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OFF-SITE NUCLEAR CROSS-SECTIONS MEASUREMENT PROGRAM

DIVISION OF RESEARCH
ATOMIC ENERGY COMMISSION

October, 1963

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The following letter, dated September 12, 1963, was sent to the addressees on the attached list:

One of the important continuing tasks of the Atomic Energy Commission's Nuclear Cross Sections Advisory Group is to recommend to the Atomic Energy Commission a course of action designed to fulfill the needs for nuclear cross section work recently accomplished, underway, or planned in your laboratory. The group has found such reports to be very helpful and we once again request of you a new report.

We also plan to make your report available to the European-American Nuclear Data Committee. This committee, as one of its tasks, makes recommendations on the coordination of work in the determination of nuclear cross sections and basic nuclear constants relevant to the atomic energy programs of the member countries.

The reports will be incorporated into a single document which will be made available not only to the above Committee, but will be given a broad distribution to those groups both in the United States and abroad engaged in this activity.

In order that appropriate information may be made available to the Committees at forthcoming meetings, it is requested that your program summary:

1. Be brief; not more than one page.
2. Not include measurements above 25 Mev, unless there is some logical reason for so doing,
3. Be forwarded prior to September 27, 1963,
4. Be marked "For Official Use Only", and
5. Be submitted in duplicate to me.

Sincerely yours,

George L. Rogosa, Chief
Nuclear, Atomic, & Classical
Physics Branch
Physics & Mathematics Programs
Division of Research

Addressees:

Bartol Research Foundation (D. Van Patter)
Boston College (R. L. Becker)
Brown University (R. A. Peck, Jr.)
California, University of - Davis (J. A. Jungerman)
California Institute of Technology (W. A. Fowler)
Chicago, University of (S. K. Allison)
Colorado, University of (D. A. Lind)
Florida State University (R. Davis)
General Atomic (E. Haddad)
Georgia, University of (L. Rayburn)
Illinois, University of (J. S. Allen)
Illinois, University of (A. O. Hanson)
Indiana University (A.C.G. Mitchell)
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Southern California, University of (G. L. Weissler)
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Virginia, University of (F. L. Hereford)
Washington, University of (D. Bodansky)
Washington University - St. Louis (F. B. Shull)

Addressees, continued:

Wisconsin, University of (H. H. Barschall)
Yale University (R. Beringer)
Yale University (D. A. Bromley)
Yale University (H. L. Schultz)

Others - For Information:

Air Force Office of Scientific Research (A. Harrison)
Army Research Office - Durham (H. Robl)
National Science Foundation (W. Rodney)
Naval Research, Office of (J. Fregeau)

The following replies were received by October 7, 1963:

BARTOL RESEARCH FOUNDATION

Neutron Polarization Studies, at En = 3.25 MeV, $\theta_2=90^\circ\pm7^\circ$.

D. W. Kent and W. P. Bucher. Using a D-D neutron source, with E_d=0.6 MeV, $\theta_1=50^\circ$, the following polarizations P_1P_2 have been obtained: Fe(-0.0208±0.0047), Ni(-0.0299±0.0048), Co(-0.0328±0.0044), Cu(-0.0439±0.0058), Zr(+0.0544±0.0042), Mo(+0.0552±0.0047), and W(+0.0018±0.0041). These values have not been corrected for multiple scattering or compound elastic scattering. Final analysis of similar measurements for C, Ca, Zn, Se, Sr, and Y is near completion.

Studies of the (n,n'γ) Reaction.

S. M. Shafroth and D. M. Van Patter. Final results for the (n,n'γ) reaction for natural Cr and Y have been recently published [Phys. Rev. 128, 1246 (1962) and 129 704 (1963)]. These include estimates of inelastic neutron cross sections for Cr^{50}, Cr^{52}, Cr^{53}, Cr^{54} and Y^{89}, as well as for individual levels in some of these nuclei.

The angular distribution of the 1.84-MeV $Sr^{88}(n,n'\gamma)$ γ-ray at E_n = 2.2 MeV has been measured as: $W(\theta)=(1\pm0.15) + (0.41\pm0.14)P_2(\cos\theta) - (0.07\pm0.13)P_4(\cos\theta)$, with $\sigma_{1.84}(n,n')$ = (0.81±0.08) barns. The yield of 1.596-MeV radiation from the first 2+ level of Ce^{140} has been observed for E_n = 1.6 to 2.6 MeV, using a ring of natural cerium. Angular distribution data, obtained at five bombarding energies ranging from 0.1 to 0.9 MeV above threshold, for an angular range of 35° to 90°, is being processed.

Studies of the $Ni^{58}(p,p'\gamma)$ Reaction.

S. M. Shafroth. The analysis of angular distribution data for various $Ni^{58}(p,p'\gamma)$ radiations at Ep = 5.0, 6.0, 7.0 and 8.0 MeV is underway. In addition, (γ-γ) angular correlations have been measured in three planes at E_p = 8.0 MeV.

BROWN UNIVERSITY

Abbreviations used below:

D = good resolution angular distributions;

S = energy spectrum with resolved groups;

E = excitation function.

Absolute cross sections have been obtained in almost all cases.

Completed since last report (22 March, 1961).

(n,d) on N^{14}, P^{31}, and S^{32}. (DS).

$C^{12}(n,\alpha)Be^{9}$. (DS).

$Li^{7}(d,\alpha)He^{5} \rightarrow \alpha + n$. (SE). Coincidence analysis of He^{5} levels.

(p,α) on Li^{7}, Be^{9}, and C^{12}. (DS). (Experimental work at Princeton).

(p,α) on O^{16}. (DSE). (Experimental work at Princeton).

(n,n) polarization at 2.8 Mev on C, Mg, Al, Ni, and Cu.

In Progress.

(n,α) on N^{14}, O^{16}. (DS).

(n,d) on Li^{6}, Li^{7}, N^{15}, S^{34}. (DS).

(n,d) and (n,p) on I^{127}. (DS).

Instrumentation development = (1) all-solid-state counter telescope for (n,d) work; (2) E x dE/dx pulse height multiplier; (3) pulse shape discrimination system for (n,n') work.

Planned for near future.

Simultaneous (n,p), (n,d), (n,t) observations (DS) on light nuclei.

(n,α) on Be^9 and B^{10}. (DS).

Polarization studies with Li^6-loaded emulsions.

Types of problems studied: (1) spectroscopy of discrete states; (2) competition among (n,p), (n,d) and (n,np) and between direct and statistical processes; (3) in direct processes, systematics of interaction radius and reduced widths; (4) in statistical processes, values of temperature, spin-dispersion parameter and their systematics; (5) gross structure for distorted nuclei, including competition between single particle and collective states; (6) various problems relating to reaction mechanisms.

CALIFORNIA, UNIVERSITY OF - DAVIS

W. J. Knox, in collaboration with H. Conzett and G. Igo of UCLRL Berkeley has measured polarization in the scattering of 22 Mev protons by deuterons. Polarization was determined by left and right scattering of polarized proton beams from a deuterium gas target at c.m. scattering angles ranging from 31° to 136°. The polarized proton beam was formed by recoils from the elastic scattering of 48 Mev α particles in hydrogen.

Measurements of scattering cross sections for 16 Mev polarized neutrons [from the (d,t) reaction] are planned using a 6 Mev deuteron beam. The n-D interactions will be investigated at first and then n-P if feasible. Neutron polarization will be changed by use of a solenoid.

CALIFORNIA INSTITUTE OF TECHNOLOGY

The following measurements are underway in the Kellogg Laboratory at the Institute.

$He^3(pp)He^3$; Elastic scattering cross section at 90° laboratory angle. E_p = 0.125-2.0 Mev.

$He^3(He^3,2p)He^4$; Total cross section 1-12 Mev He^3 energy.

$Li^6(pp')Li^{6*}$ (2.184 Mev); Total cross section, E_p = 3-10 Mev.

$C^{12}(\alpha,\gamma)O^{16}$; Total capture cross-section, E_α = 3-8 Mev.

CHICAGO, UNIVERSITY OF

The proposed research under Contract No. AT(11-1)-238 does not have a definite program of cross-section measurement. However, detailed reports* on absolute cross-sections of Li-Li reactions at 2 MeV have been published, and with the new 4 MeV Van de Graaff we expect to extend these measurements to higher energies and higher atomic number targets. Although of considerable interest to those studying the mechanism of nuclear reactions, it would appear that the reactions induced by lithium ions are only of secondary interest to the atomic energy program.

GENERAL ATOMIC

The main effort of the cross section program has been to make absolute $\sigma(n,\gamma)$ measurements in the energy interval ranging from thermal to 1 kev. Tentative absolute measurements in this energy range have been obtained for

*Phys. Rev. 129, 791 (1963).
*Phys. Rev. 131, 1701 (1963).

Au, Ag and Er. In addition Th-232 data has been obtained between 10 and 500 ev. The data is presently being analyzed. The main emphasis on the analysis of the Th-232 data has been to obtain resonance parameters for the first eight thorium resonances from which the resonance integral of Th-232 can be obtained. The Th and Er data analysis will be finished in the near future.

An investigation of the feasibility of measuring the ratio of the capture cross section to fission cross section (α) by utilizing the difference in the total energies of photons emitted in a fission event and a capture event was carried out. This work was a joint effort between ORNL and GA. In this work the large liquid scintillator was used to test the feasibility of measuring α of U-233, U-235, and Pu-239. The method is based on the difference between the pulse-height distribution resulting from the absorption of capture gamma rays in the large scintillation detector and that resulting from the absorption of fission gamma rays. The tests indicate that the method is worthy of detailed consideration.

A large effort has been directed toward the development of a machine code which calculates resonance parameters from experimental capture cross section data. The final code is comprised of those sub codes. The sub codes are: (1) an area analysis code, (2) a multiple scattering code, and (3) a shape analysis code. The general procedure in using the final code is to take an isolated resonance and obtain the resonance parameters for it using the area and multiple scattering codes. The parameters obtained are then used as a first guess in the shape analysis code.

GEORGIA, UNIVERSITY OF

He^3 Reactions - (M. M. Duncan and J. L. Duggan). Angular distributions and yields (where possible) have been measured (or are being planned) for the reactions listed below and over the indicated energy interval.

Completed:

$Be^9(He^3,p)B^{11}$, 1 - 3 MeV.

In progress:

(Maximum He^3 energy of 2 MeV).

$C^{14}(He^3,p)N^{16}$, $C^{14}(He^3,\alpha)C^{13}$, $C^{14}(He^3,d)N^{15}$.

Planned:

(Maximum He^3 energy of 2 MeV).

$Li^6(He^3,p)Be^8$, $Li^6(He^3,\alpha)Li^5$

$Li^7(He^3,np)Be^8$, $Li^7(He^3,p)Be^9$

$C^{13}(He^3,p)N^{15}$, $C^{13}(He^3,d)N^{14}$, $C^{13}(He^3,\alpha)C^{12}$, $C^{13}(He^3,n)O^{15}$

(n,2n) Reactions - (L. A. Rayburn). The cross sections for the following reactions have been measured as a function of neutron energy from approximately 12 to 18 MeV:

$F^{19}(n,2n)F^{18}$, $Sc^{45}(n,2n)Sc^{44m}$, $Sc^{45}(n,2n)Sc^{44g}$, $Cu^{65}(n,2n)Cu^{64}$, $Cd^{106}(n,2n)Cd^{105}$, $Sn^{112}(n,2n)Sn^{111}$, $Pr^{141}(n,2n)Pr^{140}$, and $Sm^{144}(n,2n)Sm^{143}$.

Further (n,2n) cross section measurements are in progress.

IOWA, UNIVERSITY OF

Recent measurements:

$$Li^6 + Li^6 \rightarrow Li^{7*} + Li^5 \qquad (1 - 3\ MeV)$$

$$\rightarrow Be^{7*} + He^5$$

$$Li^6 + Be^9 \rightarrow B^{10*} + He^5 \qquad (1 - 3\ MeV)$$

Current measurements:

$Li^6 + Be^9 \rightarrow C^{14} + p$ (1 - 3 MeV)

$\rightarrow C^{13} + d$

$\rightarrow C^{12} + t$

$Li^6 + B^{10} \rightarrow N^{15} + p$ (3 MeV)

$\rightarrow N^{14} + d$

$\rightarrow N^{13} + t$

Planned measurements:

$Li^6 + Li^6 \rightarrow Li^7 + 1i^5$ (3 - 14 MeV)

$\rightarrow Be^7 + He^5$

$Li^6 + Be^9 \rightarrow B^{10} + He^5$ (3 - 14 MeV)

$\rightarrow B^{11} + \alpha$

$\rightarrow C^{12} + t$

$\rightarrow C^{13} + d$

$\rightarrow C^{14} + p$

$Li^6 + B^{10} \rightarrow N^{15} + p$ (10 MeV)

$\rightarrow N^{14} + d$

$\rightarrow N^{15} + t$

IOWA STATE UNIVERSITY

The nuclear cross-section work being done in Ames involves measurements of interaction cross-sections of high energy photons with nuclei. In particular, we are measuring, as a function of photon energy, cross-sections for (γ,n) (γ,p) (γ,pn), etc. processes in light nuclei. We have published recently the cross-sections for $O^{16}(\gamma,n)O^{15}$ and $Be^9(\gamma,p)Li^8$ and are working now on photonuclear cross-sections for carbon, lithium, and

rare earth metals. Our cross-section work is aimed at the investigation of the region between 25 and 75 Mev, since our machine and the techniques we use have unique features unavailable elsewhere, to our knowledge. We have demonstrated the existence of absorption levels in the range 30-50 Mev, where none were thought to exist previously. These results have some theoretical confirmation in the recent calculations involving nuclear shell structure with pairing interaction. A T = 1 state of O^{16} at 33 Mev, the same as found in our work, has just been confirmed by Griffith et. al. with the proton linear accelerator at Harwell and by J. O'Connell. We have begun intensive work on a general survey of photonuclear cross-sections in the energy region above 25 Mev.

KANSAS, UNIVERSITY OF

During the past twelve months the nuclear physics laboratory has been concerned with various reactions involving the isotopes Li^7, Si^{28}, Si^{29}, and Si^{30}. The following cross section measurements were made:

1. The differential cross section of the $Li^7(p,\gamma)$ reaction has been determined in the energy range of 800 keV to 1750 keV.

2. The total and differential cross section for the $Si^{28}(d,p)$ and $Si^{30}(d,p)$ reactions have been determined in the energy range of 700 keV and 3.0 MeV.

3. The total relative yield of the reaction $Si^{29}(p,\gamma)$ has been obtained in the energy range Ep = 1.5 MeV to Ep = 3.0 MeV.

Plans are now underway to study the reactions $S^{32}(d,p)$ and $C^{14}(\alpha,\gamma)$. It is anticipated that both total and differential cross sections will be determined.

KENTUCKY, UNIVERSITY OF

Accomplished recently:

$Mn^{55}(n,n'\gamma)Mn^{55}$	$\sigma(\theta)$	E_n = 2.9 MeV
$Fe^{56}(n,n'\gamma)Fe^{56}$		
$Fe^{54}(n,n'\gamma)Fe^{54}$		
$Al^{27}(n,n'\gamma)Al^{27}$		
$F^{19}(d,\alpha)O^{17}$	$\sigma(\theta)$, for g.s. and first 3 exc. states	E_d = 0.75 - 2.5 MeV

Underway:

$Cl^{35}(n,n'\gamma)Cl^{35}$	$\sigma(90^o)$	E_n = 2.9 MeV
$Cl^{37}(n,n'\gamma)Cl^{37}$		

DWBA analysis of (d,α) and (d,p) differential cross sections.

Planned:

a) (n,n'γ) reaction sep. isotopes, Cl^{35}, Cl^{37}, S^{33}	$\sigma(90^o)$	E_n = 1-4 MeV
and Mg, Si, S^{32}, Ti, V, Mn, Bi^{209}	$\sigma(90^o)$	E_n = 1-4 MeV
b) (n,n) and (n,n'); selected elements	$\sigma(\theta)$	E_n = 1-4 MeV Isotopic comparisons.
c) $F^{19}(d,n)Ne^{20}$	$\sigma(\theta)$	E_d = 3-6 MeV Pulsed beam; time-of-flight
$Na^{23}(d,n)Mg^{24}$		
$S^{32}(d,n)Cl^{33}$		
$S^{34}(d,n)Cl^{35}$		

d) $F^{19}(d,\alpha)O^{17}$	$\sigma(\theta)$	E_d = 2.5-6 MeV
$F^{19}(d,\alpha)O^{17}$ (correlation)		
$Be^{9}(d,\alpha)Li^{7}$		
$Al^{27}(d,\alpha)Mg^{25}$		
$S^{32}(d,p)S^{33}$		
e) $Mg^{24}(p,p)Mg^{24}$	$\sigma(\theta)$	E_p = 2-6 MeV
$A^{40}(p,\alpha)Cl^{37}$	$\sigma(\theta)$	Two or three proton energies.
f) C (α,α) C O (α,α) O N (α,α) N	$\sigma(\theta)$	E_α = 1-12 MeV

g) (α,n) threshold measurements on selected isotopes.

LOCKHEED MISSILES AND SPACE COMPANY

The Lockheed 3.3-Mev Van de Graaff is engaged in measurements of neutron cross sections and cross sections induced by protons, deuterons, helium-3, and helium-4. Total neutron cross-section measurements for O^{18} have recently been completed over the neutron energy range from 100 kev to 20 Mev. The neutron energy resolution of this work varies from about 15 kev to 100 kev depending on the energy region and source reaction used. Good resolution measurements of the neutron total cross section of N^{15} is planned, certainly for neutron energies below 2 Mev.

Inelastic neutron cross sections for neutrons with energies between 340 and 1050 kev have been measured for certain states in In^{113} and In^{115}. The reaction yield is determined from scintillation spectrometer measurements of the gamma rays from the metastable states in these nuclei. These cross

sections are now being compared with the predictions of the statistical model for nuclear reactions to obtain information on the spin and parity of those excited states. Similar measurements on Rh^{103} and Ta^{180} are being considered.

Measurements of the neutron capture cross sections for In^{115} and Au^{197} have been made, and the measurements of the capture cross sections for O^{18} and Ni^{64} are planned. For the Au^{197} and In^{115} measurements a new technique was employed. The neutrons were produced from the $V^{51}(p,n)Cr^{51}$ reaction and the neutron flux determined from measurements on the Cr^{51} radioactivity. For the irradiations, the neutron target was placed at the center of a thin spherical shell of Au or In. Absolute capture cross sections in Au have been obtained from 10 to 700 kev neutron energies, and in In^{115} at 35, 200, and 500 kev.

Cross sections for the $O^{17}(n,p)N^{17}$ and $O^{18}(n,d)N^{17}$ have been measured at five neutron energies between 11 and 19 Mev. Measurements of the cross sections for the $Fe^{54}(n,p)Mn^{54}$ reaction in the neutron energy range from 3.5 to 6.5 Mev are planned.

Measurements to determine the polarizability of the neutron by measuring the neutron scattering cross section at very small angles are in progress. The small angle neutron scattering cross section is being investigated as a function of Z and neutron energy to assess that part of the scattering due to neutron polarizability from that due to nuclear and Swinger scattering.

Investigations of charged particle cross sections have concentrated on the study of low-Q deuteron induced reactions at low deuteron bombarding

energies. Most recently investigated was the angular distributions of protons from the $Be^{9}(d,p)Be^{10}$ reaction. This data, along with elastic deuteron scattering data, has been fit with DWBA calculations. Similar measurements are in progress for the $C^{13}(d,p)C^{14}$, $C^{14}(d,p)C^{15}$, $B^{11}(d,p)B^{12}$ and $O^{18}(d,p)O^{19}$ reactions. These measurements are made using either the broad range magnetic spectrograph or solid state detectors. The energy levels of Cr^{51}, Cr^{52}, and Cr^{53} are currently being investigated using the (d,p) reaction. Proton-gamma and gamma-gamma and lifetime measurements are planned for the $O^{18}(d,p\gamma)O^{19}$ reaction.

Construction on a gamma-ray goniometer system which allows gamma ray angular correlations to be measured in any "geometry" is nearing completion. Measurements with such a system allow the determination of spectroscopic parameters of nuclear energy levels to be determined uniquely, without recourse to any assumption of reaction mechanism used to produce the particular excited states--an obvious advantage for nuclear structure studies using deuterons, helium-3,etc. in the energy range which our accelerator can operate.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Linear Accelerator Program

The Linac program continues to exploit the millimicrosecond time-of-flight technique and the pulsed accelerator. The focus of interest remains photonuclear reactions. With the aid of the time-of-flight technique it has been possible to derive from photo-neutron spectra, the partial cross-section for the absorption of gamma radiation into definite energy regions

of the target nucleus (Z, A) followed by neutron emission to well defined energy regions of the daughter nucleus (Z, A-1). From the point of view of neutron physics these measurements are useful since one can single out transitions to the ground state of (Z, A-1) and by reciprocity, from the partial cross-section (γ,n_o) derive the partial cross-section (n,γ_o); the integrated absorption cross-section is a direct measure of the partial radiative width $\Gamma\gamma_o$ of the absorbing level. In addition the total neutron width $\Gamma\eta$ of (Z, A) at the energy of the absorbed gamma ray is measured. It is worth noting that these measurements provide data on $\Gamma\gamma_o$ and Γ_n for the species (Z, A) whereas neutron capture measurements provide data for the species (Z, A + 1). In elements where there are stable isotopes consecutive in A these parameters are in principle available from both kinds of measurements but in fact, current gamma ray spectroscopy makes it very difficult to distinguish the ground state transition, except in a few favorable cases. The photo-neutron measurements should be a valuable addition to the available data on radiative transitions, from the resonance region.

It is convenient to review the work by considering two neutron energy regions: above and below 0.5 Mev. Above 0.5 Mev organic scintillators are efficient neutron detectors via proton recoil events. Most of the work to date has been in this energy region with this type of detector. Below 0.5 Mev the efficiency for detection of recoil protons decreases rapidly with energy to a cut-off at about 300 Kev. For the detection of these low energy neutrons it has been found possible to employ the same detectors by intercepting neutron flux with a slug of silver and detecting the prompt gamma rays following neutron capture.

Using the recoil counter a program of measurements of $\sigma(\gamma n)$ as a function of gamma ray and neutron energy and as a function of angle has been undertaken, and data are available for Be^{9*} and C^{13}. For Be^{9} a complete analysis has been performed for gamma ray energies between about 3 and 18 Mev; at an angle of 115 degrees. In particular the ground state radiative widths for some of the states of Be^{9} have been worked out. For C^{13} data has been taken up to 17 Mev at four angles and is currently under analysis to provide the cross-section for C^{13} (γn) C^{12}.

Recently the photodisintegration of the Pb isotopes Pb^{206}, Pb^{207}, Pb^{208} has been studied up to 10 Mev excitation energy.** The neutron spectra from Pb^{208} and Pb^{209} exhibit well defined groups with a spacing greater than 20 Kev. Estimates yield typical radiative widths of 10 ev.

MICHIGAN, THE UNIVERSITY OF

The University of Michigan Nuclear Structure Group, Cyclotron Laboratory, will be engaged in measuring the absolute differential cross-sections for (d,p) and (d,n) reactions in the deuteron energy range from 5 to 40 MeV, measurements will be made in the region of 1f shell nuclei, the rare earth region, and in the region of Pb^{208}.

NATIONAL BUREAU OF STANDARDS

Elastic and Inelastic Neutron Scattering (A.C.B. Richardson and E.R. Mosburg, Jr.). $\sigma(\theta)$ has been measured for $C^{12}(n,n)$, $C^{12}(n,n')$, $Ca^{40}(n,n)$,

* Bertozzi, Demos, Kowalski, Paolini and Sargent, Proc Karlsruhe Photonuclear Conference (1960).

** Phys. Lett. Aug. 15, 1963.

and $Ca^{40}(n,n')$ at 14 Mev incident neutron energy. These angular distributions were obtained for laboratory angles from 19 to 150 degrees. The inelastic measurements resolved the 4.43 and 7.66 Mev levels in carbon, but represent the combined cross sections of the 3.35, 3.73, 3.90, and 4.48 levels in calcium. The results will shortly be submitted for publication in Nuclear Physics.

Similar measurements for 14 Mev neutrons scattered from O^{16} and Ho^{165} are planned in the near future. The measurements on O^{16} will then be extended to energies in the 2.5 to 5 Mev range.

Efficiency of a Halpern-type Neutron Detector (H. Gerstenberg and E. G. Fuller). Work is in progress to study the neutron detection efficiency for a Halpern-type neutron detector as a function of the geometrical arrangement of the BF_3 counter with respect to the sample position and beam tube. Calibrated (α,n) sources are being used as well as the $D(\gamma,n)n$, $O^{16}(\gamma,n)O^{15}$, $d(d,T)n$ and $d(T,He^4)n$ reactions to study the efficiency as a function of neutron spectrum.

Nuclear Size Determinations from π^o Photoproduction (R. Schrack, J. E. Leiss, and S. Penner). Work is continuing on the measurement of absolute differential cross section for the production of π^o mesons as a function of atomic number. The experimental techniques as well as the analysis procedure have been improved to the point where the RMS radius determined from the data depends upon the particular model chosen for the nuclear matter distribution. For a given model the RMS radius can be determined to within ± 0.1 fermi. Matter distributions as determined by π^o techniques

are in agreement, within experimental uncertainties, with the proton center distributions inferred from electron scattering measurements.

Photon Absorption Cross Sections for Aligned Nuclei (E. Ambler, E. G. Fuller, H. Gerstenberg, and H. Marshak). The experiment to measure the photoneutron yield from aligned holmium nuclei has been completed. The results showed that the tensor polarizability of the holmium nucleus was consistent within experimental uncertainties of about 15% with that determined from the analysis of the photon scattering and absorption cross sections for holmium. The data are consistent with the result expected from the Danos-Okamoto model of the nuclear photoeffect in deformed nuclei. An extension of these measurements to a study of the tensor polarizability of uranium is being considered.

Total Nuclear Absorption Cross Sections (J. Wyckoff, B. Ziegler, H. W. Koch, and R. Uhlig). Total nuclear absorption cross sections have been measured for a family of 15 elements, Be, C, O, Na, Mg, Al, Si, S, Ca, Mn, Co, Ni, Cu, Ag, and Pb with 2 to 3% energy resolution in the region between 8 and 38 Mev. Ninety Mev bremsstrahlung spectra attenuated by long absorbers were measured with a two-crystal scintillation pair spectrometer to obtain these results. The statistical significance of the results varies from element to element but shows particularly strong evidence of multi-peaked structure in Mg and Si. Shapes and absolute magnitude of these differential cross sections agree with (γ,n) and (γ,total) results obtained elsewhere. Good agreement is also obtained with total integrated cross sections obtained by other methods for a number of the elements.

NAVAL RESEARCH LABORATORY

$D(d,n)He^3$: in progress; 50 to 400 Kev; charged particle spectra, angular distributions, cross sections, relative branching ratios.

$Ni^{58}(p,\gamma)Cu^{59}$: in progress; 2-Mv Van de Graaff; triple angular correlation between directions of the proton and two gamma rays to determine spins, parities, miltipolarities.

$N^{14}(t,\alpha)C^{13}$, $N^{14}(t,d)N^{15}$, $N^{14}(t,p)N^{16}$: recently completed; 2-Mv Van de Graaff; total and differential cross sections for ground and excited states.

$Ne(t,p)Ne^{22}$: in progress; 2-Mv Van de Graaff; total and differential cross sections for ground state and first five excited states.

F^{19}, O^{18}, O^{17} plus t: planned; 2-Mv Van de Graaff; total cross sections.

$F^{19}(\gamma,p)O^{18}$, $C^{12}(\gamma,p)B^{11}$, $C^{12}(\gamma,3\alpha)$, $O^{16}(\gamma,4\alpha)$, $O^{16}(\gamma,\alpha)C^{12}$, $N^{14}(\gamma,\alpha)B^{10}$: completed using 22-Mev betatron; planned for 55-Mev electron linac; cross sections as a function of γ-ray energy.

$O^{18}(p,\gamma)F^{19}$, $Li^7(\alpha,\gamma)B^{11}$: in progress; 5-Mv Van de Graaff; absolute energies and widths of narrow resonances.

$Ca^{40}(p,\gamma)Sc^{41}$, $Ca^{40}(d,n\gamma)Sc^{41}$: planned; 5-Mv Van de Graaff; absolute energy and width of a narrow resonance and determination of deuteron binding energy.

$Li^7(He^3,p_o)Be^9$, $Li^7(He^3,t_o)Be^7$, $Li^7(He^3,\alpha_o)Li^6$: in progress; 5-Mv Van de Graaff; total and differential cross sections at various bombarding energies.

$N^{14}(He^3,\alpha)N^{13}$: in progress; 5-Mv Van de Graaff; total and differential cross sections for several α-particle groups.

In, Eu, Gd, Ta, Re, Nd polarized targets: in progress; NRL reactor; spin states of resonances are obtained with polarized monochromatic neutrons incident.

Gd(n,γ), Hf(n,γ), In(n,γ): in progress; NRL reactor; spectra of resonance capture γ-rays observed.

NORTHWESTERN UNIVERSITY

Charged Particle Physics: A series of experiments measuring absolute cross sections and polarization for elastic scattering of protons from deuterium and helium in the energy range 1 to 5 Mev was started last year. Some of these measurements have already been reported.[1,2] The experiments were interrupted to construct an eight detector scattering chamber which is designed to allow use of gaseous and solid targets within the chamber. It is planned to investigate p-D and p-He scattering cross sections and polarizations using mixtures of deuterium and helium with hydrogen in this chamber.

A measurement of total (n,p) and (n,α) cross sections for 14 Mev neutrons incident on nickel was made using a broad range spectrograph. The results were recently reported.[3] It is intended to use time of flight techniques in conjunction with solid state detectors to extend these measurements.

1. Chalmers, Cox, Seth, and Strait, Bull.Amer.Phys.Soc. 11, 8, 38 (1963).
2. Seth, Chalmers, Cox, and Strait, Bull.Amer.Phys.Soc. 11, 8, 38 (1963).
3. Singletary, Strait, and Ahn, Bull.Amer.Phys.Soc. 11, 8, 38 (1963).

Neutron Physics: A program of neutron physics was initiated earlier this year and our major effort has so far gone in equipmentation for the same. Beam pulsing facility has been installed in the terminal of our 5 Mev accelerator, and initial testing is in progress. A klystron bunching system for the terminal is anticipated in the next few months. The electronics for the time of flight neutron experiments is nearly completed. Two neutron collimator detector tanks have been designed for a new underground experimental room. Flight paths up to 8 meters will be obtainable in any direction from 0^{o} to 165^{o} and an ultimate time resolution of 2ns with a peak current of 5 ma., is anticipated. The following cross section measurements are planned as soon as the facility becomes operational:

1.	$\sigma_{nt}(E)$	Ca	0.6-3 Mev ΔE = 0.005 Mev
2.	$\sigma_{nm}(E;E',\theta)$	C	6.0-7.0 Mev ΔE = 0.1 Mev
3.	$\sigma_{n1n}(E,\theta)$ and $\sigma_{nm}(E;E',\theta)$	Li,N,O,Ca,Zr,U^{238}	5-8 Mev ΔE = 0.5 Mev

PENNSYLVANIA, UNIVERSITY OF

We plan the following measurements:

$C^{12}(\gamma,n)$ 20 to 25 Mev

$He^{4}(He^{3},p)$ ~ 12 Mev

$C^{12}(\gamma$ -) total abs. σ

20 to 25 Mev

These have recently been accomplished:

$C^{12}(\gamma,p)$	20 - 23 Mev
Be, O, Al Total γ abs.	20 - 22 Mev
$O^{18}(\gamma,n)$	10 - 20 Mev
Ca (γ,d)	24 Mev

PENNSYLVANIA STATE UNIVERSITY

$F^{19}(n,\gamma)F^{20}$: This cross section has been measured for thermal neutrons by S. S. Glickstein and R. G. Winter using a research reactor.[1] The result is $\sigma = 10.0 \pm 0.7$ mb.

$V^{51}(n,\gamma)V^{52}$: This cross section has also been measured for thermal neutrons by Glickstein and Winter using a research reactor.[2] The result is $\sigma = 4.88 \pm 0.18$ b.

$O^{16}(d,\gamma)F^{18}$: This cross section has been measured in the center of mass energy range 0.56 - 3.67 Mev by R. G. Winter and R. Owens using a Van de Graaff accelerator. This work was done while Dr. Winter was visiting at Oxford and Harwell. It is expected that the results will be published shortly.

(P,γ), $(P,P'\gamma)$, $(P,\alpha\gamma)$ cross sections using targets of K^{39}, K^{40}, K^{41} may be obtained as a by-product of experiments now being initiated by T. T. Thwaites using protons from a 5.5 Mev Van de Graaff accelerator.

1. Phys. Rev. 129, 1281 (1963); 130, 2599 (1963).
2. Bull. Am. Phys. Soc. II V. 8 No. 4 (1963).

(n,α) cross section measurements for various medium weight and heavy targets for which the Q value is positive are being attempted by J. Harris using thermal neutrons from a research reactor.

(γ,n) cross section measurements are in progress by D. J. Donahue and R. R. Hurst and by D. J. Donahue and L. Green. These measurements employ monoenergetic gamma rays in the range 4-11 Mev obtained from n,γ reactions in various isotopic radiators. Measurements are being made on a large variety of targets ranging from boron to uranium.

PITTSBURGH, UNIVERSITY OF

Energy distributions and angular distributions from (d,p), (d,t), and (d,d') reactions have been measured from some or all of the isotopes of Fe, Ni, Zn, Zr, Mo, Pd, Cd, Sn, Te, Pt, Tℓ, and Bi. Studies were made on (d,Li^6), (d,Li^7), and (d,Li^8) reactions on C, O^{16}, O^{18} and Aℓ. Single particle neutron states in a large number of nuclei were located, and the systematics of this was studied and explained theoretically. The tie-in between neutron capture and (d,p) reactions in nickel was established so that the two types of data can be included in the same analysis.

PURDUE UNIVERSITY

	Reaction	Incident Energy (Mev)	Angular Range* (Lab)	Detector
Recently Completed	$F^{19}(He^3,d_{0,1})Ne^{20}$	13.0	10° - 160°	CsI
	$F^{19}(\alpha,t_{0,1})Ne^{20}$	18.5	10° - 105°	CsI
	$Be^9(\alpha,\alpha_{0,1})Be^9$	18.4	7.5° - 172.5°,100°	Si
	$Be^9(\alpha,\alpha_{2,3})Be^9$	18.4	7.5° - 140°,90°	Si
	$P^{31}(\alpha,\alpha_{0-2})P^{31}$	18.4	7.5° - 172.5°	Si
Work in Progress	$P^{31}(d,d_0)P^{31}$	9.2	7.5° - 172.5°	Si
	$P^{31}(d,\alpha_{0-6})Si^{29}$	9.2	20° - 172.5°	Si
	$F^{19}(d,d_{(0-2)})F^{19}$	9.2	7.5° - 172.5°	Si
	$F^{19}(d,\alpha_{0-4})O^{17}$	9.2	7.5° - 172.5°	Si
	$Al^{27}(d,d_0)Al^{27}$	9.2	7.5° - 172.5°	Si
	$Al^{27}(d,\alpha)Mg^{25}$	9.2	7.5° - 172.5°	Si
	$Mn^{55}(d,d_0)Mn^{55}$	9.5	7.5° - 172.5°	Si
	$Mn^{55}(d,\alpha_{0-2})Cr^{53}$	9.5	7.5° - 172.5°	Si
	$Ca^{40}(d,\alpha_{0-30})K^{38}$	9.2	10° - 155°	BRS**
Work Planned	$Na^{23}(\alpha,\alpha_{0-3})Na^{23}$	18.4	7.5° - 172.5°	Si
	$P^{31}(d,2p)Si^{31}$	9.5	angle-energy correl.	Si
	$K^{39}(d,\alpha_{0-20})A^{37}$	9.3	10° - 155°	BRS
	$K^{39}(\alpha,d_{0-20})Ca^{41}$	18.5	10° - 155°	BRS
	$O^{16}(\alpha,P_{0-5})F^{19}$	18.5	10° - 155°	BRS
	$O^{18}(He^3,d_{0-5})F^{19}$	14.0	10° - 155°	BRS

* The angular distributions are, in general, measured in steps of 2.5° or 5°, according to their structure.

** BRS = broad-range magnetic spectrograph.

ROCHESTER, UNIVERSITY OF

Recently Done: $C^{12}(He^3,n)$ and $C^{13}(He^3,n)$ from 5.5 to 11 Mev. Excitation curves and angular distributions. (URPA-7).

$C^{13}(He^3,\alpha)C^{12}$. Angular distributions at 8.82, 9.44 and 10.30 Mev.

$Be^9(\alpha,n)$ and $C^{13}(\alpha,n)$. Angular distributions in the 5.9 to 8.4 Mev region. (URPA-8).

Coming: Study of $C^{12}(d,d)C^{12}$ in the vicinity of the 4.06 Mev resonance (to obtain optical model parameters to use in analyzing earlier).

Also others, notably those induced by He^3 bombardment.

SOUTHERN CALIFORNIA, UNIVERSITY OF

Differential cross sections for proton elastic scattering

E_p = 31 MeV

H^2, He^3, He^4, Li^6, N^{14}, O^{16}, S^{32}, Ni^{60}, Pb^{208}.

Differential cross sections for proton elastic and inelastic scattering on C^{12} for 17 MeV $\leq E_p \leq$ 31 MeV.

Differential cross sections for inelastic scattering of protons from low lying excited levels

S^{32} (Q = -2.237), Ni^{60} (Q = 1.33 MeV), Pb^{208} (Q = -2.62 MeV).

Proton total reaction cross sections E_p = 29 MeV

C, Al, Ni, Ag, Au; Cr, Fe, Co, Cu, Zn, Ge.

Proton total reaction cross sections 17 MeV $\leq E_p \leq$ 29 MeV

C, Cu.

$\sigma_{p,xn}$ E_p = 31 MeV

Be, C, O, F, Al, Ti, V, Fe, Co, Ni, Cu, Zn, Mo, Ag, Cd, Sn, Ta, Au, Pb, Ni^{58}, Ni^{60}, Cu^{63}, Cu^{65}.

$\sigma_{p,\alpha}$ E_p = 31 MeV

F^{19}, Al^{27}, Na^{23}.

$\sigma_{p,d}$ E_p = 31 MeV

He^4, C^{12}.

$\sigma_{p,pd}$ E_p = 31 MeV

Li^6, Li^7, N^{14}.

$\sigma_{p,2p}$ E_p = 31 MeV

Li^6, Li^7.

TEXAS, UNIVERSITY OF

C-14(p,p)C-14, elastic scattering cross section; differential cross sections at 90°, 125°, 141°, and 165° in interval $0.6<E_p<2.8$ Mev.

Deuteron capture in C-14 in interval $1.1<E_d<2.6$ Mev.

C-12(n,n)C-12 in interval $17<E_n<21$ Mev (now continued at Oak Ridge).

Inelastic scattering of protons from B-10 and B-10(p,α) for $2<E_p<4$ Mev (relative cross sections).

Compound elastic scattering by Pb-208 at 1.52, 1.79, 2.03, and 3.15 Mev (by comparison with results for Pb-206 and Pb-207).

Al-27(d,α)Mg-25 and F-19(d,α)O-17: angular distributions at 5 degree intervals from 20° to 165° for alphas to five lowest states in Mg-25 at E_d = 2.39, 2.48, and 2.58 Mev, and for alphas (relative cross sections) to the four lowest states in O-17 at E_d = 2.48 and 2.58 Mev.

Zr-90(d,p)Zr-91 in interval from approximately 2 to 4 Mev; present results at 2.2 and 2.7 Mev compared with distorted wave Born approximation stripping theory. Silicon and other selected nuclei will be studied.

Angular distribution of protons from C-14(d,p)C-15 at selected energies from threshold to 4 Mev.

TEXAS NUCLEAR CORPORATION

Texas Nuclear Corporation is presently engaged in a program to measure $\sigma_{nG}(E,E_\gamma)$ and $\sigma_{nG}(E,E_\gamma,\Psi)$ for a large number of elements and isotopes. $\sigma_{nG}(E,E_\gamma)$ is determined at 90°.

$\sigma_{nG}(E,E_\gamma)$ has been measured at E_n = 4.0 Mev and 15 Mev for Li, N, Na, Al, Si, S, Cr, Fe, Ni, Y, Zr, W, Pb^{206} Pb^{207}, Pb^{208}, Bi. Additional measurements in the neutron energy range from 1.0 Mev to 4.5 Mev have been performed on Li, F, Na, Mg, Al, Si, V, Mn, Fe^{56}, Cu, Y, Pb^{206}, Pb^{207}, Pb^{208}, Bi.

$\sigma_{nG}(E,E_\gamma,\Psi)$ is measured between 20° and 130° with an angular resolution of 9° determined by the scatterer size. $\sigma_{nG}(E,E_\gamma,\Psi)$ has been determined for Mg and Si at incident neutron energies of 3.0 Mev, 3.5 Mev, 4.0 Mev, and 4.5 Mev, for Al at 3.5 Mev and 4.0 Mev, for Fe^{56} at 1.0 Mev, 1.5 Mev, 2.5 Mev, 3.0 Mev, 3.5 Mev and 4.0 Mev and for Pb^{206}, Pb^{207}, Pb^{208} and Bi at 4.0 Mev.

Major emphasis in the next year will be placed on measurements of $\sigma_{nG}(E,E_\gamma,\Psi)$ at 4.0 Mev and 15 Mev for the elements that $\sigma_{nG}(E,E_\gamma)$ have been measured at this laboratory. $\sigma_{np}(E)$ and $\sigma_{nn}(E,\theta)$ for He^3 will be measured below 2 Mev. $\sigma_{np}(E)$ and $\sigma_{n\alpha}(E)$ for A will be measured up to 14 Mev.

WASHINGTON, UNIVERSITY OF

Differential cross sections for elastic and inelastic scattering of 10.4-MeV protons by N^{14} leading to N^{14} in energy states at 0.0, 2.31, 3.95, 4.91, 5.10, 5.69, 5.83, 6.23, 6.44, and 7.03 MeV have been measured at 5° intervals from 15° to 170°. The total cross sections for inelastic scattering leading to the states at energies from 2.31 to 7.03 MeV are 3.9 ± 0.3, 66.3 ± 5.3, 5.1 ± 0.4, 30.0 ± 2.4, 15.1 ± 1.2, 19.1 ± 1.6, 7.4 ± 0.6, 10.1 ± 0.8, and 24.5 ± 2.0 millibarns respectively. (R.E. Brown)

Differential scattering cross sections have been determined for $C^{12}(p,p')C^{12}$ (Q = 0 and -4.43 MeV) at proton energies 10.07, 10.20, 10.29, 10.35, 10.38 and 10.50 MeV. Relative scattering cross sections have been determined for $Mg^{24}(p,p')Mg^{24}$(Q = 0 and -1.37 MeV) at proton energies 10.37 and 10.60 MeV and for $Ni^{58}(p,p')Ni^{58}$(Q = 0 and -1.41 MeV) for proton energy 10.30 MeV. (R. E. Brown, J. B. Gerhart, W. A. Kolasinski, F. H. Schmidt)

Differential scattering cross sections have been determined for $O^{16}(d, Li^{6})C^{12}$ for 21 MeV deuterons. (P. Mizera and F. W. Slee)

Preliminary work has begun on a measurement of the differential cross section for the $T(d,n)He^{4}$ reaction, at an incident deuteron energy of 21 MeV. A solid (Ti-T) tritium target is being used. (J. Alster, K. Ilakovac, C. Williamson)

A measurement has begun of the radiative capture reaction, $H(d,\gamma)He^{3}$, at an incident deuteron energy of 21 MeV. A magnetic analyzer and a solid state detector are used in the detection system. (D. Hendrie and K. Ilakovac)

WISCONSIN, UNIVERSITY OF

Most of the experiments which have been carried out here recently do not involve measurements of cross sections. A large part of the effort was on measurements of polarization of neutrons and charged particles.

The only neutron cross sections under investigation are neutron-alpha particle differential scattering cross sections between 10 and 30 MeV.

Charged particle cross sections have been measured for bombarding energies usually up to 12 MeV for the following reactions:
Elastic and inelastic scattering of protons on oxygen
$O^{16}(p,\alpha)$, $B^{11}(p,n)$, $B^{10}(d,n)$
(p,n) cross sections for thin and thick targets of intermediate and heavy elements.

Measurements in progress:
$He^4(d,p)$, $He^4(d,d)$
(p,n) cross sections for thin targets of intermediate and heavy elements.

Measurements planned:
Deuterons on N^{14}, O^{16}, F^{19}
Differential cross sections for neutron production from proton bombardment of thin targets of intermediate weight isotopes.

YALE UNIVERSITY

Photonuclear Reactions:

Measurement of the $He^3(\gamma,d)p$ cross-section has been made in the energy range 9-30 Mev. Cross-sections were determined in terms of the

known cross-section for the $H^2(\gamma,p)n$ reaction. The He^3 cross-section exhibits a peak at E_γ = 12 Mev with γ_{max} = 90 μb/ster measured at 90°. For higher energies γ diminishes in approximate agreement with the theory of Gunn and Irving.

A similar measurement for the reaction $H^3(\gamma,d)n$ is planned.

Measurement of the angular variation of the relative cross-section for $H^2(\gamma,p)n$ is in progress with preliminary results already available.

A preliminary measurement of the cross-section for the reaction $O^{16}(\gamma,p)N^{15}$ indicates peaks in σ at 29 ± 0.5 Mev at 32 ± 0.5 Mev. The absolute integrated cross-sections for these levels are estimated to be an order of magnitude lower than σ in the giant resonance region. The cross-section for the giant resonance region is in agreement with that of Dodge and Barber as obtained from electrodisintegration measurements.

(γ,p) reactions in C and Ca will be undertaken.

Neutron Capture Gamma Ray Measurements:

The high energy gamma ray spectra emitted following capture in Au^{197} of neutrons having energies between thermal and 1 KeV have been measured. By observing the interference in the 4.9 eV resonance, an upper limit for the potential capture cross section in gold is determined which is in agreement with the predictions of Lane and Lynn. There is little correlation between the partial radiation widths and the reduced neutron widths for 12 resolved resonances which shows that channel resonance capture is quite small for gold. The chi-squared distributions for the high energy partial radiation widths indicate that either the number of degrees of

freedom of a single partial width is larger than that expected by Porter and Thomas, or the transitions are anti-correlated, or the number of gamma-ray transitions is larger than previously measured. There is evidence for little change in the gamma ray spectra averaged over resonances between thermal and 15 KeV.