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TO: USNDG Members and Contributors
FROM: John D. Anderson and John C. Browne
SUBJECT: Status Report to USNDG*

March 11, 1975

*Work performed under the auspices of the Energy Research and Development Administration.
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A. STANDARDS

1. 235\textsubscript{U} Fission Cross Section Relative to n-p Scattering. (J. B. Czirr and G. S. Sidhu)

A paper (UCRL-76508) on this experiment was presented at the Conference on Nuclear Cross Sections and Technology in Washington, D.C., March 3-7, 1975. The abstract for this paper is quoted below.

"Energy dependence of the fission cross section of 235\textsubscript{U} with respect to the n-p scattering reaction was measured for neutron energies from 0.8 to 20 MeV. The LLL linac target was used as the pulsed neutron source; neutron energies were measured by time-of-flight techniques. A 235\textsubscript{U} ion chamber was designed and operated to make the fission detection efficiency independent of the angular distribution of fission fragments. The neutron flux monitor consisted of an annular polyethylene radiator with a shielded proton recoil detector. Data in the energy range from 3 to 20 MeV were obtained with a 3.3 mg/cm\textsuperscript{2} radiator; a 0.31 mg/cm\textsuperscript{2} radiator was used for the range from 0.8 to 4 MeV. Both sets of data were normalized to yield the average fission cross section value of 1.98 b in the overlapping region from 3 to 4 MeV. Total error in the relative 235\textsubscript{U}(n,f) cross section is \pm 2\% at 14 MeV, and \pm 3\% at 20 MeV."

2. A Measurement of the 235\textsubscript{U} Fission Cross Section from Thermal to 1 MeV. (J. B. Czirr and G. S. Sidhu)

The ratio of the 235\textsubscript{U} fission cross section to the \textsuperscript{6}Li(n,\alpha) reaction has been measured for neutron energies from thermal to 1 MeV. Results of this measurement were presented at the Nuclear Cross Sections and Technology Conference mentioned above. (UCRL-76572).

B. NEUTRON DATA APPLICATIONS


We have submitted results (UCRL-76219) to the Conference on Nuclear Cross Sections and Technology, March 3-7, 1975 for the fission cross section ratios: 233\textsubscript{U}:235\textsubscript{U}, 234\textsubscript{U}:235\textsubscript{U}, 236\textsubscript{U}:235\textsubscript{U}, 238\textsubscript{U}:235\textsubscript{U} and 238\textsubscript{U}:239\textsubscript{U}. The measurements made at the LLL 100 MeV LINAC cover the energy
range from 1 keV 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.\(^1\)\(^2\)

We are presently repeating our measurements of \(^{239}\text{Pu} : ^{235}\text{U}\) and \(^{238}\text{U} : ^{239}\text{Pu}\) with new fission chambers designed to reduce the alpha pileup experienced with our preliminary measurements.\(^2\)

During the year 1975, we also plan to measure the fission cross sections of \(^{240}\text{Pu}, ^{241}\text{Pu}, ^{242}\text{Pu}\) and \(^{243}\text{Pu}\) relative to \(^{235}\text{U}\) in the energy range from about 100 keV to 20 MeV.

2. Fission \(\bar{\nu}\) Measurements. (R. E. Howe and T. W. Phillips)

We have begun measurements of \(\bar{\nu}\) for \(^{235}\text{U}\) in the MeV region \((E_\nu \leq 20 \text{ MeV})\) using the LLL linac with the same detector system used for precision \(\bar{\nu}\) measurements in the \(^{235}\text{U}\) resonance energy region.\(^3\) Preliminary results are shown in Figure B-1.

3. Recent Measurements of the \(^{93}\text{Nb}(n,2n)^{92}\text{Mn} (10.16\text{d})\) Cross Section. (D. R. Nethaway)

Table B-1 lists preliminary results for the \(^{93}\text{Nb}(n,2n)^{92}\text{Mn}\) (10.16d) cross section based on recent irradiations at the Livermore ICT facility, together with some revised results of work previously published.\(^4\) The revisions were made because of a change in the \(^{92}\text{Mn}\) counting efficiency. The results listed in Table B-1 are accurate to \(\pm 5\%\).

<table>
<thead>
<tr>
<th>Neutron Energy (MeV)</th>
<th>Cross Section (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.9</td>
<td>462</td>
</tr>
<tr>
<td>14.1</td>
<td>465</td>
</tr>
<tr>
<td>14.5</td>
<td>467</td>
</tr>
<tr>
<td>14.8</td>
<td>458</td>
</tr>
</tbody>
</table>


\(^3\) NCSAC Report, dated 10 November 1971, UCID-15937.

4. Neutron Reactions on $^{239}$U. (D. G. Gardner)

A paper (UCID-16679) on this topic has recently been written on this subject. A summary from this paper is quoted below.

"Calculations were made of the major reactions induced by neutrons in the energy range of 10 eV to 2.5 MeV incident on $^{239}$U. Both the 23.5 m $5/2^+$ ground state and the 0.78 µs $1/2^+$ isomeric state of $^{239}$U were considered as targets. The bulk of the calculations were performed with the COMNUE and UHL statistical model codes using Moldauer's optical model parameters, although a rough correction for direct reactions was also made. Specifically, the total, shape elastic, compound elastic, inelastic, capture and fission cross sections are presented in tabular and graphic form over the specified neutron energy range. In addition, the fission cross sections were tentatively extrapolated down to thermal energy where they are compared with an unpublished measurement. For neutron energies above 500 keV the fission calculations are compared with predictions derived from published experimental measurements of the (t,pf) reaction on $^{238}$U."

5. Model Calculations of Gamma-Ray Strength Functions. (D. G. Gardner)

A paper on this subject was presented at the Pittsburgh meeting of the APS, Oct. 31-Nov. 2, 1974. Results of these calculations for $^{182}$Ta and $^{198}$Au are contained in LLL Chemistry Dept. Technical Note No. 74-32. A comparison of the experimental and calculated γ-ray spectra for $^{197}$Au(n,γ) are shown in Fig. B-2.

6. Tritium Depth Profiling by Neutron Time-of-Flight. (J. C. Davis and J. D. Anderson)

A paper (UCRL-75757, Rev. 1) on this topic was presented at the 21st National Symposium of the American Vacuum Society in Anaheim, California, Oct. 7-11, 1974. The abstract of this paper is quoted below.

"A method has been developed to measure the depth profile of tritium implanted or absorbed in materials. The sample is bombarded with a pulsed proton beam. Neutron energies from T(p,n) reactions occurring in the target are measured by time-of-flight over a 10.8 m flight path. From the neutron energy the proton energy and thus the tritium depth in the target may be inferred. The measurements were initiated to determine the depletion of tritium absorbed in titanium layers. These layers had served as targets on a 400 keV T(d,n) neutron generator. A depth resolution of 0.4 ng/cm$^2$ of titanium (0.9 µm) was obtained. Unlike proton
backscattering methods, the technique can be used with thick samples. We estimate that a sensitivity of 0.1 at. % tritium in host materials can be obtained. Extension of the method to deuterium depth profiling is possible with the use of the D(d,n) reactions."

7. **Comparison Between the Integral Gamma-Ray Measurements on Nitrogen and the Calculations using the ENDF/B-IV Library.** (L. F. Hansen, T. T. Komoto, B. A. Pohl, C. Wong and J. D. Anderson)

The gamma-ray spectra from 0.5, 1.1 and 3.1 mean free paths (mfp) of nitrogen bombarded with 14-MeV neutrons, were reported in USNDC-11 (June 1974). These measurements, using the sphere transmission and time-of-flight techniques, were repeated with somewhat improved experimental conditions. NE 213 scintillators were used at angles of 26° and 120° and the flight paths were 769.62 and 912.42 cm, respectively. No major discrepancies were found with the earlier results.

Calculations have been carried out with the TARTNP Code using the ENDF/B-IV library. TARTNP is a coupled neutron-photon Monte Carlo Transport Code, which calculates the number of gammas/MeV/source neutron as function of gamma-ray energy. To this calculation is folded the recoil electron response of the detector calculated with the Monte Carlo Photon Transport Code TÖRTE.

Table B-2 gives the integral values of the measured and calculated spectra at 26° and 120° as function of mfp and the comparison for the 3 mfp is shown in Fig. B-3. The results show that the calculations are lower than the measurements with the discrepancy increasing as function of mfp.

**Table B-2**

Comparison between the measured integrals between 320 keV to 10 MeV gamma-ray energies and the calculations with the ENDF/B-IV library for nitrogen bombarded with 14-MeV neutrons.

<table>
<thead>
<tr>
<th>mfp</th>
<th>Θ</th>
<th>Experiment</th>
<th>ENDF/B-IV</th>
<th>Discrepancy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>26°</td>
<td>7.040</td>
<td>7.343</td>
<td>+4.3</td>
</tr>
<tr>
<td></td>
<td>120°</td>
<td>4.68</td>
<td>4.48</td>
<td>-4.3</td>
</tr>
<tr>
<td>1.1</td>
<td>26°</td>
<td>10.02</td>
<td>9.87</td>
<td>-1.5</td>
</tr>
<tr>
<td></td>
<td>120°</td>
<td>6.76</td>
<td>6.14</td>
<td>-9.1</td>
</tr>
<tr>
<td>3.1</td>
<td>30°</td>
<td>15.87</td>
<td>12.41</td>
<td>-22.0</td>
</tr>
<tr>
<td></td>
<td>120°</td>
<td>10.38</td>
<td>8.30</td>
<td>-20.0</td>
</tr>
</tbody>
</table>
C. NUCLEAR DATA FOR SAFEGUARDS

1. Photofission and Photoneutron Cross Sections for Actinide Nuclei. (R. A. Alvarez, B. L. Berman, and P. Meyer, LLL; J. T. Caldwell and E. J. Dowdy, LASL; T. F. Godlove, NRL)

Analysis of the data discussed in USND-11, p. 136, is proceeding. Results for $^{232}$Th and $^{235,236,238}$U will be presented at the Washington APS meeting in April. Further measurements are planned as well.

D. BASIC PHYSICS

1. Neutron Total Cross Section for Tritium. (T. W. Phillips, W. A. Barletta and B. L. Berman, LLL; J. D. Seagrave, LASL)

Measurements were completed in December, 1974; the data are being analyzed. The data analysis is expected to yield results in the neutron energy range from several tens of keV to several tens of MeV. The expected accuracy of the results is a few percent.


The neutron capture cross sections for $^{186}$, $^{187}$, $^{188}$, $^{189}$, $^{190}$ and $^{192}$Os have been measured from 2 eV to 300 keV. Data analysis is in progress. A paper on this experiment will be presented at the Washington APS meeting in late April.

3. High Resolution Neutron Resonance Measurements. (H. S. Camarda)

Using the LLL 100-MeV linac, high resolution transmission measurements on monoisotopic $^{89}$Y are being performed over the energy range 20 keV to 250 keV for a range of sample thicknesses ($\lambda/n = 6, 12, 24, 50$ barns/atom). The experiment employs Li glass detectors with 4 nsec timing jitter, a 250-meter flight path, 5 nsec beam burst and 36,000 timing channels (2 nsec width above 53 keV and 4 nsec below).

The large range of sample thicknesses and the excellent resolution coupled with shape and area analysis should enable a clean determination of the neutron width, spin and parity of most levels. With this information, various theoretical predictions will be examined.

4. Atlas of Photoneutron Cross Sections Obtained with Monoenergetic Photons. (B. L. Berman)

A second edition has been issued (UCRL-75694). A slightly revised version has been submitted for publication in Atomic Data and Nuclear Data Tables.
5. Photodisintegration of $^{18}_{0}$. (B. L. Berman, R. A. Alvarez, P. Meyer, and D. D. Faul)

Measurements have been taken in November, 1974 and February/March, 1975. Structure has been observed in all reaction channels [(γ,n), (γ,2n), and (γ,p), the last obtained from observation of the delayed neutrons following the decay of $^{17}_{N}$] throughout the energy range measured [from the (γ,n) threshold at 8 MeV through the giant-resonance region].

   (R. A. Meyer)

A paper (UCRL-76207) on this subject was submitted to the International Conference on Gamma-Ray Transition Probabilities in Delhi, India, November 11-15, 1974. The abstract for this paper is listed below.

"A detailed survey of the medium-mass region (60 < A < 140) of the nuclear chart has been made to compare a number of recent theoretical calculations with the significant body of experimental information coming into the published literature. A comparison of the level properties of the Z = 51 antimony nuclei shows very good agreement with the recent calculations of Vanden Berghe, who includes two-particle one-hole configurations. The level structure and electromagnetic properties of the Z or N = 53 nuclei are not predicted so well as the antimony nuclei. Inclusion of three-particle clustering has improved the agreement between calculated and experimental electromagnetic transition rates for the low-lying levels in odd-mass nuclei. More recent calculations using a dressed quasi-particle formalism are shown to have some success. The detailed experimental study of odd-mass iodine near the neutron shell closure at N = 82 suggests that the particle-core interaction can account for a majority of the levels observed, if one uses an even-even core that includes known low-lying two-proton states. The nonnormal parity states in a given shell have higher J values than the normal parity states (e.g., $h_{1/2}$ in the g-d-s shell). This can cause significant deviations from the expected vibrational character. Studies of the odd-mass Z = 57 lanthanum nuclei suggest that the Coriolis force and its effect on high-J state coupling to the core can be used to account for the excess negative-parity states observed in the lanthanum nuclei and
their electromagnetic decay properties. The deformability of the cadmium ($Z = 48$) core and the Coriolis force may be the causes of apparent rotation-like level structure observed in the experimental studies of the odd-mass indium nuclei. These results suggest that more attention should be paid to the inclusion of a dynamic rather than static core and that the Coriolis force should be included as part of any complete, effective interaction."

E. CONTROLLED THERMONUCLEAR RESEARCH APPLICATIONS

1. Use of Nuclear Reaction Models in Cross Section Calculations.  
(S. M. Grimes)

The following abstract is of an invited paper (Bull. Am. Phys. Soc. 19, 988 (1974)) presented at the Pittsburgh meeting of the Nuclear Physics Section of the American Physical Society:

"The design of fusion reactors will require information about a large number of neutron cross sections in the MeV region. Because of the obvious experimental difficulties it is probable that all of the cross sections of interest will not be measured. Current direct and pre-equilibrium models will be used to calculate non-statistical contributions to neutron cross sections from information available from charged particle reaction studies; these will be added to the calculated statistical contribution. Estimates of the reliability of such calculations will be derived from comparisons with the available data."

In the talk comparisons between calculations and data were presented for Fe and Ni; similar calculations are now underway for Al and Nb. The text of the talk is available as UCRL-75991 and a more extensive report of the calculations will be available shortly.

2. $^{238}$U Pulsed Sphere Measurements and CTR Fusion-Fission Blanket Calculations. (C. Wong, J. D. Anderson, R. C. Haight, L. F. Hansen and T. Komoto)

The neutron emission spectra from $^{238}$U spheres pulsed with 14-MeV neutrons have been measured from the source energy down to 10 keV and have been compared with calculations employing ENDF/B-IV and (LLL) ENDF cross sections. The low energy spectra (10 keV to 1 MeV), (fig. E-1) are better described using ENDF/B-IV cross sections while the high energy spectra (2 MeV to 15 MeV), (fig. E-2) are better described using
ENDL cross sections. Discrepancies between calculation and experiment are apparent in all the figures, however. These experiments have particular relevance to fast fission blankets of hybrid fusion-fission reactors. For one conceptual design, significant differences exist in calculations done with previous versions of ENDF/B and ENDL data sets. The present versions of these data sets continue to give large differences for three crucial reactor parameters (Table E-1).

### Table E-1

Summary of Hybrid Reactor Calculations

<table>
<thead>
<tr>
<th></th>
<th>ENDF/B-IV</th>
<th>ENDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{235}$U</td>
<td>.119</td>
<td>.127</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>.673</td>
<td>.737</td>
</tr>
<tr>
<td>Total</td>
<td>.792</td>
<td>.864</td>
</tr>
<tr>
<td>Tritium Breeding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^6$Li(n,$\alpha$)T</td>
<td>.900</td>
<td>1.040</td>
</tr>
<tr>
<td>$^7$Li(n,$n'\alpha$)T</td>
<td>.066</td>
<td>.057</td>
</tr>
<tr>
<td>Total</td>
<td>.966</td>
<td>1.107</td>
</tr>
<tr>
<td>Pu-Breeding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{238}$U(n,$\gamma$)</td>
<td>2.225</td>
<td>2.143</td>
</tr>
</tbody>
</table>

All results are reactions per 14-MeV source neutron.

3. Cross Section for the $^9$Be(n,t$_1$) $^7$Li Reaction for $E_n$(lab) Between 13.3 and 15 MeV. (F. S. Dietrich, L. F. Hansen, and R. P. Koopman)

We have measured the magnitude and energy dependence of the $^9$Be(n,t$_1$) $^7$Li cross section in the 13.3 to 15 MeV energy range by observing the isotropic 481 keV decay gammas from the first-excited state of $^7$Li. The experiment was performed in a ring-and-shadow-cone geometry, and the gammas were detected with a Ge(Li) spectrometer. The

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neutrons were supplied by the Livermore ICT D-T neutron generator, and their energy was varied by changing the angle subtended by the Be ring. Neutron-induced backgrounds were reduced by time-of-flight discrimination. The results are shown in Fig. E-3, together with a recent estimate of the cross-section at 14.0 MeV. These results are in disagreement with a previous measurement using a NaI detector which yielded cross-sections in the range 10-30 mb, with a sharp dip near 14 MeV.

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Fig. B-1. Prompt Fission Neutrons $\bar{\nu}$ as a function of incident neutron energy for $^{235}\text{U}(n,f)$. The data were normalized to $\bar{\nu} (1.0 \text{ MeV}) = 2.51$. 
Fig. B-2. Calculation of the $^{197}$Au$(n,\gamma)$ capture spectrum compared with the thermal capture data of V. Orphan et al., Gulf General Atomic Report No. GA-10248 (1970).
Fig. B-3. Comparison between the measured y-ray spectrum (X) and the calculation (Y) using TAKNP with the ENDF/B-IV library for 3.1 m.f.p. of nitrogen at angles of 30° and 120°.
Fig. E-1. Comparison between the low energy measurements and calculations for the 2.8 m.f.p. 
238U sphere at 30°.
Fig. E-2. Comparison between the high energy measurements and calculations for the 0.8 m.f.p. sphere.
Fig. E-3. The $^9$Be($n,t_1$)$^7$Li* Cross Section.
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