurement	Higher precision resonance parameters (planned), more branching ratio measurements
^{242}Am	Very Poor	Unknown	Unknown	One reasonable integral fission measurement	Difficult to do much about
^{242m}Am	Poor	Non 1/v	0.173 eV	Good differential fission data, some integral fission data	Capture data
^{242}Cm	Very Poor	Unknown	Unknown	Two poor-quality integral measurements	Capture and fission measurements when possible
^{243}Cm	Poor	Unknown	1.5 eV	Some differential fission and total data, limited integral data	Not crucial at present
^{238}Pu	Good	Non 1/v	2.89 eV	Good differential and integral data	Data adequate at present

CALIFORNIUM-252

The status of experimental neutron cross section data is mixed. Ample data are, or will be, available in the immediate future to provide evaluations for a few of the nuclides in the ^{252}Cf chain, e.g., ^{242}Pu, ^{243}Am, ^{244}Cm, and ^{249}Cf. For some nuclides, such as ^{249}Bk, ^{250}Cf, and ^{251}Cf, there is almost no data. Several particular problem areas stand out, such as the low-energy differential fission and capture data for ^{245}Cm and ^{247}Cm, the capture data for ^{248}Cm, and the fission data for ^{251}Cf.

When making two energy-group calculations for a very thermal lattice, the integral data may be used without modifications. This is the case with many of the Savannah River calculations, and, as a result, a set of consistent integral cross sections has been developed.[1] This data set is compared with an evaluation of the currently available experimental values in Table III. A "consistent" cross section set was obtained by matching the then-available individual measurements with data derived from long-term irradiations of plutonium at high flux. Reasonable values and limits were determined in this manner with the net result that one integral cross section in the set may not be changed by itself, but several must be modified simultaneously to give continued agreement with the production results.[1] The data survey for this cross section set was completed more than two years ago, but the values are still reasonably good, which gives credence to the technique. However, as shown in Table III, a revision is currently in order. Significant changes have appeared for ^{244}Cm (I_n), ^{251}Cf (σ_n and I_n), and ^{252}Cf (σ_{nf} and I_{nf}). Isotopes for which integral measurements are clearly needed are ^{248}Cm (σ_n), ^{250}Cf (all), and ^{251}Cf (σ_{nf} and I_{nf}). In cases where more detailed cross sections are required and only integral data are available, a technique for synthesizing epithermal resonance cross section behavior through combining nuclear systematics and the Hennelly cross section data is available.[2]

Detailed, experimentally determined differential cross sections for the heavy actinides have been measured in only a few cases. For many of these isotopes, the shape of the cross section in the thermal region and the position of the first resonance

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[1] E. J. Hennelly. "The Heavy Actinide Cross Section Story." *Proc. Third Conf. on Neutron Cross Sections and Technology, March 1971, Knoxville.* USAEC Report CONF-710301, Vol. 2, p. 494 (1971).

[2] F. J. McCrosson. "A Practical Model for Generating Resonance Energy Cross Sections for Heavy Nuclides." *Proc. Third Conf. on Neutron Cross Sections and Technology, March 1971, Knoxville.* USAEC Report CONF-710301, Vol. 2, p. 714 (1971).

remain to be determined. For most of the curium isotopes, there are no differential data in the thermal and low epithermal regions at all, although measurements above a neutron energy of about 20 eV have been made for all of them using a nuclear detonation as a neutron source.[3] Among the berkelium and californium isotopes, differential data have been taken only for ^{249}Cf (0.3 eV to 1.5 MeV) and ^{252}Cf (25 eV to 1 keV). Table IV summarizes the differential data situation in some detail. The important areas which need to be considered for measurements in the immediate future are:

- the ^{248}Cm capture cross section. A cooperative total cross section measurement involving Oak Ridge National Laboratory and Savannah River Laboratory personnel is complete, and analysis of the data obtained should give the requisite information.

- the ^{251}Cf fission cross section. Sufficient sample material is available but is not of sufficient purity for the measurement. Isotope separation must be done before reasonable differential fission measurements can be made.

- the ^{245}Cm and ^{247}Cm fission cross sections below 30 eV. These measurements have the same problem as ^{251}Cf, insufficient isotopic purity. No measurements are currently planned.

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[3] M. S. Moore and G. A. Keyworth. "Analysis of the Fission and Capture Cross Sections of the Curium Isotopes." *Phys. Rev. C3*, 1656 (1971).

TABLE III

Comparison of Current Best Individual Values With "Self-Consistent Set" Values[a]

Isotope	Needed Integral Measurements	$\sigma_{n\gamma}^{2200}$ Best Individual	$\sigma_{n\gamma}^{2200}$ Self-Consistent Set	σ_{nf}^{2200} Best Individual	σ_{nf}^{2200} Self-Consistent Set	$I_{n\gamma}$ Best Individual	$I_{n\gamma}$ Self-Consistent Set	I_{nf} Best Individual	I_{nf} Self-Consistent Set
^{242}Pu	*b*	18.7 ± 0.7	20	*b*	*b*	1275 ± 40	1180	*b*	*b*
^{243}Am	*b*	77 ± 2	90	*b*	*b*	1813 ± 70	1770	*b*	*b*
^{244}Cm	*b*	14 ± 4	12.6	1.1 ± 0.5	1.1	606 ± 23	650	18 ± 1	18
^{245}Cm	*b*	342 ± 20	390	2018 ± 37	2250	102 ± 7	110	772 ±30	800
^{246}Cm	*b*	1.3 ± 0.3	1.2	0.17 ± 0.10	*b*	121 ± 7	121	10 ± 0.4	*b*
^{247}Cm	$\sigma_{n\gamma}$, $I_{n\gamma}$	60 ± 30	55	82 ± 5	98	800 ±400	500	778 ±50	800
^{248}Cm	$\sigma_{n\gamma}$, $I_{n\gamma}$	4 ± 2	1.35	0.34 ± 0.07	*b*	300 ± 75	240	13.2 ± 0.8	*b*
^{249}Bk	all	1400[d]	*c*	*b*	*c*	1240[d]	*c*	*b*	*c*
^{249}Cf	*b*	475 ± 25	270	1685 ± 39	1630	765 ± 35	1030	2114 ±70	1720
^{250}Cf	all	1470[d]	1485	*b*	*b*	8540[d]	4975	*b*	*b*
^{251}Cf	σ_{nf}, I_{nf}	2850 ±150	1980	3500[d]	4930	1600 ± 30	1730	*e*	1370
^{252}Cf	*b*	20 ± 1.5	22	32 ± 4	6	42 ± 3	46	110 ±30	12
^{253}Cf	$I_{n\gamma}$, I_{nf}	17.6 ± 1.8	15	2530 ±400	2235	*b*	15	*b*	2235
^{254}Cf	all	<2	100	*b*	*b*	*b*	100	*b*	*b*
^{253}Es	σ_{nf}, I_{nf}	155 ± 20	*c*	*b*	*c*	7308 ±275	*c*	*b*	*c*
^{254}Es	$\sigma_{n\gamma}$, $I_{n\gamma}$	<40	*c*	2830 ±130	*c*	*b*	*c*	2200 ±90	*c*

a. Errors quoted are those listed by the measurer or weighted means of several measurers. They represent typically the standard deviation.

b. No value given.

c. Isotope not considered.

d. Based upon insufficient, ambiguous, or low precision data.

e. Value probably appreciable, no data available.

TABLE IV

^{252}Cf Chain Cross Sections Summary

Nuclide	Status	Low Energy Shape	First Resonance, eV	Comments	Recommendations
Pu	Excellent	1/v <0.5 eV	2.68	Very good differential measurements with metal example	-
^{243}Am	Very good	1/v ≲0.3 eV	0.420	Good differential measurements; good integral measurements	-
^{244}Cm	Good	Probably 1/v	7.667	Good differential measurements; good integral fission; poor integral capture	-
^{245}Cm	Poor	Unknown	1.962	Good differential fission >20 eV; good integral fission and capture	Differential fission <40 eV; samples available
^{246}Cm	Acceptable	Probably 1/v	4.316	Good differential fission >20 eV; limited differential total; good integral fission and capture	Differential total <30 eV; enough sample may be available
^{247}Cm	Poor	Unknown	Unknown	Good differential fission >20 eV; good integral fission; poor integral capture	Differential fission <40 eV; samples probably available
^{248}Cm	Very Poor	Unknown	Unknown	Good differential fission >20 eV; good integral fission; poor integral capture	Differential total <1 keV; samples available
^{249}Bk	Very Poor	Unknown	Unknown	Some differential fission >20 eV; not yet available; some crude capture	Not crucial at present
[illegible]Cf	Good	Unknown	∿0.7 eV	Differential fission from 0.3 eV to 1.5 MeV; reasonable integral fission and capture	-
^{250}Cf	Very Poor	Unknown	Unknown	No differential data; very limited and questionable integral data	Sample limitations - integral capture data would help
^{251}Cf	Very Poor	Unknown	Unknown	No differential data; reasonable integral capture data; limited and questionable integral fission data	Differential fission <100 eV; sample available
^{252}Cf	Poor	Unknown	Unknown	Good differential fission - 25 eV to 1 keV; good integral fission and capture data	Further differential measurements very, very difficult
^{253}Cf	Very Poor	Unknown	Unknown	No differential data; limited integral data	Not crucial at present
^{254}Cf	Very Poor	Unknown	Unknown	No differential data; one poor integral measurement	Not crucial at present
^{253}Es	Very Poor	Unknown	Unknown	No differential data; good integral capture data	Not crucial at present
^{254}Es	Very Poor	Unknown	Unknown	No differential data; good integral fission data	Not crucial at present

SUGGESTED FUTURE WORK

MEASUREMENTS

The most needed measurements that are currently possible, considering present technology and sample availability, all involve isotopes in the ^{252}Cf chain:

^{248}Cm, capture, thermal to about 1 keV

^{245}Cm, fission, thermal to about 40 eV

^{247}Cm, fission, thermal to about 40 eV

^{251}Cf, fission, thermal to about 1 keV

Total cross section measurements on ^{248}Cm in the energy region of interest are in progress and should give the desired information; however, no firm plans exist for the remaining top-priority measurements. The other measurements and refinements to existing data as outlined in Tables II and IV would also be very useful for accurate production forecasts.

The most significant technical problem in the fission cross section measurements on ^{245}Cm, ^{247}Cm, and ^{251}Cf is the availability of sufficient high-purity sample material. This problem could be solved, at least in part, through improvement of the ion source and thus the collection efficiency of one of the existing small, isotopic separator facilities (e.g., both Oak Ridge National Laboratory and Lawrence Livermore Laboratory have such facilities). The technology is available to accomplish this task at modest cost, and then sufficient high-purity isotopic material could be prepared for at least the ^{245}Cm and ^{251}Cf measurements. The fission cross section measurement techniques for very small samples appear to be quite adequate at both the ORNL and LLL linear accelerators.

EVALUATION AIDS

If the following suggestions with regard to performing and analyzing measurements of the type described above were observed, the work of the evaluator would be eased considerably and could be more accurate:

Integral Data

- Clear definition of the spectrum used for either thermal or resonance measurements.
- Specification of the cut-off energy. A major problem in using resonance integrals lies in uncertainties in the cut-off energy if, indeed, any value is given.
- A complete description of the geometry and the cadmium (or other filter) thickness.

Differential Data

- Complete descriptions of the details of any cross section normalization must be included. A serious source of difficulty with many partial differential cross section measurements is the normalization of the data to produce cross section values.
- The shape-elastic cross section. When total cross sections are analyzed, the value used for the shape-elastic (or potential) cross section in the analysis must be given as well as its source, whether derived from experiment or calculated from theory.

Single-Level Parameters

- Single-level Breit-Wigner parameter. Although the ENDF/B cross section format can accommodate multi-level resonance parameters, most reactor codes are only capable of handling single-level, Breit-Wigner parameters with a smooth underlying contribution. The ENDF/B data sets which have multilevel parameters are, therefore, not useful for many applications. When differential data are analyzed a single-level Breit-Wigner analysis should be performed in addition to the more-elegant and physically complex multi-level fits which allow for level-level interference. Thus, the cross section data may be stored in the ENDF/B compilation in more directly usable form.

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TML:sce