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TITLE: LASL STATUS REPORT TO THE U. S. NUCLEAR DATA COMMITTEE

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LOS ALAMOS SCIENTIFIC LABORATORY, UNIVERSITY OF CALIFORNIA

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A. STANDARDS

1-6

1. Interaction of Fast Neutrons with the Isotopes of Hydrogen and Helium (J. D. Seagrave)

Because of their intrinsic interest, LASL has a continuing program of measurements of the neutron interactions with the isotopes of hydrogen and helium. Recent LASL publications have included studies of neutron interactions with ^{4}He,[1] and of neutron interactions with deuterium and tritium.[2] As a part of this program, we have recently completed a study of the elastic scattering of neutrons by ^{3}He in the energy range from 8 to 24 MeV. Final values for the integral cross sections are shown in Table A-1 and plotted with other data in Fig. A-1. This presentation supersedes and extends the previous graphical summary given by Seagrave.[3] New ^{3}He(n,p)T cross sections are derived (by time-reversal calculations) from the recent LASL measurements of T(p,n)^{3}He by McDaniels et al.[4] The ^{3}He(n,d)D cross sections are from various older sources. New measurements at LASL of the D(d,n)^{3}He reaction at higher energies will permit extension of the ^{3}He(n,d)D cross section calculations in a similar manner.

From the integral values of the new elastic cross sections and the calculated ^{3}He(n,d)D and ^{3}He(n,p)T cross sections, together with new total cross section values (see below), it was possible to derive upper limits for the sum of the *^{3}He(n,2n) and ^{3}He(n,3n) reactions.*

The differential cross sections are shown in Fig. A-2 and tabulated in Table A-2. Recent work by P. W. Lisowski[5] has provided n-^{3}He polarization

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[1] n-^{4}He Elastic Scattering near 20 MeV, A. Niiler, M. Drosg, J. C. Hopkins, J. D. Seagrave, and E. C. Kerr, Phys. Rev. C4, 36 (1971).

[2] Elastic Scattering and Polarization of Fast Neutrons by Liquid Deuterium and Tritium, J. D. Seagrave, J. C. Hopkins, D. R. Dixon, P. W. Keaton, Jr., E. C. Kerr, A. Niiler, R. H. Sherman, and R. K. Walter, Ann. Phys. 74, 250 (1972).

[3] Elastic Scattering of Fast Neutrons by Liquid Hydrogen, Deuterium, Tritium and by ^{3}He, J. D. Seagrave (in Few-Body Problems, Light Nuclei, and Nuclear Interactions, Brela, Yugoslavia, 1967, Gordon and Breach, London 1969, Vol. 2, p. 820).

[4] Angular Distributions and Absolute Cross Sections for the T(p,n)^{3}He Neutron Source Reaction, D. K. McDaniels, M. Drosg, J. C. Hopkins, and J. D. Seagrave, Phys. Rev. C6, 1593 (1972).

[5] P. W. Lisowski, Ph.D Thesis, Duke University (1973).

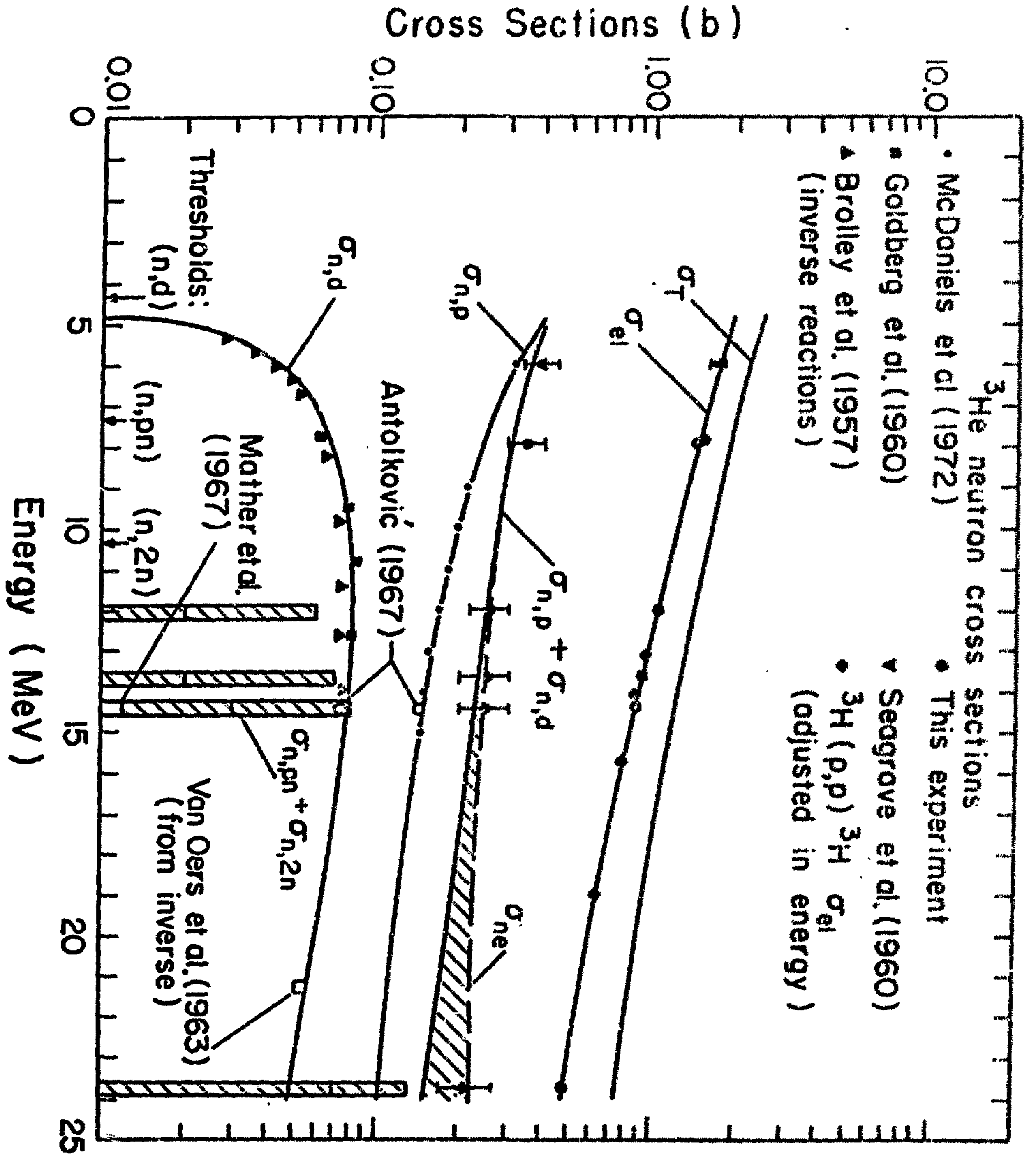

Fig. A-1. The ^{3}He integral elastic scattering cross sections (σ_{el}) for neutrons in the energy range 8-24 MeV. Cross sections for other neutron interactions with ^{3}He and earlier measurements of σ_{el} are shown for comparison.

Table A-1

n-^{3}He Integral and Elastic 0° Differential Cross Sections (in barns)

Type	E_n (MeV) 7.90	12.00	13.60	14.40	23.70
σ_T[a]	1.78 ±0.018	1.30 ±0.020	1.17 ±0.035	1.12 ±0.035	0.70 ±0.055
$\sigma_{el}(0°)$Wick[b]	0.43	0.35	0.32	0.31	0.20
$\sigma_{el}(0°)$[b,c]	0.44	0.36	0.34	0.33	0.22
σ_{el}[d]	1.43 ±0.05	1.04 ±0.03	0.92 ±0.03	0.87 ±0.03	0.48 ±0.02
$\sigma_{ne} = \sigma_T - \sigma_{el}$	0.35 ±0.05	0.26 ±0.04	0.25 ±0.05	0.25 ±0.05	0.22 ±0.06
$\sigma_{n,p}$[e] + $\sigma_{n,d}$[f]	0.31 ±0.01	0.24 ±0.01	0.23 ±0.01	0.22 ±0.02	0.15[c] ±0.02
$\sigma_{n,pn} + \sigma_{n,2n}$	0.04 ±0.05	0.02 ±0.04	0.02 ±0.05	0.03 ±0.05	0.07 ±0.06

[a] Data of Goulding, Stoler, and Seagrave (LA-UR-73-1319).

[b] Barns/steradian.

[c] Extrapolated.

[d] By integration.

[e] Converted data of McDaniels et al. [Phys. Rev. C6, 1593 (1972)].

[f] Adjusted from data of Brolley et al. [Phys. Rev. 107, 821 (1957)], Goldberg and Leblanc [Phys. Rev. 119, 1992 (1960)], and Van Oers and Brockman [Nucl. Phys. 48, 625 (1963)].

Table A-2

Lab Cross Sections for the Reaction $^3He(n,n)^3He$ in mb (liquid samples only)

Energy	7.00 MeV		12.00 MeV		13.60 MeV		14.40 MeV		23.70 MeV	
$\cos\theta_{cm}$	θ_{lab}	$\sigma\pm\Delta\sigma$	θ_{lab}	$\sigma\pm\Delta\sigma$	θ_{lab}	$\sigma\pm\Delta\sigma$	θ_{lab}	$\sigma\pm\Delta\sigma$	θ_{lab}	$\sigma\pm\Delta\sigma$
0.90	19.4	620. ±39.	19.5	537. ±18.	19.4	471. ±17.	19.3	436. ±15.	19.4	267. ±12.
0.80	27.9	496. ±25.	28.0	415. ±18.	27.9	345. ±13.	27.7	341. ±11.	27.8	194. ± 7.
0.70	34.5	421. ±13.	34.6	301. ± 7.	34.6	273. ± 9.	34.5	265. ± 9.	34.6	140. ± 6.
0.60	40.5	320. ±10.	40.5	228. ± 8.	40.5	209. ± 7.	40.5	189. ± 7.	40.5	96.8 ± 5.4
0.55	43.4	274. ±11.	43.4	195. ± 5.	43.4	172. ± 4.	43.4	166. ± 5.	43.4	76.1 ± 3.5
0.40	51.2	186. ± 8.	51.5	121. ± 8.	51.4	106. ± 4.	51.4	104. ± 4.	51.3	47.4 ± 3.2
0.25	58.8	109. ± 5.	58.9	75.2 ± 4.7	58.8	69.2 ± 2.8	58.8	66.2 ± 2.6	58.9	28.1 ± 1.7
0.10	66.4	66.5± 3.3	66.4	44.9 ± 2.5	66.5	36.9 ± 1.8	66.3	33.0 ± 1.8	66.3	17.6 ± 1.5
0.00	71.4	42.4± 1.9	71.6	27.8 ± 1.1	71.6	24.6 ± 1.1	71.4	23.7 ± 1.0	71.5	10.5 ± 1.9
-0.10	76.5	29.1± 1.3	76.8	17.6 ± 1.3	76.8	17.0 ± 1.0	76.6	14.3 ± 0.8	76.6	7.44± 0.86
-0.30	87.9	15.7± 0.8	87.8	7.53± 0.39	87.8	6.26± 0.31	87.8	6.08± 0.35	87.8	5.50± 0.72
-0.50	100.8	17.7± 1.2	100.9	7.31± 0.52	100.8	5.94± 0.32	100.7	5.06± 0.33	100.7	4.10± 0.73
-0.60	108.4	22.3± 1.3	108.4	11.4 ± 0.7	108.4	8.53± 0.44	108.5	7.84± 0.36	108.3	4.33± 0.55
-0.715	118.3	29.7± 1.0	118.2	16.7 ± 1.0	118.5	12.4 ± 0.7	118.5	12.3 ± 0.46	118.5	5.46± 0.58
Scale Errors (not included above)		±3.1%		±2.8%		±3.1%		±2.8%		±2.9%

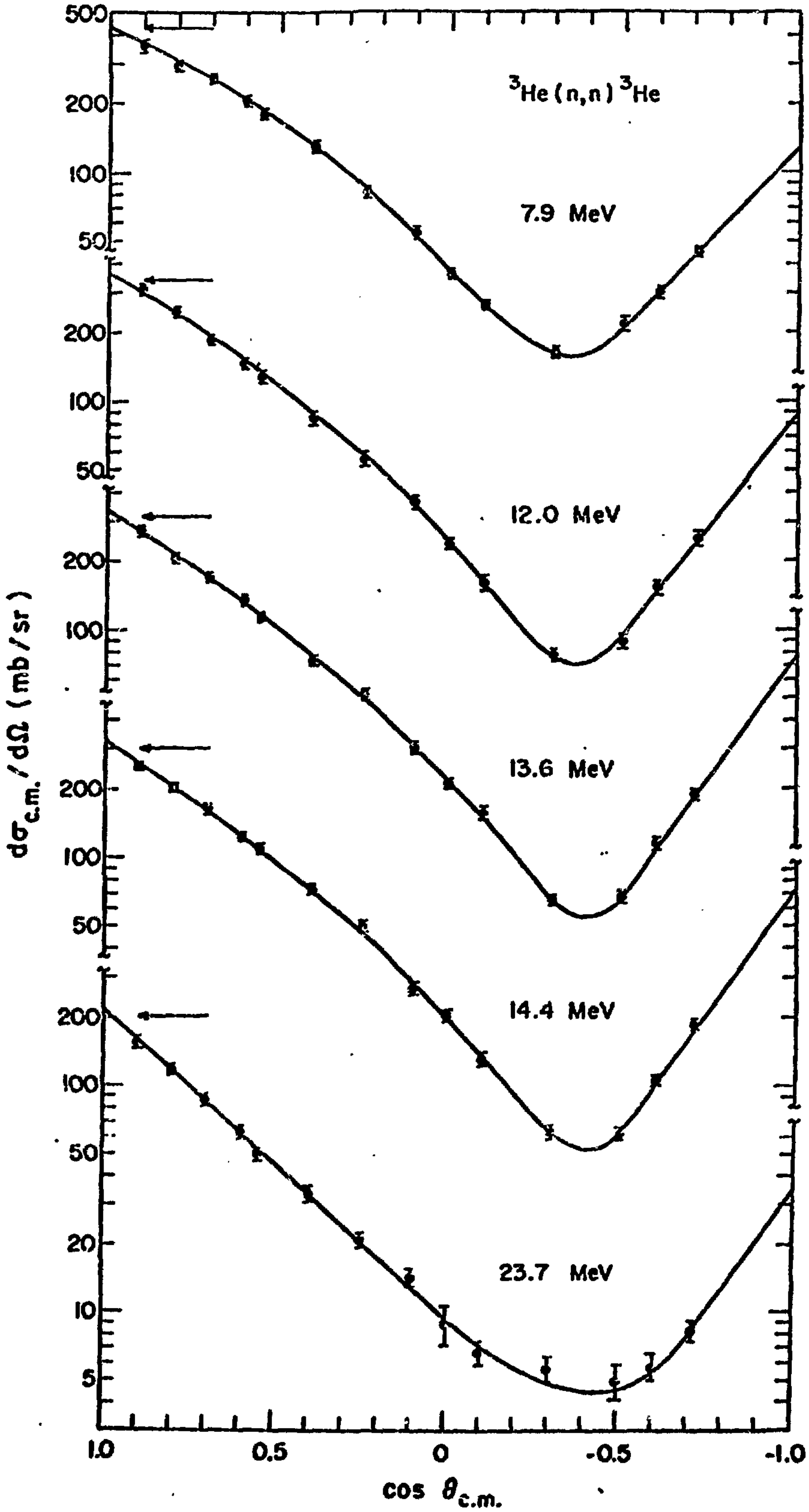

Fig. A-2. The ^{3}He differential elastic scattering cross section for neutrons in the energy range 8-24 MeV.

data at 8.0, 12.0, and 17.1 MeV, which superseded earlier work of Behof et al. at 8 MeV and of Büsser et al. at 12 MeV. Lisowski also made phase-shift analyses which give excellent fits to the LASL elastic cross sections and the Duke polarizations and clearly rule out all previous data above 6 MeV as erroneous. Dodder (LASL Group T-9) et al. will use the new data in their four-body energy-dependent analysis.

Total cross sections for the interaction of fast neutrons with hydrogen, tritium, ^{3}He, and ^{4}He were measured at LASL many years ago[1] and also with deuterium.[2] Recently, in a collaboration with Goulding and Stoler at the Rensselaer Polytechnic Institute Electron Linac, we made improved measurements of the neutron total cross section of ^{3}He and ^{4}He in the MeV energy region. The n-^{4}He measurements are of value in energy-dependent five-body calculations of the most strongly polarizing nuclear interaction known, and the new n-^{3}He measurements represent a nearly ten-fold increase in precision over the earlier measurements.

We are also making preparations to measure the neutron total cross section of tritium with Berman at the LLL Electron Linac with apparatus similar to that used at RPI. Because of the extraordinary quantity of tritium involved (100 liters, or 250,000 Ci), dry runs will be made with hydrogen and deuterium for the high-energy measurements (0.5-50 MeV), and with deuterium and ^{3}He for those at low energies (1-500 keV).

2. Breakup of Deuterium (J. D. Seagrave)

A preprint of the work of Carlson et al. at UCLA gives results for the p-D total reaction cross section in the energy range 20-50 MeV. These results are compared with other measurements and estimates of the neutron reaction cross section in Fig. A-3 (adapted from Carlson et al). It is interesting to note that the asymptotic trend is to approach more nearly 2/3 σ_T than the value of 1/2 σ_T which might be expected from the optical representation under the condition of complete absorption in all channels. Preliminary results of Pauletta and Brooks at the University of Cape Town for $\sigma_{n,p}$ in the range 8-22 MeV using a pulse-shape discrimination method lie consistently above this composite picture, and extend above 200 mb at the upper end of the range. The source of this divergence is not clear, but it may involve a flux-measurement problem. The LASL value of 158±16 mb (E. R. Graves, 1971) at 14.46 MeV was based on reference to the hydrogen cross section by the inclusion of a known small amount of hydrogen in a deuterated scintillator.

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[1] Total Neutron Cross Sections of the Hydrogen and Helium Isotopes, Los Alamos Physics and Cryogenics Groups, Nucl. Phys. 12, 291 (1959).

[2] Total Cross Section of Deuterium for Neutrons from 0.2 to 22 MeV, J. D. Seagrave and R. L. Henkel, Phys. Rev. 98 666 (1955).

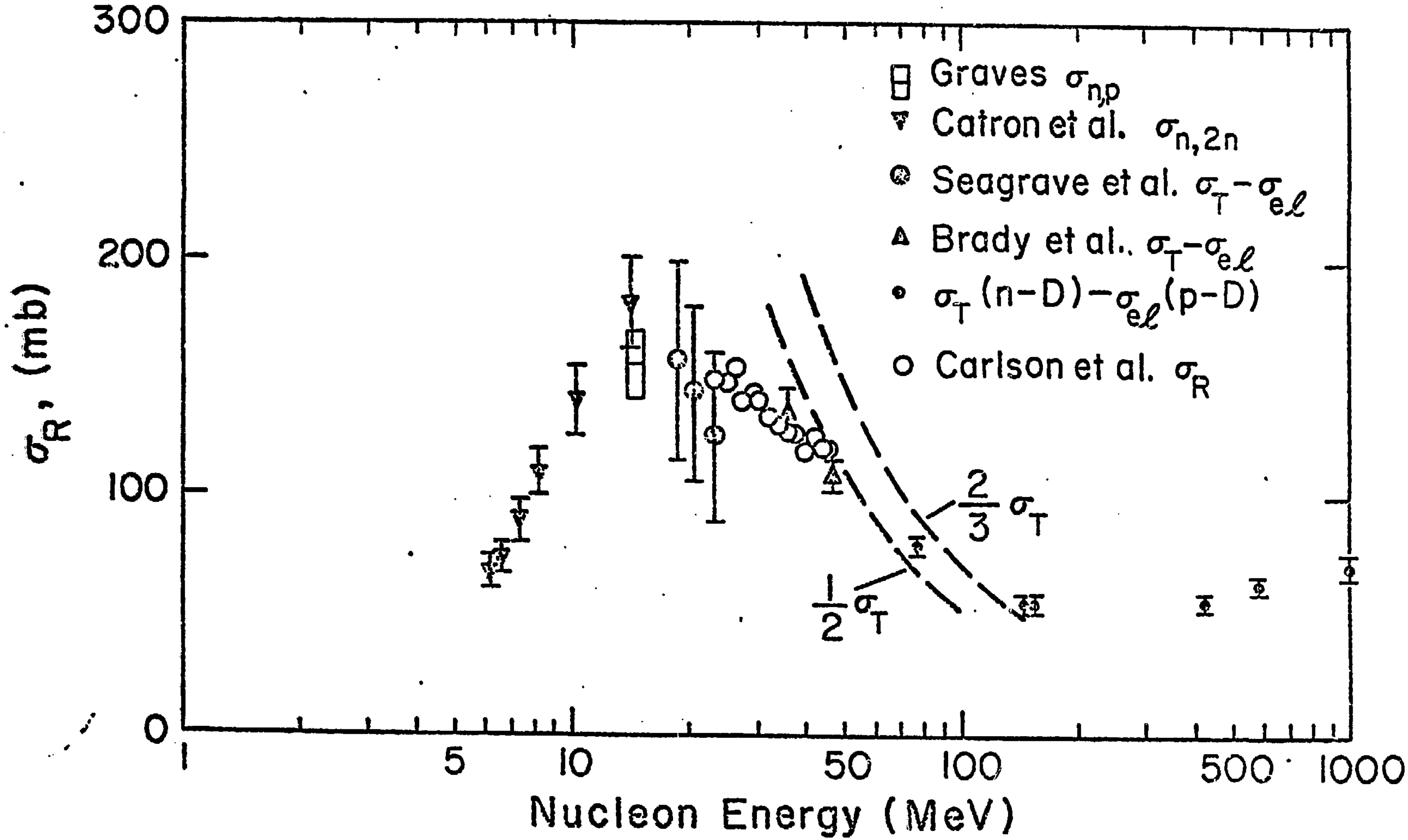

Fig. A-3. Break up Cross Sections of deuterium (after Carlson).

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3. Thermal Capture Cross Sections for ^{6}Li and ^{7}Li (E. T. Jurney) 8-13

a. Thermal Neutron Radiative Capture by ^{7}Li

Values given in Brookhaven National Laboratory report BNL-325 for the thermal neutron radiative capture cross section of ^{7}Li cover the range from 33±5 to 44±10 mb. Serious uncertainties also exist in the literature regarding the degree of branching of the gamma rays which deexcite the compound ^{8}Li nucleus directly to the ground state and those which form a 2-step cascade by decays through the only energy level known to exist between the ground level and the neutron binding energy of ^{8}Li. We have measured the energies and intensities of the three prompt gamma rays from the reaction ^{7}Li(n,γ)^{8}Li and from the measurements arrived at new values for both the capture cross section of ^{7}Li and the gamma-ray branching ratio of the subsequent deexcitation of the compound ^{8}Li nucleus.

Gamma rays from a 1.4-g target of Li_2CO_3 placed in the internal target neutron capture facility in the LASL Omega West Reactor thermal column were viewed by a Ge(Li) spectrometer. A separate run with a 0.1-g target of CH_2 was made to provide a capture cross section standard; thus the unknown intensities were determined relative to the hydrogen capture cross section, σ_c = 332±1 mb.

The radiative capture cross section of ^{7}Li was obtained by summing the partial cross sections for producing ^{8}Li deexcitation to the ground level and to the 981 keV level. The result and a comparison with previous measurements are given in Table A-3.

Energies and intensities of the three gamma rays produced by thermal neutron capture in ^{7}Li are given in Table A-4. Although the absolute intensities of the 1052-981 cascade can be stated only to an accuracy of ~10%, their intensities relative to each other are equal to within ~1%. This equality and the gamma ray branching ratio of ~10% from the compound capture state places a limit on the β decay from the 981 keV level of ~0.1 per 100 neutrons captured.

b. Thermal Neutron Radiative Capture by ^{6}Li

The recommended value[1] for the thermal (n,γ) reaction cross section for ^{6}Li is 45±10 mb. This value is based on the observation of the gamma rays which deexcite the compound ^{7}Li nucleus following neutron

[1] "Neutron Cross Sections," J. R. Stehn, M. D. Goldberg, B. A. Magurno, and R. Weiner-Chasman, Brookhaven National Laboratory report BNL-325, Vol. I, 2nd Ed., Suppl. No. 2 (1964).

Table A-3

$\sigma(n,\gamma)$ for Thermal Neutron Capture by ^7Li

$\sigma(n,\gamma)$ (mb)	Reference
45.4±3	This work.
40 ±12	L. Jarczyk, et al. (1961), reported in BNL-325.
40 ± 8	W. Imhof, et al. (1959), reported in BNL-325.
44 ±10	E. A. Koltypin and V. M. Morozov (1956), reported in BNL-325.
33 ± 5	D. J. Hughes, et al. (1947), reported in BNL-325.
37 ± 4	Recommended value, BNL-325

Table A-4

Energies and Intensities of γ-Rays from Thermal Neutron Capture by ^7Li

E_γ (keV)[a,b]	I_γ (mb)[b]	I_γ (γ/100 n)[b]	I_γ (γ/100 n)[c]	I_γ (γ/100 n)[d]
980.7 ±0.2	4.8±0.5	10.6±1	30	10.62
1052 ±0.2	4.8±0.5	10.6±1	20	5.30
2032.78±0.28	40.6±3	89.4±1	80	96.49

[a]Corrected for nuclear recoil.

[b]Present work.

[c]L. Jarczyk, et al. (1961), reported in BNL-325.

[d]"Line and Continuum γ-Ray Yield from Thermal-Neutron Capture in 75 Elements," V. J. Orphan, N. C. Rasmussen, and T. L. Harper, Gulf General Atomic report GA-10248 (1970). Intensities renormalized to take into account the abundance of ^7Li in natural lithium.

capture; Bartholomew[1] reports deexciting transitions of 7.26 and 6.78 MeV with a combined capture cross section (corrected[2]) of 30±8 mb, while Jarczyk et al.[3] report deexciting gamma rays of 7.26, 6.78, and 2.61 MeV to give a capture cross section of 48±10 mb. The two measurements on which the recommended cross section is based can be said to be in agreement only because of the large quoted individual uncertainties; it is also of interest to confirm the presence reported by Jarczyk et al.[3] of the 2.61 MeV transition to the first excited state in ^{7}Li at 4.629 MeV and its subsequent decay to the ground state.

The prompt gamma-ray spectrum from a 1.7-g target of Li_2CO_3 was measured with the Ge(Li) spectrometer and thermal neutron capture facility at the LASL Omega West Reactor. A target with the two lithium isotopes in their natural abundance was chosen, since the 40.6 mb partial cross section for the 2032 keV transition from capture in ^{7}Li (see Section A.3.a, above) could be used as an intensity standard, thereby eliminating uncertainties in determining the average neutron flux in the target caused by the large (n,α) cross section of ^{6}Li.

Results of the present experiment are given in Table A-5. The uncertainty shown for $\sigma(n,\gamma)$ is dominated by the ±3 mb uncertainty in the absolute intensity of the transition in ^{8}Li taken as a standard. Neither member of the 2.61 → 4.63 MeV transition reported in Ref. 3 was observed, yet the 2.18 MeV transition following capture in ^{16}O ($\sigma_c \approx 120$ μb) was clearly present. It is thus possible to place a limit of <1 γ/100 n on the deexcitation of ^{7}Li via the 4.63 MeV state.

The reaction $^{10}B(n,\alpha)^{11}B$ leads to excitation of the 478 keV state in ^{7}Li via a 93% α branching (see Fig. A-4). Deexcitation to the ^{7}Li ground state takes place while the recoiling nucleus is in motion, however, and the observed gamma ray is severely Doppler broadened. Figure A-5 shows the 478 keV transition from the $^6Li(n,\gamma)$ reaction superimposed on a broad pedestal, caused by the broadened gamma-ray deexcitation of the same level in ^{7}Li. The area of the broad peak corresponds to a boron impurity of ~18 ppm in the target sample. The peaked appearance of the low-energy shoulder is caused by a 472 keV transition following neutron capture in chlorine, another chemical contaminant in the sample.

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[1] G. A. Bartholomew and P. J. Campion, Can J. Phys. 35, 1347 (1957).

[2] "Neutron Cross Sections," J. R. Stehn, M. D. Goldberg, B. A. Magurno, and R. Weiner-Chasman, Brookhaven National Laboratory report BNL-325, Vol. I, 2nd Ed., Suppl. No. 2 (1964).

[3] L. Jarczyk, J. Lang, R. Müller, and W. Wölfli, Helv. Phys. Acta 34, 483 (1961).

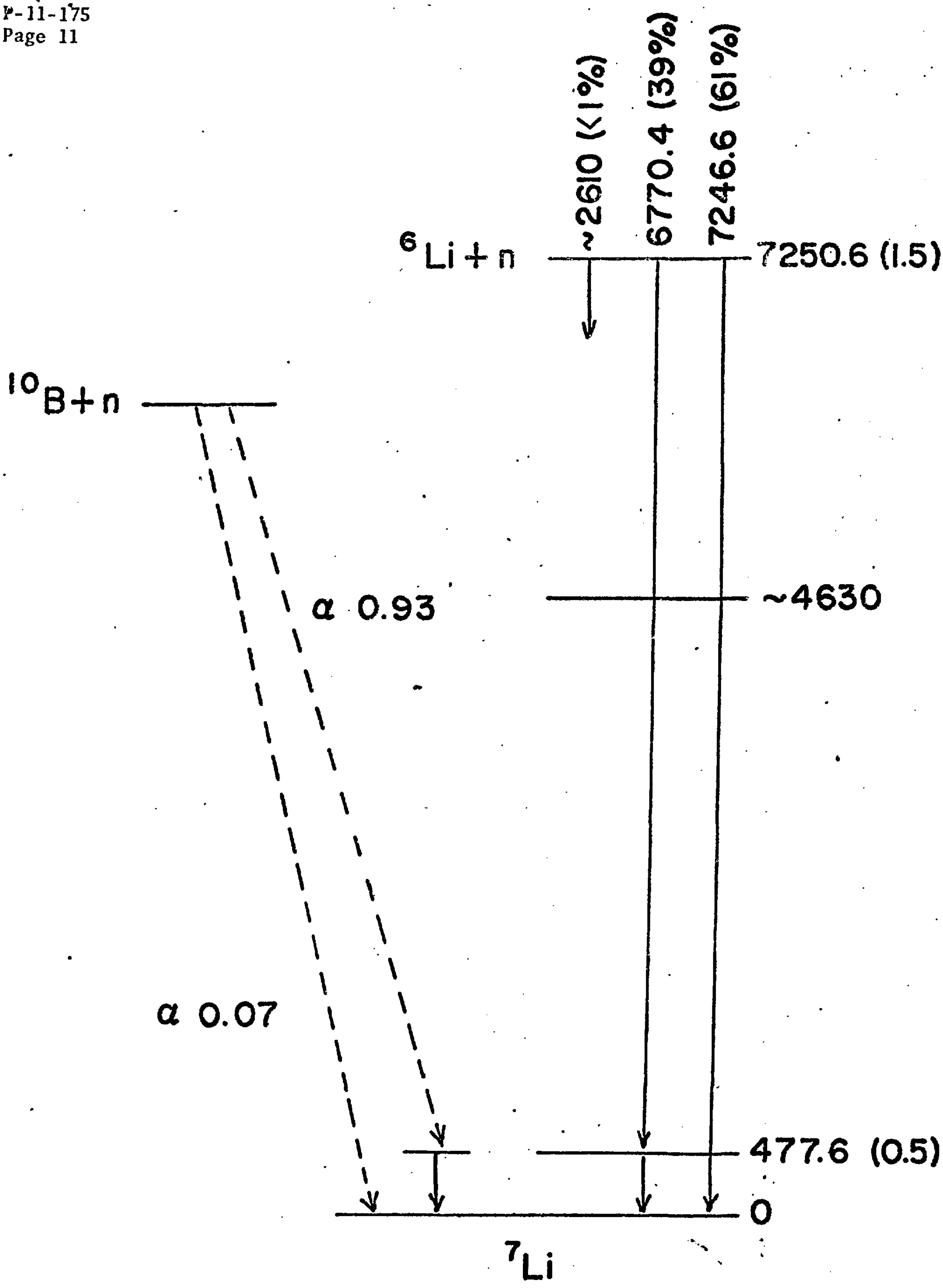

Fig. A-4. Gamma decay of ^{7}Li produced by the (n,γ) reaction. Also shown is the excitation and decay of the 477.6 keV level in ^{7}Li by the ^{10}B(n,α) reactions.

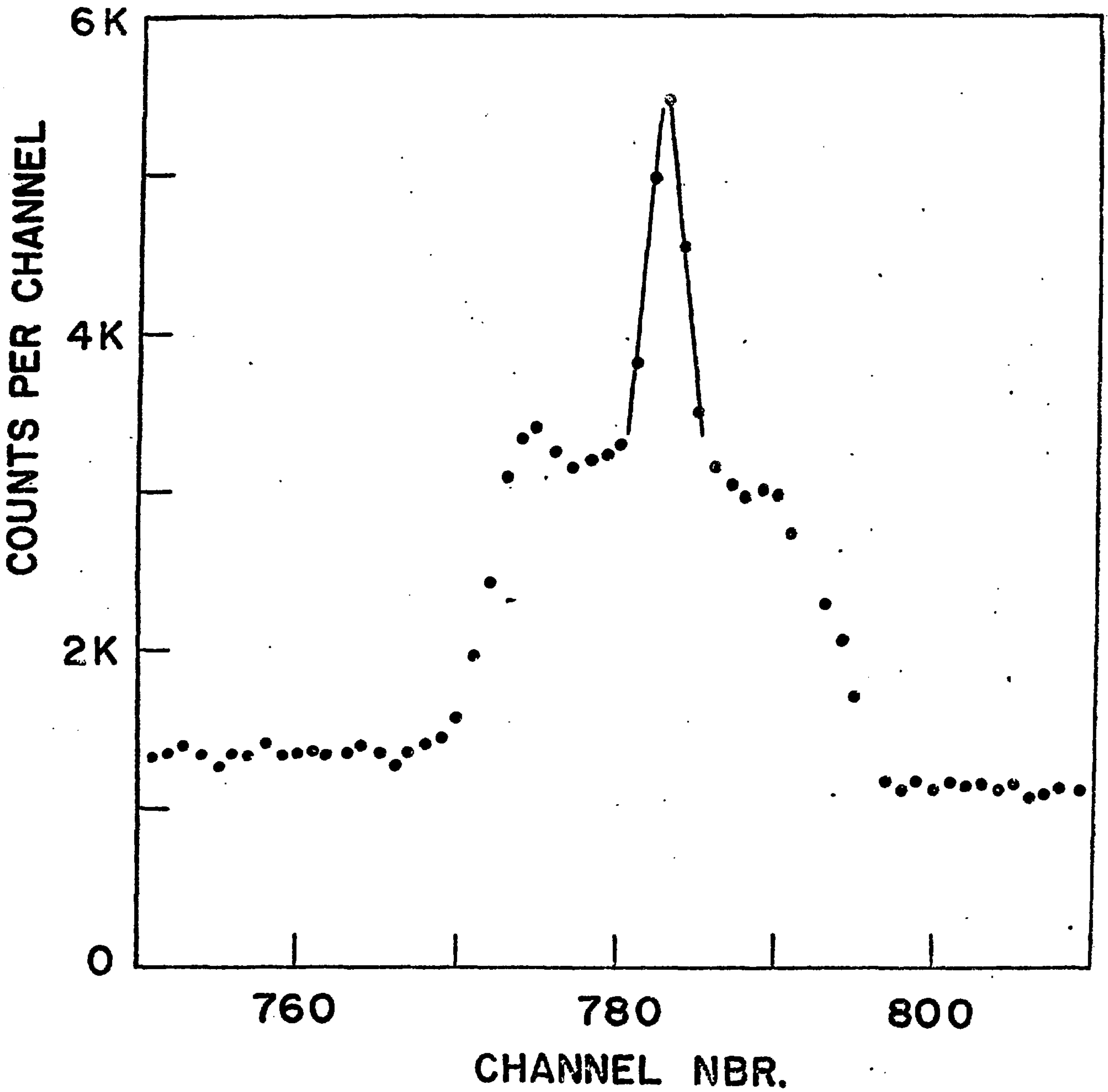

Fig. A-5. Appearance of the 477.6 keV transition in ^{7}Li when capture takes place in a target containing ^{6}Li and a small amount of ^{10}B impurity.

Table A-5

Energies and Intensities of γ-Rays from the Reaction $^{6}Li(n,\gamma)^{7}Li$

E_γ (keV)	E_{REC} (keV)	E_{TRANS} (keV)	I (mb)	I(γ/100 n)
477.6±0.5	0.02	477.6±0.5	17 ±2	44±5
6770.4±1.5	3.5	6773.9±1.5	15.1±1.1	39±1
7246.6±1.5	4.0	7250.6±1.5	23.4±1.7	61±1

$\Sigma[\sigma(6773.9)+\sigma(7250.6)] = 38.5\pm3$ mb $= \sigma(n_{th},\gamma)$

4. Fission Cross Section of ^{235}U (Hansen, Barton, Jarvis, Koontz, Smith)

Data reduction of the LASL ^{235}U fission cross section measurements in the 1-6 MeV neutron energy range has been completed and a report is being prepared for submission to Nuclear Science and Engineering. Table A-6 lists the $\sigma_f(25)/\sigma_s(H)$ ratios as directly determined from the fragment and proton outputs of back-to-back ^{235}U and polyethylene radiators, as well as the $\sigma_f(25)$ values based on the Yale evaluation of $\sigma_s(H)$.

B. NEUTRON DATA APPLICATIONS

1. Neutron Polarization Experiments (G. A. Keyworth)

An experiment to determine spins of subthreshold fission resonances in ^{237}Np has been completed and the results accepted for publication in The Physical Review. The abstract is given below:

"A polarized neutron beam and a polarized target have been used to determine spins of 15 intermediate structure groups observed in the fission of ^{237}Np below 1 keV and of 94 resonances observed in transmission below 102 eV. The pulsed neutron beam, from the Oak Ridge Electron Linear Accelerator, was polarized by transmission through a dynamically polarized proton sample. The ^{237}Np, in the ferromagnetic compound $NpAl_2$, was cooled by a ^{3}He-^{4}He dilution refrigerator. Nine individual fine-structure resonances comprising the first group at 40 eV were determined to have the same spin, $J = 3$, substantiating the current interpretation of intermediate structure in subthreshold fission in

Table A-6

LASL $\sigma_f(^{235}U)$ Data (Final)

E_n (MeV)	$\sigma_f(25)/\sigma_s(H)$	% Uncert. Stat.	% Uncert. Syst.	$\sigma_s(H)$[a]	$\sigma_f(25)$	% Uncert. Stat.	% Uncert. Syst.
1.0	0.2908	0.8	0.8	4.261	1.239	0.8	1.3
1.1	0.3116	1.0	0.8	4.051	1.262	1.0	1.3
1.2	0.3245	0.8	0.8	3.868	1.255	0.8	1.3
1.3	0.3376	0.8	0.8	3.706	1.251	0.8	1.3
1.4	0.3466	1.7	0.8	3.561	1.234	1.7	1.3
1.5	0.3703	0.8	0.7	3.429	1.270	0.8	1.2
1.6	0.3752	0.8	0.7	3.309	1.242	0.8	1.2
1.7	0.4050	1.0	0.7	3.198	1.295	1.0	1.2
1.8	0.4122	1.1	0.7	3.097	1.277	1.1	1.2
1.9	0.4248	1.1	0.7	3.003	1.276	1.1	1.2
2.0	0.4362	0.4	0.7	2.915	1.272	0.4	1.2
2.2	0.4620	0.8	0.7	2.759	1.275	0.8	1.2
2.4	0.4785	1.3	0.7	2.622	1.255	1.3	1.2
2.5	0.4892	1.4	0.7	2.560	1.252	1.4	1.2
2.6	0.4879	0.6	0.7	2.501	1.220	0.6	1.2
2.7	0.5013	0.8	0.7	2.445	1.226	0.8	1.2
2.8	0.5064	0.7	0.7	2.392	1.211	0.7	1.2
2.9	0.5104	0.9	0.7	2.341	1.195	0.9	1.2
3.0	0.5281	0.3	0.7	2.293	1.211	0.3	1.2
3.2	0.5520	1.1	0.7	2.203	1.216	1.1	1.2
3.4	0.5589	1.2	0.7	2.120	1.185	1.2	1.2
3.5	0.5664	0.6	0.7	2.081	1.179	0.6	1.2
3.6	0.5792	1.2	0.7	2.043	1.183	1.2	1.2
3.7	0.5760	1.1	0.7	2.007	1.156	1.1	1.2
3.8	0.5906	1.3	0.7	1.973	1.165	1.3	1.2
4.0	0.5967	0.6	0.7	1.907	1.138	0.6	1.2
4.2	0.6203	1.4	0.8	1.845	1.144	1.4	1.3
4.4	0.6258	1.2	0.8	1.788	1.119	1.2	1.3
4.6	0.6340	1.3	0.8	1.734	1.099	1.3	1.3
4.8	0.6590	1.2	0.8	1.683	1.109	1.2	1.3
5.0	0.6668	1.1	0.8	1.635	1.090	1.1	1.3
5.1	0.6739	0.9	0.9	1.612	1.086	0.9	1.4
5.2	0.6868	1.0	0.9	1.589	1.091	1.0	1.4
5.3	0.6925	1.0	0.9	1.568	1.086	1.0	1.4
5.4	0.6903	0.7	0.9	1.547	1.068	0.7	1.4
5.5	0.6975	1.0	0.9	1.526	1.064	1.0	1.4
5.6	0.6966	1.0	0.9	1.506	1.049	1.0	1.4
5.7	0.7193	1.1	0.9	1.486	1.069	1.1	1.4
5.8	0.7454	2.1	0.9	1.467	1.093	2.1	1.4
5.9	0.7751	1.5	0.9	1.448	1.122	1.5	1.4
6.0	0.8015	1.8	0.9	1.430	1.146	1.8	1.4

[a]Yale evaluation reported by Stewart, LaBauve, and Young in LA-4574 [ENDF-141, EANDC-141]. As suggested by Stewart, $\sigma_s(H)$ is assigned a 1.0% uncertainty and in the 1-6 MeV range this is assumed to be a systematic uncertainty.

terms of the Strutinsky double-humped deformation barrier. Correlation of these results with existing data on the angular distribution of fission fragments from aligned ^{237}Np indicates an apparent admixing of transition states, as evidenced by non-integral values of the projection quantum number, K."

In addition, the results of a preliminary measurement on ^{235}U have been published in the Physical Review Letters with the following abstract:

"A pulsed beam of polarized neutrons and a polarized target have been used to determine the spins of 65 resonances below 60 eV. Comparison of these spin assignments with those determined by less direct methods reveals poor agreement, in general. Interpretation of recent data on the angular distribution of fission fragments from aligned ^{235}U with the present spin assignments reveals the absence of the K = 0 channel and an apparent admixing of transition states."

Additional measurements on ^{235}U with higher neutron polarization and improved statistics will hopefully be undertaken in the near future.

2. <u>Total Cross Sections of ^{16}O, ^{17}O, ^{18}O, and ^{12}C from 1.6 MeV to 18 MeV</u> (G. F. Auchampaugh, C. E. Ragan) 15

The total cross sections of the three stable oxygen isotopes and carbon have been measured from 1.6 MeV to 18 MeV using time-of-flight techniques with a 1-nsec pulsed 15-MeV deuteron beam from the LASL Tandem accelerator bombarding a thick Be target and with a 31-m flight path. A NE-110 scintillator (12.7-cm diam by 2.5-cm thick) mounted on an RCA 8054 phototube was used as the neutron detector. The overall timing resolution was limited by the burst width which varied from 1 to 2 nsec during these measurements. The data are presented in Fig. B-1.

3. <u>MULTI, a FORTRAN Code for Least-Squares Shape Fitting of Neutron Cross-Section Data Using the Reich-Moore Multilevel Formalism</u> (G. F. Auchampaugh)

A LASL report (LA-4633) describing the FORTRAN code MULTI has been written and will be available for distribution in the near future. The present configuration of MULTI requires 40,000 words of central memory (system and user programs and common blocks) and 400,000 words of large-core storage memory. In this configuration MULTI will:

a. Simultaneously fit all four neutron cross sections: Total scattering, fission, and capture.

b. Doppler and resolution broaden all cross sections with a common resolution function which must be well defined and represented analytically.

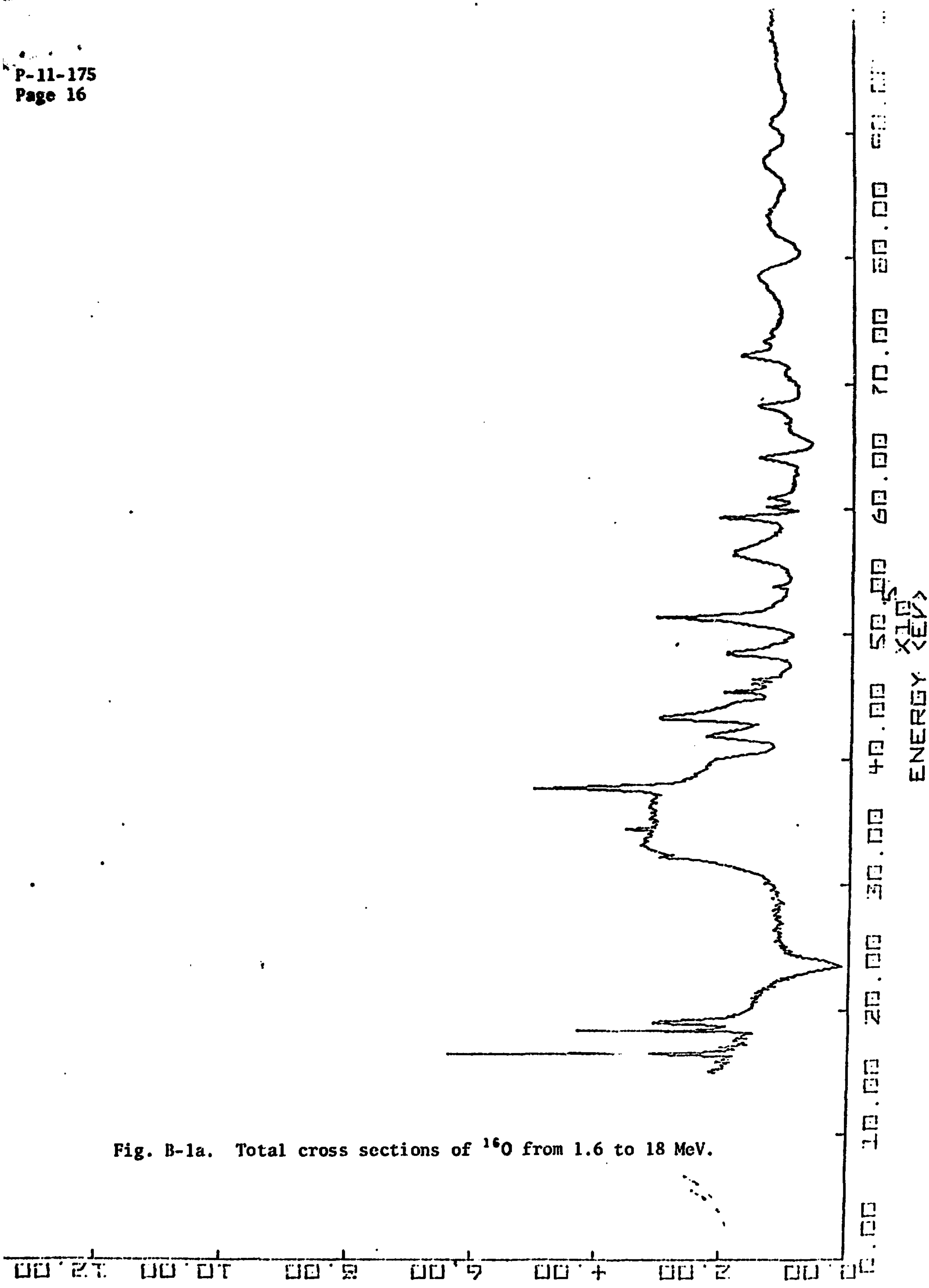

Fig. B-1a. Total cross sections of ^{16}O from 1.6 to 18 MeV.

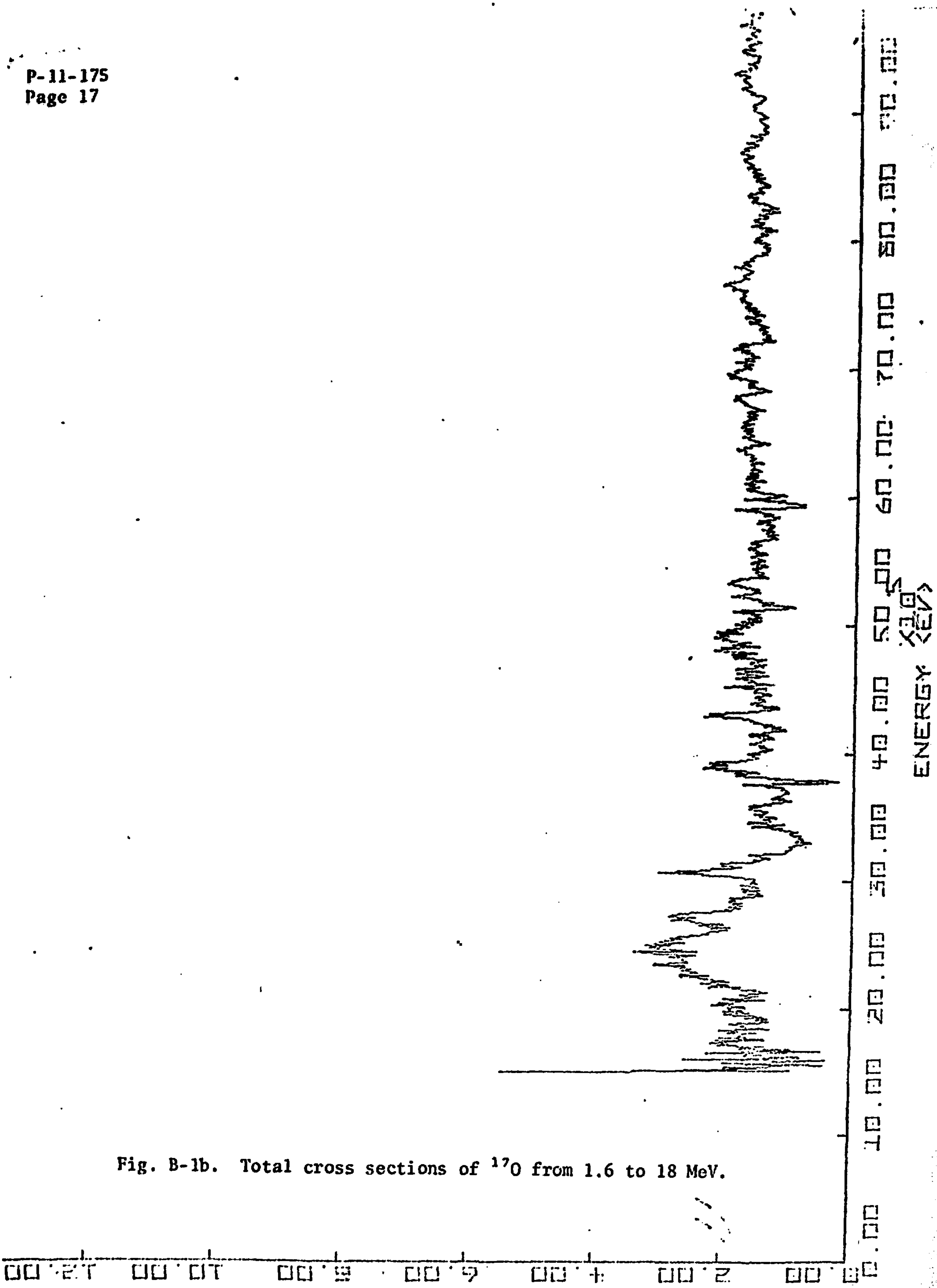

Fig. B-1b. Total cross sections of ^{17}O from 1.6 to 18 MeV.

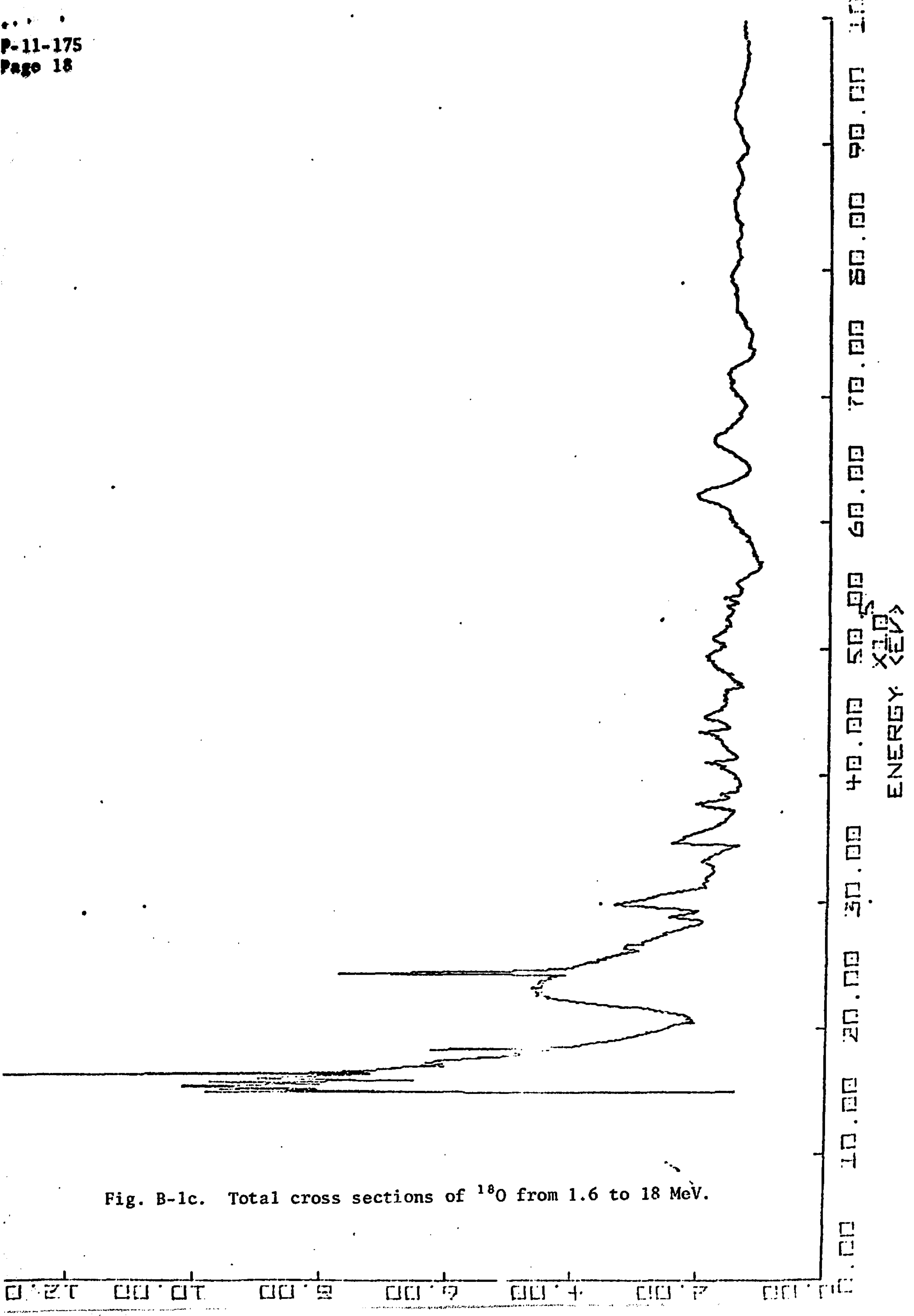

Fig. B-1c. Total cross sections of ^{18}O from 1.6 to 18 MeV.

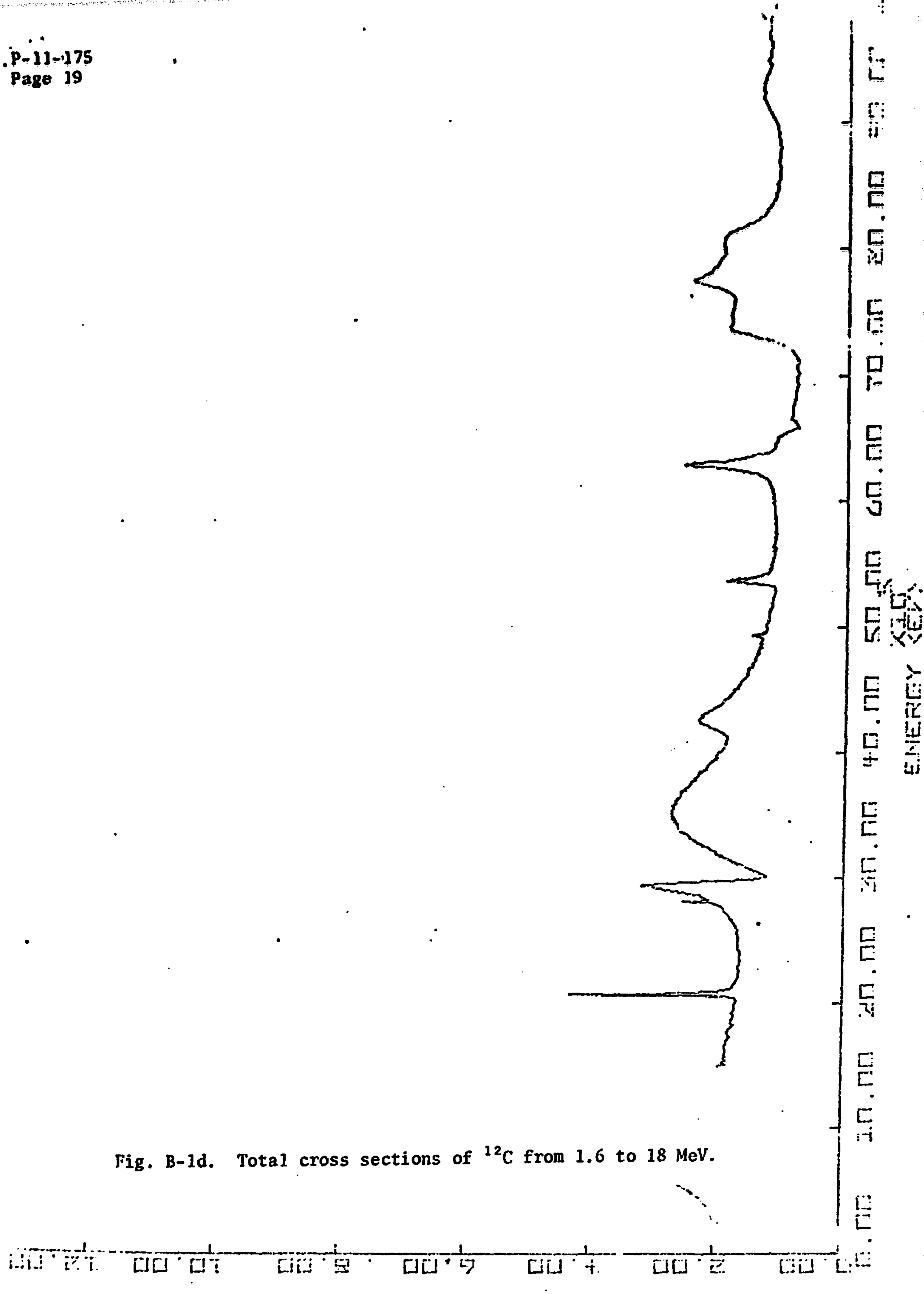

Fig. B-1d. Total cross sections of ^{12}C from 1.6 to 18 MeV.

c. Handle up to 100 resonances which need not be located in the energy region being fitted and therefore can be used to generate a pseudobackground R^{∞}-type matrix.

d. Handle 0 (with or without the shift and boundary functions), 1, or 2 fission channels per spin state with a total of ten spin states each representing either s, p, d, f, or g wave neutron reactions.

e. Search on up to 150/N parameters where N is the number of cross sections fitted.

f. Handle 1600/N data points per cross section.

Running times per iteration on the CDC 7600 (6600) for the largest problem MULTI will handle are less than 10 (60) seconds.

4. Cross Section Evaluations for Version IV of ENDF/B

Several evaluations of neutron-induced cross sections are being submitted for Version IV of ENDF/B, as well as to the Defense Nuclear Agency's cross-section library at Oak Ridge. A list of the elements involved is given below, together with a brief description of the most important features of the new data.

a. ^{1}H, ^{3}H (Stewart, LaBauve)

An improved representation of the capture gamma-ray data for ^{1}H was incorporated into the ENDF/B Version III evaluation and an existing ^{3}H LASL data set[1] was converted to ENDF format.

b. ^{4}He (Nisley, Hale, Young)

A new evaluation based on an R-matrix analysis of the combined n-^{4}He and p-^{4}He systems has been submitted.

c. ^{6}Li, ^{7}Li (LaBauve, Stewart)

Gamma-ray production data were added to the Version III evaluations.

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[1] L. Stewart, "Evaluated Neutron Cross Sections for Tritium," Los Alamos Scientific Laboratory report LA-3270 (1965).

d. ^{10}B (Hale, Nisley, Young)

A new coupled-channel R-matrix analysis has been incorporated below 1 MeV, and the Version III evaluation at higher energies has been extensively revised and expanded to include gamma-ray production data.

e. ^{14}N (Young, Foster, Hale)

The existing Version III evaluation was revised to better represent the gamma-ray production measurements of Dickens et al[1] for E_n = 1-20 MeV.

f. ^{16}O (Hale, Foster, Young)

A coupled channel R-matrix analysis for E_n = 0-6 MeV has been incorporated in the evaluated data, and extensive improvements were made at higher energies to better describe inelastic neutron scattering and gamma-ray production, including anisotropic angular distributions.

g. ^{27}Al (Young, Foster)

Extensive improvements have been made to the total cross section below 1 MeV and to the inelastic neutron scattering and gamma-ray production data at all energies, based mainly on the (n,n') measurements of Kammerdiener[2] at E_n = 14 MeV and the (n,xγ) measurements of Dickens et al.[3] for E_n = 1-20 MeV.

h. $^{182-186}W$ (Young)

A new evaluation of gamma-ray production for ^{182}W, ^{183}W, ^{184}W, and ^{186}W has been incorporated into the recent neutron file evaluations by Rose.[4]

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[1] J. K. Dickens, T. A. Love, and G. L. Morgan, "Gamma Ray Production Due to Neutron Interactions with Nitrogen for Incident Neutron Energies Between 2 and 20 MeV: Tabulated Differential Cross Sections," Oak Ridge National Laboratory report ORNL-4864 (1973).

[2] J. L. Kammerdiener, "Neutron Spectra Emitted by ^{239}Pu, ^{238}U, ^{235}U, Pb, Nb, Ni, Al, and C Irradiated by 14-MeV Neutrons," Thesis, University of California at Davis (1972).

[3] J. K. Dickens, T. A. Love, and G. L. Morgan, "Gamma-Ray Production Due to Neutron Interactions with Aluminum for Incident Neutron Energies Between 0.85 and 20 MeV: Tabulated Differential Cross Sections," Oak Ridge National Laboratory report ORNL-TM-4232 (1973).

[4] P. F. Rose, J. M. Otter, and E. Ottewitte, "Evaluation of ^{182}W, ^{183}W, ^{184}W, and ^{186}W Cross Sections for the ENDF/B Data File," Atomics International report TI-707-130-026 (1973).

i. ^{235}U, ^{239}Pu (Stewart, Hunter, LaBauve)

LASL is collaborating with other laboratories[1] in the evaluation of neutron files for Version IV and is providing complete gamma-ray production data.

5. Decay Data for ENDF/B-IV (T. R. England)

LASL Groups T-2 and CNC-11 have been actively involved in a national task force to include decay data in ENDF/B-IV. This first file represents the cumulative efforts of all task force members.

The file contains decay data for 823 nuclides and 10 sets of direct fission yields each covering 1016 nuclides. All fission cumulative yields and their distribution vs charge have been evaluated. Approximately 300 unstable nuclides were identified as being of particular importance in decay heating and most of these received a new evaluation (based on their order of importance). The remainder use data from recent compilations and theoretical estimates where no measurements exist.

The decay data include: half-lives and uncertainties, the average β (and/or other particle emissions) and total γ energy, the detailed γ line data and emission probabilities, and β end-point energies and their branching fractions.

C. BASIC PHYSICS

$^{33}S(n,\alpha)$ (G. F. Auchampaugh, W. M. Howard)

The branching ratio $\sigma(n,\alpha)/\sigma(n,\gamma)$ for ^{33}S in the interval 50 to 500 keV is important to the astrophysicists in the study of the nucleosynthesis of the isotope ^{36}S. A preliminary measurement was made of the $^{33}S(n,\alpha)$ cross section at the LASL Vertical Van de Graaff accelerator using a thick (260 keV) natural Li target bombarded by a 1-nsec pulsed beam of 2.4 MeV protons. The data were obtained with conventional time-of-flight techniques. The flight path was 0.56 m. Four 6-cm^2 surface barrier detectors were used to detect the ^{33}S alpha particles. A total of 12.3 mg of 91%-enriched ^{33}S was available for these measurements. The cross section was normalized to the $^{10}B(n,\alpha_0+\alpha_1)$ cross section. A preliminary average value of $\bar{\sigma}(n,\alpha) = 39.2\pm0.6$ (stat.) mb was obtained for the energy interval from ~400 to ~680 keV using a value of 676 mB for the $^{10}B(n,\alpha_0+\alpha_1)^7Li$ cross section.

[1] B. Hutchins (General Electric) and H. Alter (formerly Atomics International).

Further measurements are planned to cover the interval from 50 to 600 keV with 5-kev resolution. A collaborative measurement of the (n,γ) cross section is planned in the near future at Oak Ridge National Laboratory's ORELA.

D. NUCLEAR DATA FOR MATERIALS ANALYSIS, SAFEGUARDS, AND ENVIRONMENTAL MATTERS

3909

Delayed Neutron Yield from the $^9Be(n,p)^9Li$ Reaction for $14.1 \leq E_n \leq 14.9$ MeV (R. H. Augustson and H. O. Menlove)

23-2

The absolute value of the cross section for the delayed neutron yield from the $^9Be(n,p)^9Li$ reaction for neutron energies of 14.1, 14.5, and 14.9 MeV has been measured. Lithium-9 decays by beta emission with a half-life of 175 msec to excited states of ^9Be which lie above the neutron-binding energy, resulting in prompt neutron decay to ^8Be. Thus ^9Li, along with ^{17}N, is one of the few nonfission delayed neutron precursors.[1] Previous measurements[2] of the cross section have had large assigned errors and have differed by orders of magnitude.

The 300-kV Cockcroft-Walton accelerator operating in the pulsed mode provided the neutron irradiation utilizing the D,T reaction. An associated particle technique was used to determine the absolute neutron flux, and the delayed neutrons were detected in a calibrated flat response detector.[3] The half-life of the β decay was accurately measured by following the delayed neutron decay. This half-life determination enabled a correction to be made to the cross-section value for the length of the irradiation period. Two Be samples, 5.08-cm diam and 0.317-cm thick, were used either singularly or combined for the measurements. Determinations of flux depression across the samples were made using Al activation foils placed in front and in back of the samples.

To determine the half-life of the delayed neutron decay, the ^9Be sample was irradiated for approximately one half-life and the decay followed for ten half-lives. The computer fit to the data yielded only one decay constant with a value of 0.175±0.001 sec.

A value for the average delayed neutron energy from the ^9Be decay was obtained by using the front-to-back ratio of the slab detector as described in Ref. 3. This technique gave an average energy of 500 keV for the ^9Be

[1] H. O. Menlove, R. H. Augustson, and C. N. Henry, Nucl. Sci. Eng. Vol. 40, p. 136 (1970).

[2] D. E. Alburger, Phys. Rev. 132, 328 (1963); G. Barnemisza, Magy. Tud. Akad. Atommag Kut. Int. (Debrecen) Kozlemen, 4, 79 (1962).

[3] L. V. East and R. B. Walton, Nuc. Instr. & Meth. 72, p. 161 (1969).

delayed neutrons, a value much lower than had previously been reported.[1]

For the cross-section measurement the accelerator was pulsed on and off repetitively at a 50% duty with a total period of 120 msec. A similar irradiation technique to measure the delayed neutron yields from fissionable isotopes has been described by Masters et al.[2] A 3.6% correction based on the 175-msec half-life was made in the data analysis for decay of delayed neutrons during the 60-msec irradiation.

The absolute efficiency of the delayed neutron detector was obtained using a ^{238}Pu-Li source calibrated by the National Bureau of Standards to within ±3%. The average energy of this source is 650 keV, thus lying close to the ^{9}Be delayed neutron average energy.

The resulting cross-section values are:

$$\sigma_{n,p}(\text{activation}) = 0.210 \text{ mb} \pm 0.013 \text{ at } 14.9 \text{ MeV}$$
$$0.053 \text{ mb} \pm 0.005 \text{ at } 14.5 \text{ MeV}$$
$$< 0.004 \text{ mb at } 14.1 \text{ MeV}$$

It can be seen that the ^{9}Be(n,p) cross section varies quite rapidly in this energy region, possibly explaining the apparent discrepancies between previous values.

E. CONTROLLED THERMONUCLEAR RESEARCH

1. $D(\vec{d},\vec{n})^{3}$He Reaction [Salzman, Ohlsen, Martin; Jarmer (AWU-U of Wyoming) and Donoghue (Ohio State)]

A paper with the above authors and the following abstract, on the angular distribution of the polarization and polarization transfer functions for the D(d,n)^{3}He reaction has been submitted to Nuclear Physics:

[1] K. Way et al., Nuclear Data Sheets, National Academy of Sciences--National Research Council, Washington, D. C. (1958-64).

[2] C. F. Masters, M. M. Thorpe, and D. B. Smith, Nucl. Sci. Eng. 36, 202 (1969).

"Angular distributions of six polarization transfer coefficients $K_x^{x'}(\theta)$, $K_x^{z'}(\theta)$, $K_z^{x'}(\theta)$, $K_z^{z'}(\theta)$, $K_y^{y'}(\theta)$, and $K_{yy}^{y'}(\theta)$; of the four analyz-powers $A_y(\theta)$, $A_{xx}(\theta)$, $A_{yy}(\theta)$, and $A_{zz}(\theta)$; and of the polarization function $P^{y'}(\theta)$, have been measured at E_d = 10.00 MeV for the reaction B(d,n)^{3}He. Measurements were made for neutron laboratory angles between 0 and 80° in 10° steps. Additionally, the y axis associated quantities were measured at θ_{lab} = 99°. Most of the coefficients are large at some angles and all show considerable variation with angle."

2. ^{4}He($\vec{d}$,$\vec{d}$) Polarization Transfer [Ohlsen, Salzman, Mitchell (EG&G), Gruebler (ETH, Zurich), and Simon (U. Wyoming)]

A paper on this work with the above authors and the following abstract has been submitted to Physical Review C:

"We report measurements of the four analyzing tensors and of up to fourteen polarization transfer coefficients, at each energy and angle studied, for ^{4}He(d,d)^{4}He elastic scattering. This number of observables greatly overdetermines the scattering matrix, and many consistency checks are therefore available. These data represent the first measurements of deuteron polarization transfer phenomena. Bombarding energies were in the range 4.8 to 9.0 MeV."

3. Absolute M Matrix Elements for ^{4}He($\vec{d}$,$\vec{d}$)^{4}He (Salzman and Ohlsen)

A gradient search technique has been used to determine the elements of the ^{4}He($\vec{d}$,$\vec{d}$)^{4}He scattering matrix at eight energy-angle pairs. The polarization transfer data reported above was the input for this work. This represents the first case, we believe, in which all elements of the scattering matrix are known for such a complex case. However, we are not yet satisfied with the fits, so the writing of a Physical Review Letter has been delayed. We also wish to compare our results to the 6-nucleon problem analysis being carried out in collaboration with Dodder, Lovoi, and Crosthwaite.