27
3-8-71
25 Sept 71

MASTER

UCID- 17390

Lawrence Livermore Laboratory

STATUS REPORT TO ERDA NUCLEAR DATA COMMITTEE

John D. Anderson

John C. Browne

Donald G. Gardner

February 11, 1977

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.

Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LAWRENCE LIVERMORE LABORATORY

A. STANDARDS

1. High-Precision Neutron Flux Monitor. (J. B. Czirr and D. W. Shosa)

A totally-absorbing time-of-flight neutron detector was designed to permit flux measurements of standards accuracy in the 1 keV to 1 MeV energy range. The efficiency of the detector is calculated to be a constant over the energy range within $\pm 2\%$. Neutrons are moderated and captured in 4 m³ of compressed ⁶LiH and the capture distribution is sampled with thin slabs of ⁶Li-glass scintillator. The mean capture time is calculated to be approximately 100 nsec. See UCRL-79089 for further details.

B. NUCLEAR DATA APPLICATIONS

1. Studies of (n,xp), (n,xd) and (n,x α) Cross Sections at 15 MeV.
(R. C. Haight, S. M. Grimes, J. D. Anderson, K. R. Alvar,*
H. H. Barschall* and R. R. Borchers*)

We have continued measurements of hydrogen- and helium-producing reactions of interest to the Division of Magnetic Fusion Energy. A summary of the cross sections measured to date is given in Table B-1.

The spectra of the emitted charged particles have been compared with statistical model calculations. The agreement is particularly sensitive to several parameters of the calculation, namely nuclear level densities, optical model parameters, angular momentum effects and gamma-ray strength functions.

From the measured alpha particle spectrum and angular distribution, we can infer the spectrum of recoils from (n,x α) reactions. These particular recoils constitute the high energy part of the spectrum of recoiling nuclei and hence are important in discussions of displacement damage. The inferred spectrum of recoils in stainless steel 316 from (n,x α) reactions at $E_n = 15$ MeV is given in Figure B-1. Using the experimental data, we avoid making assumptions, which were previously necessary, about the alpha particle angular distributions and spectra.

*University of Wisconsin, Madison, Wisconsin

Fig. B-1

Table B-1
Cross Sections at 15-MeV Neutron Energy

Material	Cross Sections (mb)			Reference
	(n,xp)	(n,xd)	(n,xα)	
²⁷ Al	405 ± 60	19 ± 8	121 ± 25	1
⁴⁶ Ti	669 ± 90	9 ± 4	98 ± 18	1
⁴⁸ Ti	85 ± 16	7 ± 3	28 ± 6	1
SS-316 and 304	252 ± 38	8 ± 2	48 ± 7	2
⁶³ Cu	320 ± 45	<10	56 ± 10	3
⁶⁵ Cu	86 ± 12	<10	13.5 ± 2.6	3
V	91 ± 14	7 ± 2	17 ± 3	4
Nb	51 ± 8	8 ± 2	15 ± 3	4

¹S. M. Grimes, R. C. Haight and J. D. Anderson, "Measurement of Sub-Coulomb Barrier Charged Particles Emitted from Al and Ti Bombarded by 15-MeV Neutrons," UCRL-78314 (1976) - to be published in Nucl. Sci. Eng. (Feb. 1977).

²R. C. Haight, S. M. Grimes and J. D. Anderson, "Hydrogen and Helium Production Cross Sections for 15-MeV Neutrons on Stainless Steels 316 and 304," UCRL-78785 (1976) - to be published in Nucl. Sci. Eng.

³In preparation.

⁴In preparation.

2. Isomer Ratio for the $^{175}\text{Lu}(n,2n)^{174}\text{Lu}$ Reaction at 14.8 MeV
(D. R. Nethaway and D. G. Gardner)

The ratio of the 142-day isomer to the 1204-day ground state of ^{174}Lu produced by the $(n,2n)$ reaction of ^{175}Lu with 14.8 MeV neutrons was measured by following the relative growth and decay of various ^{174}Lu gamma-rays, and by absolute gamma-ray counting. The results were, respectively, 0.47 ± 0.04 and 0.45 ± 0.03 . These results are consistent with the recent LASL value⁵ of 0.475.

The reaction was studied in the incident neutron energy range of 8-16 MeV via statistical model and coupled-channel calculations. We find that the first few rotational bands in ^{174}Lu must be enumerated up to spins of 12 or 13 in order for the calculations to fit the experimental data. This required about 90 levels in ^{174}Lu , so that each band might span the entire spin distribution produced by the 14.8 MeV neutrons. The calculations for various sets of ^{174}Lu levels are shown in Figure B-2. These suggest that even the high spin band members are relatively pure, and that once a gamma-ray cascade is initiated within a band it continues with very little crossing until the lower levels are reached. It is also clear that attempts to extract spin-cutoff parameters from isomer ratio data involving deformed nuclei will yield questionable results, unless a very large number of final levels are considered in the gamma-ray cascade.

3. Radiation Doses from Iron, Concrete and Water as a Function of Mean-Free-Path for 14-MeV Neutrons. (L. F. Hansen, T. T. Komoto, C. Wong and B. A. Pohl)

The extensive use of iron, concrete and water as shielding materials in fast and fusion reactors suggests the importance of being able to predict with accuracy the characteristics of the transmitted neutron and gamma-ray fluxes through these materials. Comparison of these predictions with pertinent experimental results assures their reliability.

The gamma spectra from the interaction of 14-MeV neutrons with 0.9, 2.9 and 4.8 mfp* of iron, 2 and 4 mfp of concrete, and 1.1 and 1.9 mfp of water have been measured using the sphere transmission and time-of-flight techniques. These measurements have been compared with calculations using TARTNP, a coupled neutron-photon Monte Carlo Transport code. The ENDF/B-IV and ENDL libraries for neutrons and gamma rays were used in these calculations. Earlier neutron spectra measurements on all these spherical assemblies were recalculated with TARTNP. These results were in very good agreement with those obtained earlier with TART, where only neutrons were included in the Monte Carlo Transport calculations.

⁵B. Bayhurst et al., Phys. Rev. C12, 451 (1975).

*mfp-mean free path.

Fig. B-2

The discrepancies between the gamma measurements and calculations for these materials range between 10 and 25%, with both libraries giving similar results. From the neutron and gamma fluences, the radiation doses in tissue have been calculated as a function of mfp for these materials. (This paper was accepted for presentation at the 5th International Conference on Reactor Shielding to be held at Oak Ridge National Laboratory April 18-22, 1977.)

4. Transport of 14-MeV Neutrons Through Fissionable Materials.

(L. F. Hansen, T. T. Komoto, C. Wong and B. A. Pohl)

The neutron and gamma spectra resulting from the interaction of 14-MeV neutrons with ^{232}Th , ^{235}U , ^{238}U and ^{239}Pu have been measured using the sphere transmission and time-of-flight techniques. Because these materials are being used in the design of hybrid reactors (fusion-fission), it is of interest to have assurance that the calculations give a good representation of the interaction of the 14-MeV neutron with these materials.

Spherical assemblies of 1 mfp Th, 0.7 and 1.5 mfp ^{235}U , 0.8 and 2.8 mfp ^{238}U , and 0.7 mfp ^{239}Pu were bombarded with the 14-MeV source positioned at the center of the spheres. The neutron spectra were measured with improved time resolution over earlier measurements. The present results agree well with these earlier measurements. The ^{239}Pu and ^{235}U time spectra showed the presence of delayed gamma radiation presumably from fission fragment isomers, the effect being most pronounced in ^{235}U . The measurements are being compared with TARTNP calculations (coupled neutron-photon Monte Carlo transport code) for neutrons and gamma rays. Preliminary results indicate that the calculations overestimate the gamma production, the discrepancy being largest for ^{239}Pu .

5. Investigation of Gamma-ray Strengths Following Inelastic Proton Scattering on Even-Even Vibrational Nuclei. (R. P. Koopman, L. F. Hansen, and F. S. Dietrich)

A systematic survey of cross-sections for gamma rays de-exciting the low-lying levels of even-even vibration-like nuclei following inelastic proton scattering has been completed. The purpose of these experiments was to provide detailed information on the gamma decays which could be used to test nuclear-modeling codes intended to predict the yields of neutron-induced reactions. It was also desired to test the hypothesis that the production cross-section for the lowest excited-state gamma decay in this class of nuclei is closely equivalent to a measurement of that portion of the inelastic events which is not followed by particle decay. Using the LLL cyclograaff accelerator and Ge(Li) detectors, gammas were detected following 7- to 26-MeV proton bombardment of ^{56}Fe , ^{62}Ni , ^{64}Zn , ^{108}Pd , $^{110,114,116}\text{Cd}$, $^{116,120}\text{Sn}$, and ^{206}Pb . The

excitation function for the low-lying gamma decays of ^{56}Fe is shown in Fig. B-3; qualitatively similar results were found for all of the targets. The 0.847-MeV gamma cross section is in good agreement ($\sim 10\%$) with a value obtained by integrating measured (p,p') spectra⁶ over energy and angle. Preliminary nuclear-modeling calculations (including collective excitation) show that pre-equilibrium reactions are required to explain the data at high bombarding energies (~ 14 MeV), and that isospin effects must be included to reproduce the correct magnitudes of the cross-sections.

6. Measurement of (n,n' γ) Cross Sections Induced by 14-MeV Neutrons on Even-Even Vibration-like Nuclei. (R. P. Koopman, F. S. Dietrich and L. F. Hansen)

A series of (n,n' γ) experiments was performed at the Livermore RTNS facility, using ring geometry and Ge(Li) detectors. Pulsed-beam timing techniques were used to eliminate asynchronous backgrounds and fast-neutron events. Measurements were made on rings of natural Fe, Ni, Zn, Cd, Sn, and Pb; the high resolution of the Ge(Li) detector allowed identification of gammas from the various isotopic constituents of the samples. Data were taken at angles near 50° between the incident neutrons and the gammas for all samples, and additionally near 80° and 125° for several samples. A partial list of cross sections measured for Fe and Cd is given in Table B-2. Because neutron energy varies with angle in a ring-geometry experiment, the data must be corrected to a common energy if the angular distribution is to be inferred. If the total cross section is assumed to behave linearly over the energy range 13.6-14.8 MeV, the cross section and angular dependence of the $2^+ \rightarrow 0^+$ transition in ^{56}Fe are in good agreement with the results of Abbondanno et al.⁷, but not those of Lachkar et al.⁸ The systematic behavior of the relative strengths of transitions between the low-lying levels is very similar to that observed in (p,p' γ) reactions on the same nuclei.

⁶A. Sprinzak, et al., Nucl. Phys. A203, 280 (1973).

⁷U. Abbondanno et al., J. Nucl. Energy 27, 227 (1973).

⁸J. Lachkar et al., Nucl. Sci. and Eng. 55, 168 (1974).

Fig. B-3

Table B-2. Differential cross sections in mb/sr for (n,n'γ) reactions producing various gamma rays in Fe and Cd samples. Energies in MeV.

Nucleus	θ	E _n	E _γ	σ _{2⁺-0⁺}	E _γ	σ _{4⁺-2⁺}	E _γ	σ _{2₁⁺-2⁺}
⁵⁶ Fe	124°	13.5	0.847	65±3	1.239	31±1	1.810	3.3±1
	80°	14.3		43±3		21±1		2.6±1
	51°	14.8		50±3		25±1		4.0±1
¹¹⁰ Cd	49°	14.8	0.658	149±6	0.835	75±4	0.818	8±2
¹¹² Cd	49°	14.8	0.617	114±6	0.797	59±2	0.694	7±2
¹¹⁴ Cd	49°	14.8	0.558	45±2	0.725	12±2	0.651	10±1
¹¹⁶ Cd	49°	14.8	0.514	39±12	0.706	35±7	0.700	2±6

7. High Energy Fission Cross Section Ratio Measurements.
(J. W. Behrens and J. C. Browne)

We have completed neutron-induced fission cross section measurements on a series of thorium, neptunium, plutonium, and americium isotopes using ionization fission chambers at the LLL 100-MeV electron linear accelerator. Ratios of the cross sections of ^{232}Th , ^{237}Np , ^{244}Pu , and ^{241}Am relative to ^{235}U have been measured as functions of neutron energy over the range .001 to 30 MeV, except where limited by low cross sections on the threshold isotopes. We normalized the results independent of other measurements by using the threshold cross section method. These ratio measurements ⁹⁻¹¹ were obtained in a manner similar to the series of uranium (i.e., 233 , 234 , 236 , ^{238}U) and plutonium (i.e., 239 , 240 , 241 , ^{242}Pu) isotopes which were presented at the NEANDC/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections, June 28-30, 1976.¹² Preliminary results for the $^{241}\text{Am}/^{235}\text{U}$ and $^{237}\text{Np}/^{235}\text{U}$ ratios are shown in Figure B-4 and are compared to ratios (line) obtained using the ENDF/B-IV evaluated fission cross-section files.

8. ^{241}Pu Fission Cross Section. (G. W. Carlson, J. W. Behrens and J. B. Czirr)

We have completed a measurement of the fission cross section of ^{241}Pu from 8 eV to 70 keV. The incident neutron spectrum measurement was obtained with a thin ^6Li -glass scintillator. The data were normalized to accepted values near thermal energies. The data exhibit significant discrepancies when compared to the ENDF/B-IV evaluated cross section. See UCRL-78696 for further details.

- ⁹J. W. Behrens and J. C. Browne, Measurement of the Neutron-Induced Fission Cross Section of ^{241}Am Relative to ^{235}U from 0.001 to 30 MeV, Lawrence Livermore Laboratory, Rept. UCID-17324 (1976).
- ¹⁰J. W. Behrens, R. S. Newbury, J. C. Browne, and G. W. Carlson, Measurement of the Neutron-Induced Fission Cross Section of ^{244}Pu Relative to ^{235}U from 0.2 to 30 MeV, Lawrence Livermore Laboratory, Rept. UCID-17341 (1976).
- ¹¹J. W. Behrens, J. W. Magana, and J. C. Browne, Measurement of the Neutron-Induced Fission Cross Section of ^{237}Np Relative to ^{235}U From 0.02 to 30 MeV, Lawrence Livermore Laboratory, Rept. UCID-17370 (1977).
- ¹²J. W. Behrens and G. W. Carlson, Measurements of Neutron-Induced Fission Cross-Section Ratios Involving Isotopes of Uranium and Plutonium, Proc. NEANDC/NEACRP Specialists Meeting on the Fast Neutron Fission Cross Sections of U-233, U-235, U-238, and Pu-239, Argonne National Laboratory, June 28-30, 1976, Argonne National Laboratory, Rept. ANL-76-90, p. 47.

Fig. B-4. Preliminary data for the (a) $^{241}\text{Am}/^{235}\text{U}$ and (b) $^{237}\text{Np}/^{235}\text{U}$ fission cross section ratios over the neutron energy range 0.1 MeV to 30 MeV. The lines were obtained using ENDF/B-IV evaluated fission cross sections.

9. ^{245}Cm Fission Cross Section. (J. C. Browne, R. W. Benjamin,* and D. G. Karraker**)

The fission cross section of ^{245}Cm has been measured from 0.01 eV to 35 eV at the LLL 100-MeV linac. By normalizing to previous integral data, a thermal fission cross section of 2143 ± 58 b is obtained. The cross section below 1 eV is non- $1/v$ due mainly to a slightly bound level. The recommended thermal value of 2020 b (BNL-325) differs from our result because it was obtained under the assumption of a $1/v$ energy dependence. Resonance parameter analysis has been completed and a paper is being prepared for submittal to Nuclear Science and Engineering.

10. A New Isotope of Curium: ^{251}Cm . (R. W. Loughheed, J. F. Wild, E. K. Hulet, J. H. Landrum, R. W. Hoff)

We produced this new isotope by neutron capture on ^{250}Cm at the Livermore LPTF reactor. The primary identification was by chemical milking of its beta-decay daughter ^{251}Bk . Its beta-halflife is 16.8 ± 0.2 min, and measured beta-endpoint is 1.42 MeV. We have found a total of thirteen gamma rays from ^{251}Cm , which we have fitted into a consistent decay scheme (Fig. B-5). According to this scheme, Q_{β^-} is also 1.42 MeV. As a by-product of these experiments, an approximate thermal cross-section of 80 barns at a cadmium ratio of 2.84 was measured for neutron capture on ^{250}Cm .

11. A New Isotope of Californium: ^{255}Cf . (R. W. Loughheed, E. K. Hulet, J. Evans, B. Qualheim)

We produced this new beta-emitter by neutron capture on ^{254}Cf at the Vallecitos reactor. We identified and measured ^{255}Cf by chemically milking its daughter, ^{255}Es , at periodic intervals, and subsequently alpha-pulse-height analyzing its granddaughter ^{255}Fm . ^{255}Fm ($\tau_{1/2}=20$ -hr alpha) reaches equilibrium in a few days with its parent, ^{255}Es ($\tau_{1/2}=40$ -d beta). Our measured beta halflife for ^{255}Cf is 90 ± 30 minutes.

C. NUCLEAR DATA FOR SAFEGUARDS

1. Photofission Studies with Monoenergetic Photons. (B. L. Berman, R. A. Alvarez, P. Meyer, J. T. Caldwell,** and E. J. Dowdy**)

Preliminary analysis of data acquired to date in this LLL-LASL collaborative program has yielded $(\gamma, n_{\text{total}})$, (γ, n) , $(\gamma, 2n)$ and (γ, f) cross sections for ^{232}Th , ^{235}U , ^{236}U , ^{237}Np , and ^{238}U . Lorentz curves have been fitted to the $\sigma(\gamma, n_{\text{total}})$ data in the giant-resonance region, and the parameters extracted. Similar data have been obtained for ^{233}U and ^{234}U which are presently being analyzed. Figure C-1 shows some

*Savannah River Laboratory, Aiken, South Carolina.

**Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

BETA DECAY SCHEME FOR ^{251}Cm

Fig. B-5

representative photofission data for ^{238}U where the cross section has been decomposed into first- and second-chance fission. The prompt fission neutron multiplicity, $\bar{\nu}$, has also been extracted as a function of incident photon energy. Shown in Fig. C-2 are the $\bar{\nu}$ results for ^{236}U along with the evaluated $\bar{\nu}$ for $^{235}\text{U} + n$ for comparison. Fig. C-3 shows the delayed neutron fraction obtained in the present measurement compared with previous results. Further analysis of these photofission data for the actinides is continuing.

D. NUCLEAR DATA COMPILATION

1. Atlas of Photoneutron Cross Sections. (B. L. Berman)

The Bicentennial Edition of the Atlas of Photoneutron Cross Sections Obtained with Monoenergetic Photons has been issued as UCRL-78482. In addition to the graphs of the cross-section data, tables of giant-resonance properties and comparison information from bremsstrahlung data, together with reference lists, are included as well. Figure D-1 shows the current scope of giant-resonance data obtained with monoenergetic photons. The compilation is current as of December, 1976.

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research & Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."

U-238 PHOTOFISSION

Fig. C-1

Fig. C-2

Fig. C-3

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research & Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights.

NOTICE

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

Printed in the United States of America

Available from

National Technical Information Service

U.S. Department of Commerce

5285 Port Royal Road

Springfield, VA 22161

Price: Printed Copy \$: Microfiche \$3.00

Page Range	Domestic Price	Page Range	Domestic Price
001-025	\$ 3.50	326-350	10.00
026-050	4.00	351-375	10.50
051-075	4.50	376-400	10.75
076-100	5.00	401-425	11.00
101-125	5.50	426-450	11.75
126-150	6.00	451-475	12.00
151-175	6.75	476-500	12.50
176-200	7.50	501-525	12.75
201-225	7.75	526-550	13.00
226-250	8.00	551-575	13.50
251-275	9.00	576-600	13.75
276-300	9.25	601 up	*
301-325	9.75		

* Add \$2.50 for each additional 100 page increment from 601 to 1,000 pages;
add \$4.50 for each additional 100 page increment over 1,000 pages.

Technical Information Department

LAWRENCE LIVERMORE LABORATORY

University of California | Livermore, California | 94550