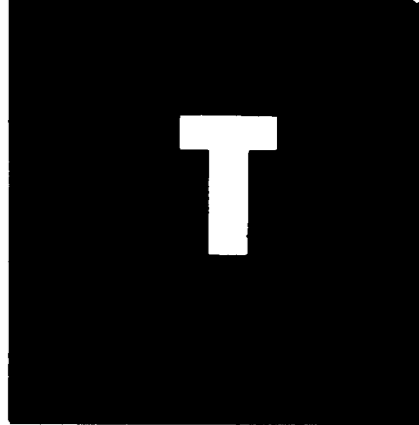


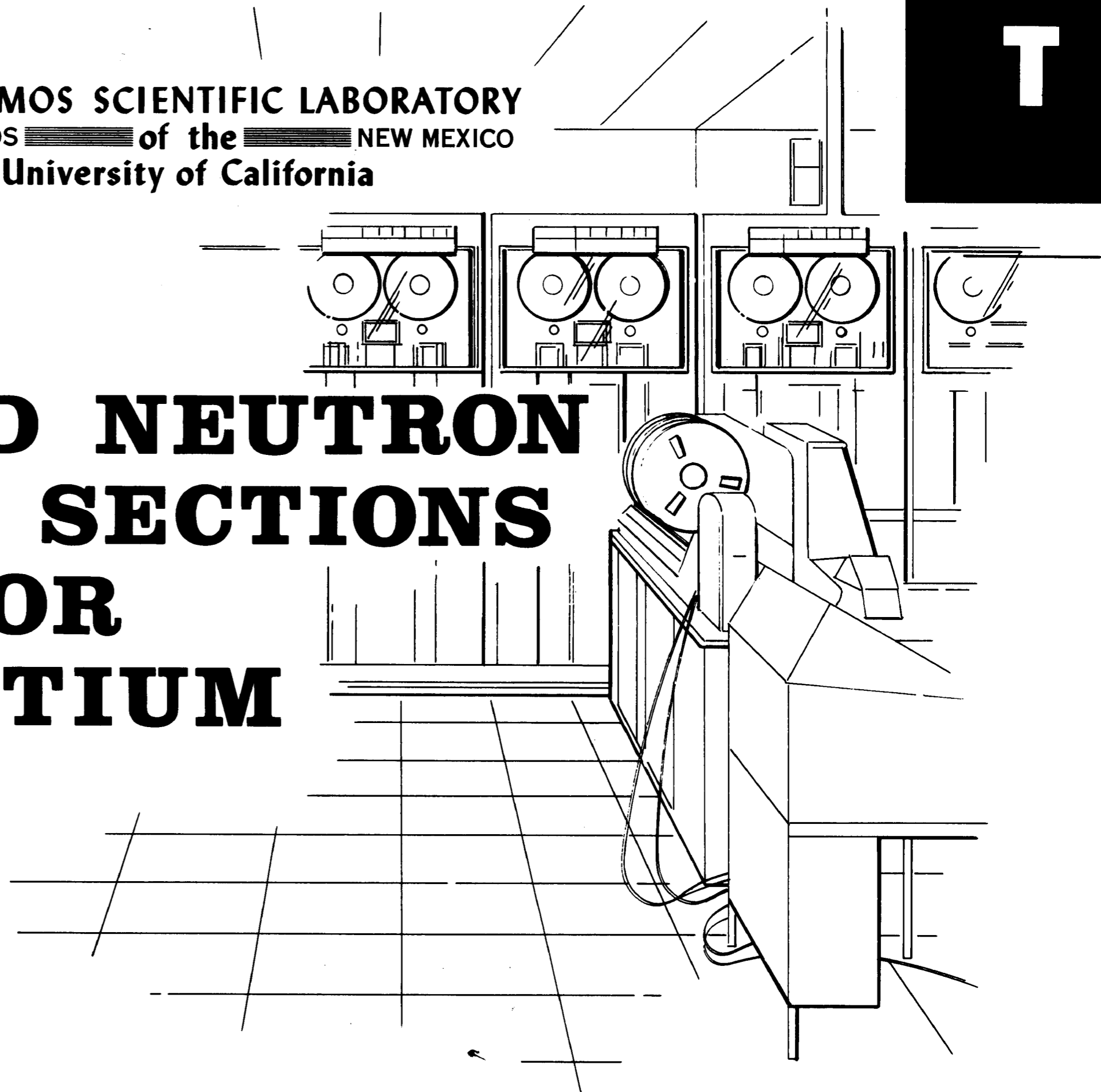
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# EVALUATED NEUTRON CROSS SECTIONS FOR TRITIUM



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# EVALUATED NEUTRON CROSS SECTIONS FOR TRITIUM

by  
LEONA STEWART



NOV 05 1996





## FOREWORD

Evaluation of the experimental data on the light isotopes, hydrogen through beryllium, was initiated by LASL in mid-1963. Since the data compilations available were completely inadequate for the task at hand, the tedious program of compiling and plotting was undertaken. As the work progressed an attempt was made to eliminate many of the obvious errors and inconsistencies found in the literature and existing compilations.

In addition, "critical users" of evaluated data files emphasized the need for a presentation of the experimental data upon which the evaluations were made. Many experimentalists have also commented on the inconvenience and effort involved in searching through several compilations to find the most recent (and/or corrected) cross sections.

In the hope that these reports on the light isotopes could serve as a working manual with a useful half-life for both experimentalists and theoreticians, the following specifications have been established:

1. The size of the graph paper and the scales chosen most often permit the inclusion of the standard deviations.
2. Only standard size tracing paper is used.
3. The grids are reproduced.
4. The graphs are neither enlarged nor reduced in the printing process.
5. Individual pages can be added or deleted; therefore, corrections can be made when necessary.

Perhaps this method will allow a "new" evaluation program to begin where this one ended. Any comments, corrections, and criticisms will be most welcomed by the author.

## ACKNOWLEDGMENTS

Without the support and encouragement of many people both at Los Alamos and at other laboratories, this evaluation program for the light isotopes would never have passed the compilation stage. A complete listing of names would be prohibitive in length, but a few will be mentioned here. In particular, I wish to express my appreciation to Robert Howerton and his group at Livermore, for suggestions, discussions, and help in preparation of the original evaluated data file. Also, Ken Parker, Robert Batchelor, Eric Pendlebury, and others at AWRE have written many excellent reports on evaluated cross sections, and these have proven most valuable to me as references and guide lines.

At LASL, Roger Lazarus in T-7 has established the working group for expeditious handling of the automated data files; the effort, encouragement, and cooperation of the members of this group have made this report possible. Louis Rosen, John Seagrave, Ben Diven and John Hopkins, along with many others, have offered excellent discussions, suggestions, and criticisms. Finally, the monumental task of performing many calculations and of coordinating and handling the experimental data and subsequent graphical displays was undertaken by Opal Milligan. Her work and cooperation have proven invaluable in setting up a useable file and reference system.

# EVALUATED NEUTRON CROSS SECTIONS FOR TRITIUM

## I. CROSS SECTIONS AND POSSIBLE REACTION MECHANISMS FOR INCIDENT NEUTRONS BELOW 20 MeV

All reactions, except capture, produce neutrons in the exit channel. For convenience, the reaction Q values\* and threshold energies are listed along with the various cross sections:

	Q <sub>mass</sub> (MeV)	Lab Threshold (MeV)
1. Total Cross Section, $\sigma_{TOT} = \sum_i \sigma_i$		
2. Elastic Scattering, $\sigma_{el} = \int \sigma(\theta) d\Omega$ where $\sigma(\theta)$ is the differential cross section		
3. Nonelastic Scattering, $\sigma_{NON} = \sigma_{TOT} - \sigma_{el}$ $\sigma_{NON} = \sigma_{n,\gamma} + \sigma_{n,d} + \sigma_{n,p}$		
4. Capture, $\sigma_{n,\gamma}$		
5. T(n,d)2n or $\sigma_{n,2n}$	-6.2576	~ 8.35
6. T(n,p)3n or $\sigma_{n,3n}$	-8.4823	~11.31
7. Emission (all neutrons except elastic) $\sigma_{emis} = 2\sigma_{n,2n} + 3\sigma_{n,3n}$		

\*Using the masses given in Periodic System of Isotopes, I. P. Selinov, U.S.S.R. Academy of Sciences, 1962.

## II. EXPERIMENTAL DATA

### 1. Total

The total cross section from 290 keV to 20 MeV has been measured by the Physics and Cryogenics Groups at Los Alamos.<sup>1</sup> Unfortunately, only one value exists between 7 and 18 MeV; therefore, several different curves could fit the data equally well over this energy region. The Russian experiment<sup>2</sup> at 2.5 and 14 MeV does not add to the present information, since the errors quoted are 20 to 30%.

### 2. Elastic Scattering

Differential cross sections have been measured by Seagrave et al at 1.0, 2.0, 3.5, and 6.0 MeV.<sup>3</sup> In 1951, data over a limited angular region at 14.3 MeV were published by Coon et al.<sup>4</sup> Recently, Seagrave reevaluated Coon's work, and these cross sections have been reported in BNL-400, Second Edition.

Since experimental data on the nonelastic cross sections are completely non-existent, some method had to be devised for predicting not only the shape of the elastic differential cross sections but also the total integrals.

Elastic-scattering angular distribution measurements have been made on the charge-conjugate system p+He<sup>3</sup>. Data from Rice,<sup>5</sup> Wisconsin,<sup>6</sup> Los Alamos,<sup>7</sup> Minnesota,<sup>8</sup> and Russia<sup>9</sup> were spread over the energy region from 4.5 to 19.4 MeV. The p+He<sup>3</sup> data were, therefore, used to extend the differential cross sections to higher energies and to obtain an estimate of the total nonelastic contribution from:

$$\sigma_{NON} = \sigma_{TOT} - \sigma_{el}$$

<sup>1</sup>See references listed on page 9.

Obviously the Coulomb interaction presents a large interference effect at small angles in the  $p+\text{He}^3$  interaction. A simple calculation using Wick's Limit<sup>10</sup> will give the smallest zero-degree cross section allowed from scattering theory, and this limit can be used to extrapolate the  $p+\text{He}^3$  data over the interference region to zero degrees. For convenience, the pertinent formulae are listed below:

Since

$$\sigma(0^\circ) = \left| f_{\text{R}}(0^\circ) \right|^2 + \left| f_{\text{I}}(0^\circ) \right|^2 ,$$

it follows that

$$\sigma(0^\circ) \geq \left| f_{\text{I}}(0^\circ) \right|^2$$

where  $f_{\text{R}}(0^\circ)$  and  $f_{\text{I}}(0^\circ)$  are the real and imaginary parts, respectively, of the complex scattering amplitude at zero degrees.

It is easily proven<sup>11</sup> that

$$f_{\text{I}}(0^\circ) = \frac{k\sigma_{\text{TOT}}}{4\pi} ,$$

the latter equality being known as the optical theorem. Then,

$$\sigma_{\text{W}} \equiv \frac{k^2(\sigma_{\text{TOT}})^2}{(4\pi)^2} ;$$

where

$$k^2 = (2.187)^2 \frac{m_1 m_2^2}{(m_1 + m_2)^2} E_0 ; \quad \left[ \text{units barn}^{-1}, \text{ or } \frac{10^{24}}{\text{cm}^2} \right]$$

for mass  $m_1$  incident on target mass  $m_2$ , and  $E_0$  the incident neutron energy in the laboratory system in units of MeV. Then,

$$\sigma_{\text{W}} = (3.0276 \times 10^{-2} E_0) \frac{m_1}{\left(1 + \frac{m_1}{m_2}\right)^2} (\sigma_{\text{TOT}})^2 , \quad \left[ \frac{\text{barns}}{\text{sr}} \right]$$

with  $\sigma_{\text{TOT}}$  in barns.

### 3. Nonelastic Scattering

In the absence of experimental data, the elastic angular distributions were integrated and this integral subtracted from the total cross section to obtain  $\sigma_{\text{NON}}$ .

### 4. Capture

At thermal energies Imhof et al<sup>12</sup> have measured:

$$\sigma_{\text{n},\gamma} \leq 6.7 \mu\text{b} .$$

Therefore, this reaction has been neglected over the energy region considered in this report.

$$\begin{array}{l} 5. \quad \text{n, 2n} \\ 6. \quad \text{n, 3n} \end{array}$$

Recently, the energy spectrum of the charged particles emitted at  $4.8^\circ$  when tritium is bombarded by 14.4-MeV neutrons was published by the Zagreb group.<sup>13</sup> The spectrum is presented as the number of charged-particle counts versus channel number; therefore, absolute values of the cross sections are impossible to estimate. The authors make the statement, "The measurement reveals that at  $0^\circ$  the breakup cross section is almost of the order of magnitude of the elastic cross section."

With both solid and gas targets, this experiment was repeated in a joint effort by groups at Zagreb and Belgrade.<sup>14</sup> The deuteron spectrum shows a pronounced peak at  $0^\circ$ , with a cross section at the maximum of  $\sim 32$  mb/sr  $\text{MeV}^{-1}$ . The values drop to approximately zero as the deuteron energy decreases to  $\sim 5$  MeV. Whether this indicates that direct 3-body interactions do not occur is not clear. The proton spectrum indicates that (n,3n) reactions are small. The data as presented do not give the information necessary for a detailed comparison or better estimate of the break-up cross section.

Several theoretical papers have been written on  $n+\text{T}$  scattering, but only recently has the treatment been extended to include the inelastic channels. Gammel and MacKellar<sup>15</sup> calculated the ratio of the first Born approximation for inelastic to that for elastic scattering at 14 MeV. They reported  $\sigma_{\text{NON}} = 343$  mb and "from an order of magnitude estimate,"  $\sigma_{\text{n,3n}} = 0.4$  mb.

At 14 MeV,  $\sigma_{\text{TOT}} = 975$  mb; and  $\sigma_{\text{el}}$  would be approximately 632 mb using the nonelastic cross section of Gammel and MacKellar. The elastic



angular distribution as measured by Coon et al at 14.3 MeV is incompatible with  $\sigma_{\text{NON}} = 343$  mb, since the cross section at zero degrees would be a factor of two lower than Wick's Limit to give the comparable integral. It seemed desirable, therefore, to explore the possibilities of obtaining better estimates of the  $n+T$  cross sections from the  $p+\text{He}^3$  measurements.

### 7. Emission Spectra as a Function of Angle

Rather than assume that the neutrons are emitted isotropically in the laboratory system, a first-order correction was applied: that is, assume that the neutrons have an isotropic distribution in the center-of-mass system. An n-body interaction code was programmed for the LASL Maniac II by Roger Lazarus.\* The basic principles are briefly outlined as follows: If "n" particles are produced in a direct reaction, that is, sequential decay does not occur, then the energy distribution in the center-of-mass system of any one of the "n" particles emitted can be represented by:

$$N(E_i) dE_i = \text{Constant}(E_i)^{1/2} [E_i(\text{max}) - E_i]^{3/2} dE_i,$$

by assuming equal probability in phase space.<sup>16</sup>  $E_i(\text{max})$  is the maximum energy available to particle "i" and depends only on the incident neutron energy and the Q of the reaction.

Although this operation represents an unfolding of a double integral, all of the transformation equations are simple analytic functions; therefore, the cross sections in the laboratory system, as a function of energy and angle, can be obtained by normalizing to a total breakup cross section.

### III. PRESENTATION OF THE RESULTS

The smooth curves on the graphs represent the "best" values chosen for the data library. On the individual graphs each experiment (or quantity) is identified by a short reference notation, consisting of: the name of one of the authors, the institution (or city or country), and the year of publication (abbreviated to the last two digits).

\*A detailed report on this program and the analyses will appear separately, since the same application will be used for many of the light-isotope reactions.

A complete reference, including any notes or comments which may be of interest, appears on the page facing each display.† For the differential cross sections, a tabular list of the cross sections and probabilities representing the smooth curve is also included on the facing page.

For convenience, the graphs have been labeled in a manner that should insure their return to the proper report in the correct sequence.

The tabular and graphical results are arranged in the following manner:

#### 1. Total and Integral Values of the Cross Sections

a) $\sigma_{\text{TOT}} = \sigma_{\text{el}} + \sigma_{\text{NON}}$	Summary:	Table 1
	Graphs:	TOT-1-3-1 TOT-1-3-2 TOT-1-3-3
b) $\sigma_{\text{el}} = \int \sigma(\theta) d\Omega$ (Evaluated)	Summary:	Table 1
	exp. Seagrave Graphs:	TOT-1-3-1 TOT-1-3-2 TOT-1-3-3
c) $\sigma_{\text{NON}} = \sigma_{n,\gamma} + \sigma_{n,2n} + \sigma_{n,3n}$ (Evaluated only)	Summary:	Table 1
	Graph:	NON-1-3-1

#### 2. Differential Cross Sections for Elastic Scattering

a) $E_n = 500$ keV (Calculated from an interpolation - linear with energy - using the 1.0 MeV experimental data and the assumption of isotropy at 100 keV.)		Table 2
b) $E_n = 1.0$ MeV	Graph:	ANG-1-3-1
c) $E_n = 2.0$ MeV	Graph:	ANG-1-3-2
d) $E_n = 3.5$ MeV	Graph:	ANG-1-3-3
e) $E_n = 6.0$ MeV	Graph:	ANG-1-3-4

†Where the cross section data used in this report differ from those published previously (especially in BNL-325 and BNL-400) or attributed earlier to a particular author, an asterisk is included in the abbreviated reference notation on the graph to call attention to this fact.

f)	Comparison of p+He <sup>3</sup> with n+T scattering around 6 MeV	Graph:	ANG-1-3-5
g)	E <sub>n</sub> = 8.5 MeV (obtained from p+He <sup>3</sup> )	Graph:	ANG-1-3-6
h)	E <sub>n</sub> = 9.5 MeV (obtained from p+He <sup>3</sup> )	Graph:	ANG-1-3-7
i)	E <sub>n</sub> = 9.75 MeV (obtained from p+He <sup>3</sup> )	Graph:	ANG-1-3-8
j)	E <sub>n</sub> = 10.4 MeV (obtained from p+He <sup>3</sup> )	Graph:	ANG-1-3-9
k)	E <sub>n</sub> = 11.5 MeV (obtained from p+He <sup>3</sup> )	Graph:	ANG-1-3-10
l)	14 MeV region (Comparison of the predicted 14.1-MeV differential cross sections using the p+He <sup>3</sup> data with the 14.3-MeV distributions measured by Coon, et al.)	Graph:	ANG-1-3-11
m)	E <sub>n</sub> = 19.4 MeV (obtained from p+He <sup>3</sup> )	Graph:	ANG-1-3-12

### 3. Breakup Cross Sections

About the time this analysis was completed, John Anderson<sup>17</sup> made an estimate of the n,2n cross section for tritium at 14 MeV. From the zero-degree T(p,np)D data of Holbrow<sup>18</sup> et al and the cross sections for two deuterons in the exit channels, he obtained "an over estimate of the upper limit" for T(n,2n) of ~130 mb. Even in this crude estimate he did take isospin into account, and his arguments do not depend upon the specific structure of the triton. Gammel<sup>19</sup> and MacKellar assumed that the triton "looks something like n+d."

Measurements are in progress at Los Alamos on the differential cross sections for p+He<sup>3</sup> elastic scattering around 14.3 MeV. The preliminary data substantiate the shape and magnitude derived for n,T in this analysis near 14 MeV.

In this evaluation, the n,2n cross section was assumed to be equal to the total nonelastic. Calculations were made for the emission of one neutron for the 3-body interaction at 10, 11, 12, 13, 14, and 15 MeV with  $\sigma_{n,2n} = \sigma_{NON}$ . As an example, a combination of 3-body and 4-body interactions was treated as follows: the 125-mb cross section at 14 MeV was broken down into (n,d) of 75 mb and (n,p) of 50 mb. A few of the distributions calculated in this manner are reproduced for comparison. Note that the cross section given is for the emission of one neutron; therefore the correct cross section for neutron emission would be  $2\sigma_{n,2n} + 3\sigma_{n,3n}$ . The graphical results, presented as an appendix to this volume, are arranged as follows:

a)	3-Body; $\sigma_{n,2n} = \sigma_{NON}$		
		<u>E<sub>0</sub></u>	<u><math>\theta_n</math> (lab)</u>
		10	0°
1)		11	20°
		12	
		10	
2)		11	40°
		12	90°
		10	
3)		11	Angular distributions integrated over energy
		12	
		10	
4)		11	Energy distributions integrated over angle
		12	
		13	
5)		14	0°
		15	20°
		13	
6)		14	40°
		15	90°
		15	120°
		13	
7)		14	Angular distributions integrated over energy
		15	
		13	
8)		14	Energy distributions integrated over angle
		15	
b)	Combination 3-body and 4-body at 14 MeV		
		<u><math>\theta_n</math> (lab)</u>	
			3-body
1)		0°	4-body
			Sum

2)	20° 40°	3-body 4-body Sum	Appendix-1-3-10
3)	50° 60°	3-body 4-body Sum	Appendix-1-3-11
4)	Angular distributions of 3-body, 4-body, and sum; integrated over energy		Appendix-1-3-12
5)	Energy distributions of 3-body, 4-body, and sum; integrated over angle		Appendix-1-3-13

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TABLE I

## EVALUATED NEUTRON CROSS SECTIONS SCATTERED FROM TRITIUM

(TABULAR DATA FROM GRAPHS)

## ASSUMPTIONS:

a) At thermal energies  $\sigma_{n,\gamma} \leq 6.7 \mu\text{b}$ ; therefore the capture cross section is neglected at all energies.b) For simplicity,  $\sigma_{\text{NON}} = \sigma_{n,2n}$ ; therefore  $\sigma_{n,3n} = 0$ .

	$E_0$	$\sigma_{\text{TOT}}$ Barns	$\sigma_{\text{el}}$ Barns	$\sigma_{\text{NON}}$ Barns	$\sigma_{n,\gamma}$	$\sigma_{n,2n}$ Barns	$\sigma_{n,3n}$ Barns	$E_0$ MeV	$\sigma_{\text{TOT}}$ Barns	$\sigma_{\text{el}}$ Barns	$\sigma_{\text{NON}}$ Barns	$\sigma_{n,\gamma}$	$\sigma_{n,2n}$ Barns	$\sigma_{n,3n}$ Barns
eV	0.0253	1.3	1.3	0	0	0	0	4.7	2.30	2.30	0	0	0	0
	.	↓	↓	↓	↓	↓	↓	5.0	2.24	2.24	↓	↓	↓	↓
	.	↓	↓	↓	↓	↓	↓	5.2	2.20	2.20	↓	↓	↓	↓
	.	↓	↓	↓	↓	↓	↓	5.5	2.14	2.14	↓	↓	↓	↓
	.	↓	↓	↓	↓	↓	↓	5.7	2.095	2.095	↓	↓	↓	↓
keV	100	1.3	1.3	↓	↓	↓	↓	6.0	2.03	2.03	↓	↓	↓	↓
	150	1.3	1.3	↓	↓	↓	↓	6.2	1.985	1.985	↓	↓	↓	↓
	200	1.315	1.315	↓	↓	↓	↓	6.5	1.925	1.925	↓	↓	↓	↓
	250	1.325	1.325	↓	↓	↓	↓	6.7	1.87	1.87	↓	↓	↓	↓
	300	1.35	1.35	↓	↓	↓	↓	7.0	1.815	1.815	↓	↓	↓	↓
	350	1.37	1.37	↓	↓	↓	↓	7.5	1.705	1.705	↓	↓	↓	↓
	400	1.40	1.40	↓	↓	↓	↓	8.0	1.615	1.615	↓	↓	↓	↓
	450	1.425	1.425	↓	↓	↓	↓	8.35	↓	↓	↓	↓	(Thresh.)	↓
	500	1.45	1.45	↓	↓	↓	↓	8.5	1.535	1.5345	0.0005	↓	0.0005	↓
	550	1.48	1.48	↓	↓	↓	↓	9.0	1.46	1.4545	0.0055	↓	0.0055	↓
MeV	600	1.51	1.51	↓	↓	↓	↓	9.5	1.395	1.3775	0.0175	↓	0.0175	↓
	650	1.53	1.53	↓	↓	↓	↓	9.75	1.36	1.331	0.029	↓	0.029	↓
	700	1.56	1.56	↓	↓	↓	↓	10.0	1.33	1.288	0.042	↓	0.042	↓
	800	1.61	1.61	↓	↓	↓	↓	10.4	1.285	1.222	0.063	↓	0.063	↓
	900	1.65	1.65	↓	↓	↓	↓	10.5	1.275	1.206	0.069	↓	0.069	↓
	1.0	1.70	1.70	↓	↓	↓	↓	11.0	1.22	1.1285	0.0915	↓	0.0915	↓
	1.25	1.795	1.795	↓	↓	↓	↓	11.3	↓	↓	↓	↓	(Thresh.)	↓
	1.5	1.895	1.895	↓	↓	↓	↓	11.5	1.17	1.061	0.109	↓	0.109	↓
	1.75	2.015	2.015	↓	↓	↓	↓	12.0	1.125	1.006	0.119	↓	0.119	↓
	2.0	2.12	2.12	↓	↓	↓	↓	12.5	1.075	0.9495	0.1255	↓	0.1255	↓
	2.25	2.21	2.21	↓	↓	↓	↓	13.0	1.045	0.916	0.129	↓	0.129	↓
	2.5	2.295	2.295	↓	↓	↓	↓	13.5	1.005	0.877	0.128	↓	0.128	↓
	2.75	2.35	2.35	↓	↓	↓	↓	14.0	0.975	0.850	0.125	↓	0.125	↓
	3.0	2.40	2.40	↓	↓	↓	↓	14.1	0.965	0.841	0.124	↓	0.124	↓
	3.2	2.42	2.42	↓	↓	↓	↓	14.3	0.950	0.8275	0.1225	↓	0.1225	↓
3.5	2.435	2.435	↓	↓	↓	↓	14.5	0.937	0.8165	0.1205	↓	0.1205	↓	
3.7	2.44	2.44	↓	↓	↓	↓	14.6	0.930	0.8105	0.1195	↓	0.1195	↓	
4.0	2.41	2.41	↓	↓	↓	↓	15.0	0.905	0.7905	0.1145	↓	0.1145	↓	
4.2	2.38	2.38	↓	↓	↓	↓	15.5	0.878	0.7700	0.108	↓	0.108	↓	
4.5	2.335	2.335	↓	↓	↓	↓	16.0	0.850	0.749	0.101	↓	0.101	↓	
								19.4	0.695	0.639	0.056	↓	0.056	↓

T            Z            MASS  
             1               3

DATA REFERENCES

TOTAL CROSS SECTIONS

TOTAL:

1. ● Los Alamos Physics and Cryogenics Groups, Nucl. Phys. 12, 291 (1959).

Transmission measurements using a high-purity enriched gas target and monoenergetic neutrons from the  $T(p,n)He^3$ ,  $D(d,n)He^3$ , and the  $T(d,n)He^4$  reactions.

Detectors were scintillation counters or ionization chambers.

NOTE: These cross sections have been corrected for  $He^3$  contamination since the issue of BNL-325 (1958).

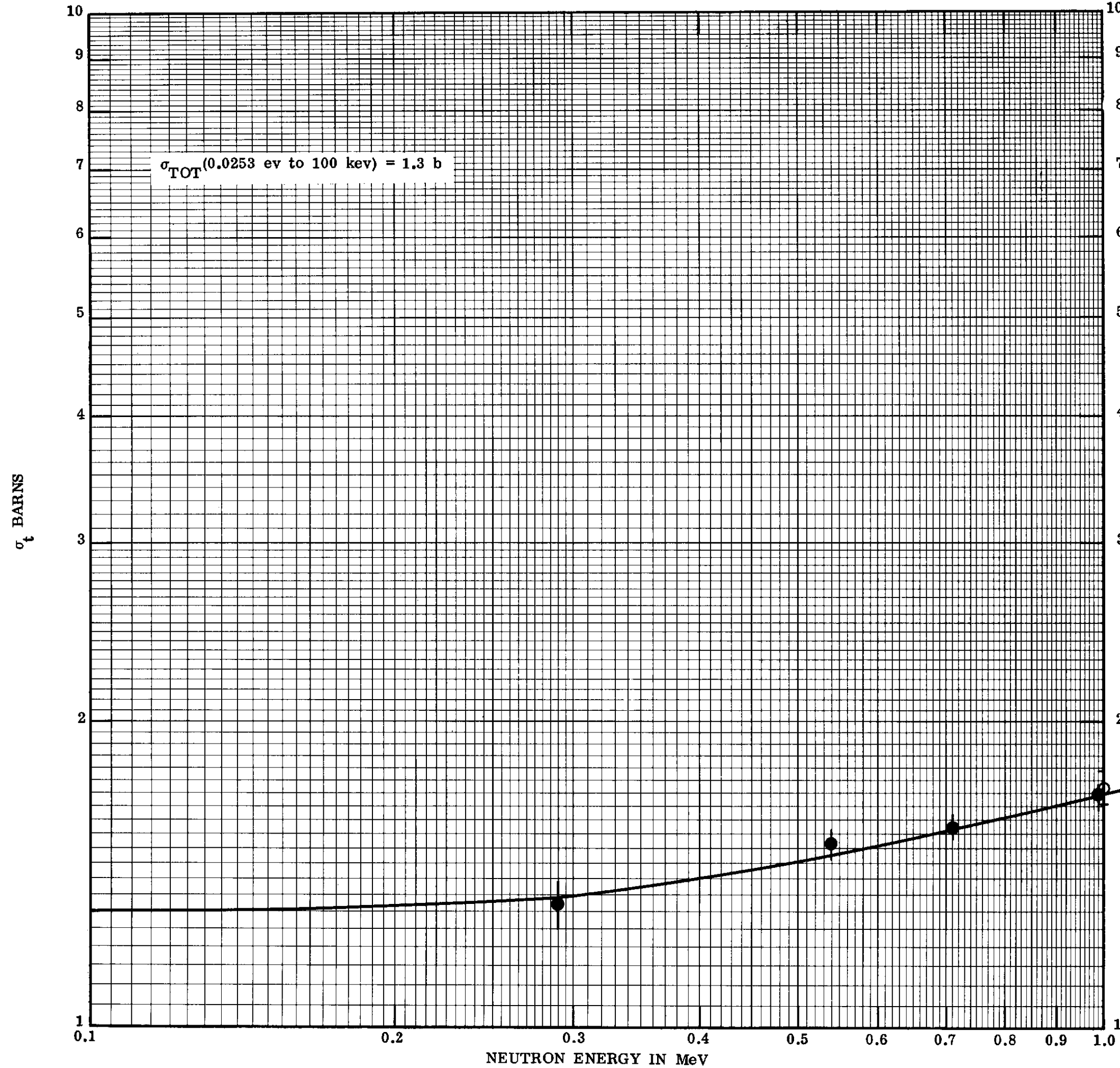
TOTAL ELASTIC CROSS SECTIONS

INTEGRATED ELASTIC:

1. ○ J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. 119, 1981 (1960).

TOTAL

T      Z      MASS  
         1      3



TOTAL

● LASL Groups, 59

INTEGRATED ELASTIC

○ Seagrave, LASL, 60

LOGARITHMIC  
1 CYCLE X 1 CYCLE

FEB. 1965

TOT-1-3-1

T            Z            MASS  
             1            3

DATA REFERENCES

TOTAL CROSS SECTIONS

TOTAL:

1. ● Los Alamos Physics and Cryogenics Groups, Nucl. Phys. 12, 291 (1959).

Transmission measurements using a high-purity enriched gas target and monoenergetic neutrons from the  $T(p,n)He^3$ ,  $D(d,n)He^3$ , and the  $T(d,n)He^4$  reactions.

Detectors were scintillation counters or ionization chambers.

NOTE: These cross sections have been corrected for  $He^3$  contamination since the issue of BNL-325 (1958).

2. L. H. Katsurov, P. M. Musaelian, and B. M. Popov have published the following measurements:

$$E_0 = 2.5 \text{ MeV}, \sigma_{TOT} = 2.5 \pm 0.5 \text{ barns}$$

$$E_0 = 14 \text{ MeV}, \sigma_{TOT} = 0.63 \pm 0.17 \text{ barns}$$

in Sov. J. Atomic Energy, Supplement #5, 71 (1957). Since a water target containing only 9.2%  $T_2O$  was used for this experiment, the data were not included in this evaluation.

TOTAL ELASTIC CROSS SECTIONS

INTEGRATED ELASTIC:

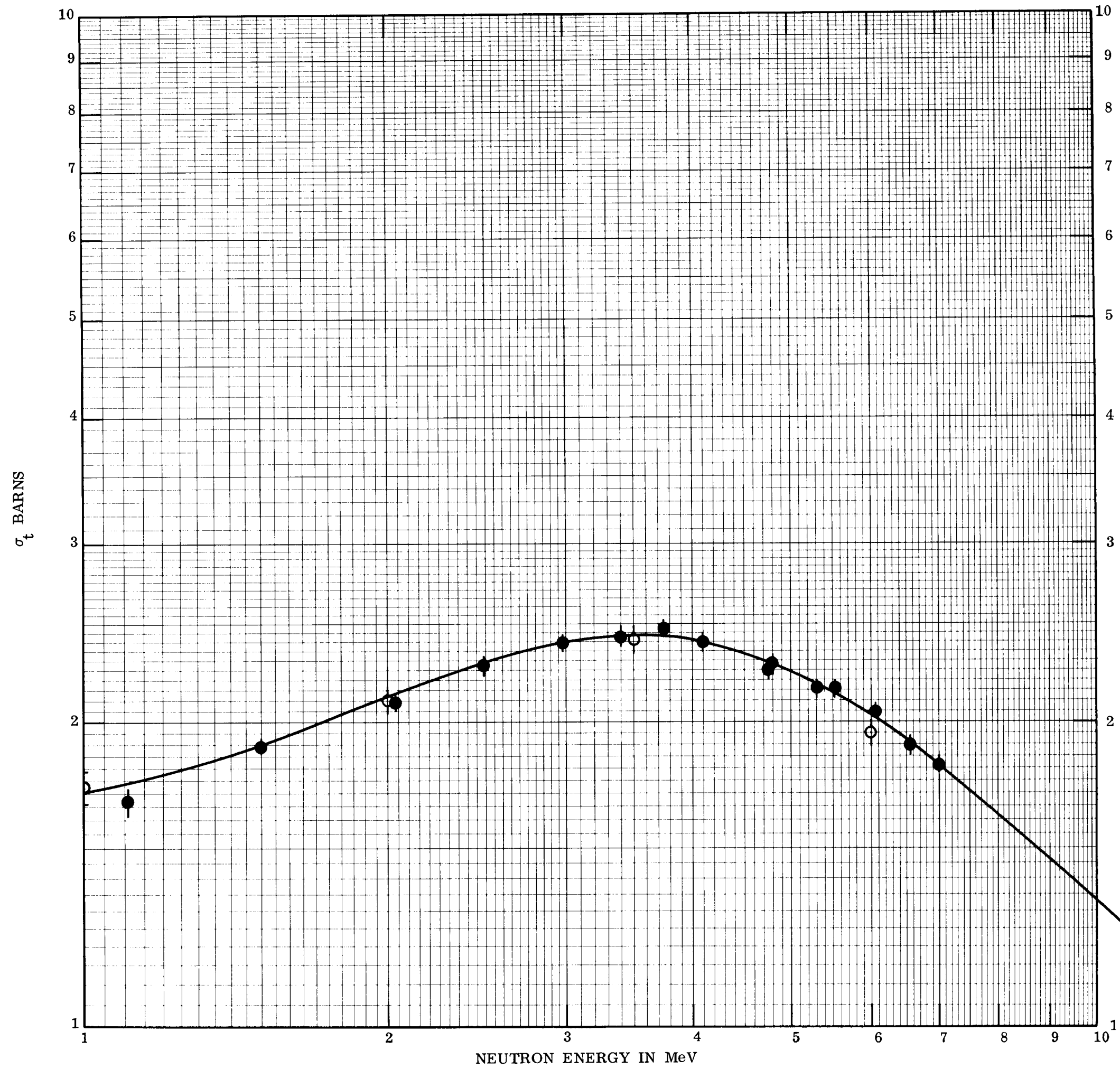
1. ○ J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. 119, 1981 (1960).

TOT-1-3-2



TOTAL

T      Z      MASS  
         1      3



TOTAL  
● LASL Groups, 59

INTEGRATED ELASTIC  
○ Seagrave, LASL, 60

1 CYCLE X 1 CYCLE

FEB. 1965

TOT-1-3-2

DATA REFERENCES

TOTAL CROSS SECTIONS

TOTAL:

1. ● Los Alamos Physics and Cryogenics Groups, Nucl. Phys. 12, 291 (1959).

Transmission measurements using a high-purity enriched gas target and monoenergetic neutrons from the  $T(p,n)He^3$ ,  $D(d,n)He^3$ , and the  $T(d,n)He^4$  reactions.

Detectors were scintillation counters or ionization chambers.

NOTE: These cross sections have been corrected for  $He^3$  contamination since the issue of BNL-325 (1958).

2. L. H. Katsaurov, P. M. Musaelian, and B. M. Popov have published the following measurements:

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$$E_0 = 14 \text{ MeV}, \sigma_{TOT} = 0.63 \pm 0.17 \text{ barns}$$

in Sov. J. Atomic Energy, Supplement #5, 71 (1957). Since a water target containing only 9.2%  $T_2O$  was used for this experiment, the data were not included in this evaluation.

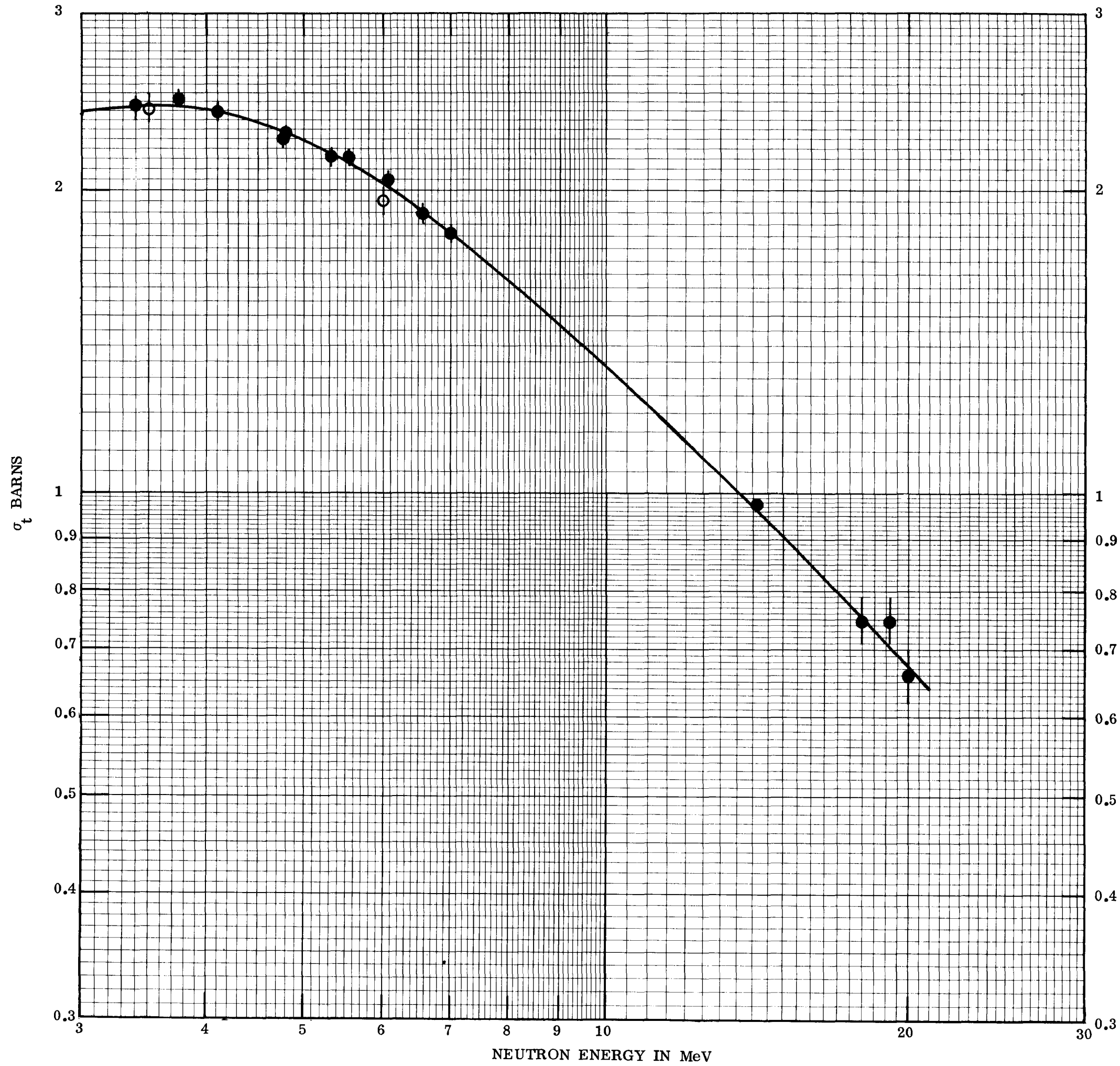
TOTAL ELASTIC CROSS SECTIONS

INTEGRATED ELASTIC:

1. ○ J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. 119, 1981 (1960).

TOTAL

T      Z      MASS  
         1      3



LOGARITHMIC  
1 CYCLE X 1 CYCLE

FEB. 1965

TOT-1-3-3

T	Z	MASS
	1	3

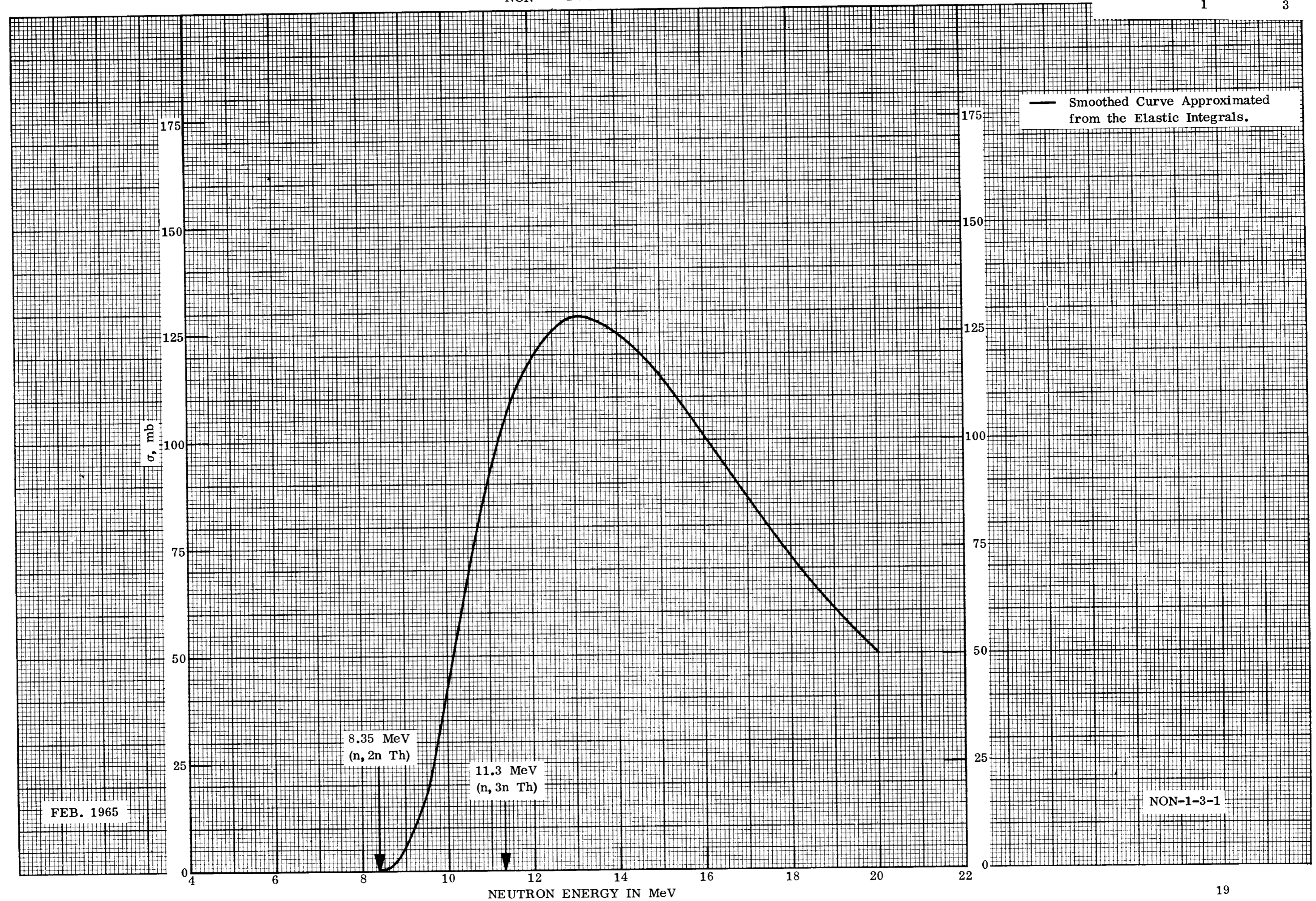
#### NONELASTIC CROSS SECTIONS

This curve was obtained mostly by guesswork. There is really no reason to expect the  $n, 2n$  cross section to rise to such large values and then to drop as fast as this curve indicates. It should be noted, however, that a completely different curve could be drawn through the "total" cross sections; therefore, it seemed reasonable to allow the  $n, 2n$  cross section to reach a value obtained by the best guess one can make at this time on both the total and the integral of the elastic.

NON-1-3-1

$$\sigma_{\text{NON}} = \sigma_{\text{TOT}} - \sigma_{\text{el}}$$

T      Z      MASS  
         1      3



T        Z        MASS  
           1        3

$E_0 = 0.5 \text{ MeV}$

Table II

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

<u>COSINE</u> <u><math>\theta</math></u>	<u><math>\sigma(\theta)</math></u> <u>mb/sr</u>	<u>P(<math>\theta</math>)</u>
1.0	80.6	0.3437
0.9	80.8	0.3446
0.8	81.3	0.3467
0.7	81.9	0.3493
0.6	83.7	0.3569
0.5	85.9	0.3663
0.4	88.6	0.3778
0.3	91.9	0.3919
0.2	95.9	0.4090
0.1	100.6	0.4290
0.0	105.7	0.4508
-0.1	111.7	0.4764
-0.2	118.4	0.5049
-0.3	125.5	0.5352
-0.4	133.5	0.5693
-0.5	142.2	0.6064
-0.6	152.2	0.6491
-0.7	163.1	0.6956
-0.8	174.6	0.7446
-0.9	187.3	0.7988
-1.0	199.7	0.8516
SUM =	2344.9	10.0002
$\times \sin \theta d\theta =$	234.49	1.00002
$\times d\phi =$	1.473 barns	

(Comparison with curve),  $\sigma_{TOT} = 1.45 \text{ barns}$

NOTE: The above cross sections were obtained from an interpolation, linear with energy, using the 1.0-MeV angular distributions and the assumption of isotropy at 100 keV. At 100 keV, a total cross section of 1.3 barns and a differential of 103.45 mb/sr were used.



T            Z            MASS  
               1            3

$E_0 = 1.0$  MeV

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

<u>COSINE</u> <u><math>\theta</math></u>	<u><math>\sigma(\theta)</math></u> <u>mb/sr</u>	<u><math>P(\theta)</math></u>
1.0	52	0.1933
0.9	52.5	0.1952
0.8	53.5	0.1989
0.7	55	0.2045
0.6	59	0.2194
0.5	64	0.2380
0.4	70	0.2603
0.3	77.5	0.2881
0.2	86.5	0.3216
0.1	97	0.3606
0.0	108.5	0.4034
-0.1	122	0.4536
-0.2	137	0.5094
-0.3	153	0.5689
-0.4	171	0.6358
-0.5	190.5	0.7083
-0.6	213	0.7919
-0.7	237.5	0.8830
-0.8	263.5	0.9797
-0.9	292	1.086
-1.0	320	1.190

SUM = 2689.0            9.9983

$\times \sin \theta d\theta =$  268.90            0.99983

$\times d\phi =$  1.690 barns

(Comparison with curve),  $\sigma_{TOT} =$  1.70 barns

(Seagrave's integral),  $\sigma_{el} =$  1.72  $\pm$  0.06 barns

DATA REFERENCE

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

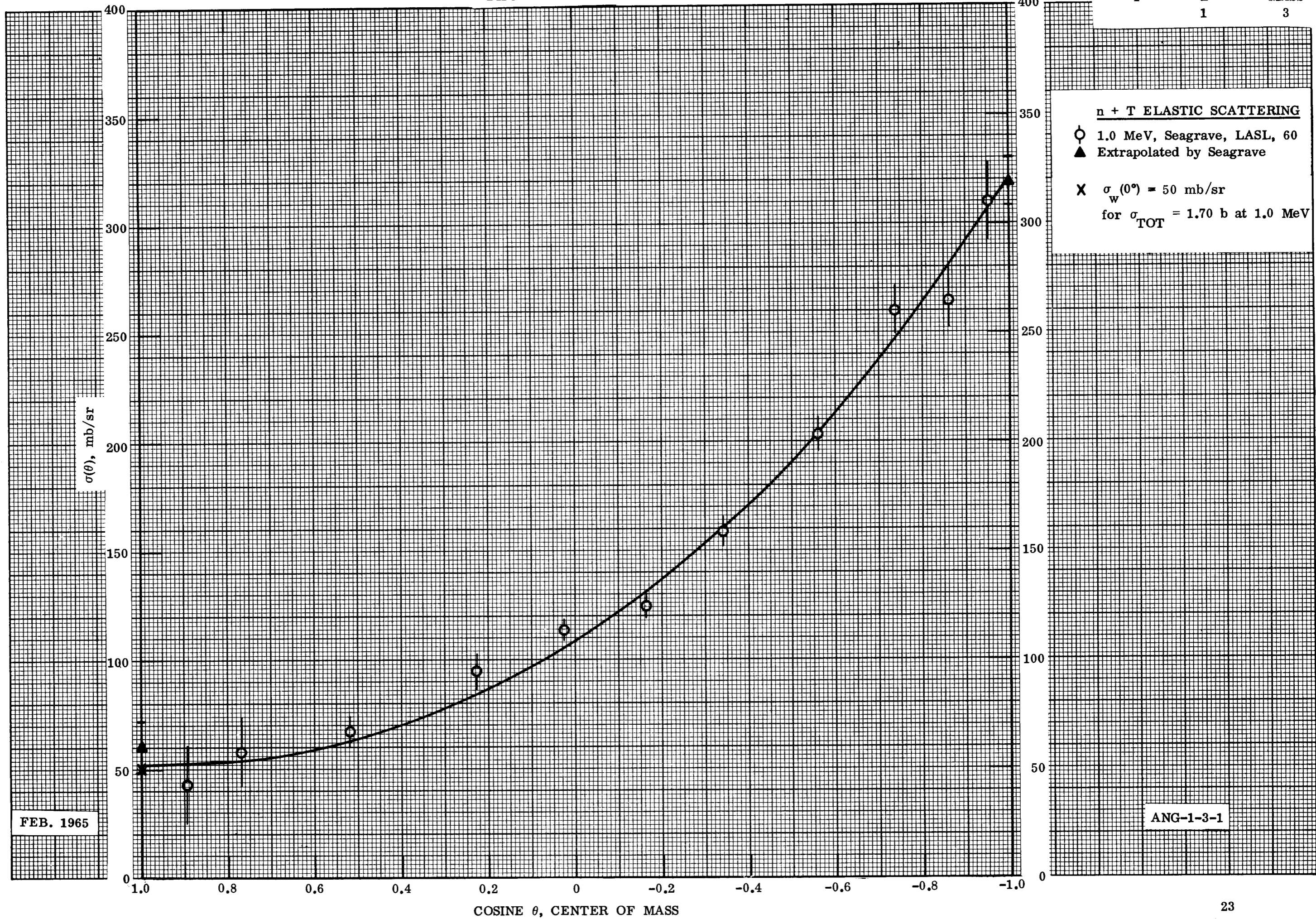
n + T ELASTIC SCATTERING:

1.  $\begin{matrix} \circ \\ \blacktriangle \end{matrix} \left\{ \begin{array}{l} \text{J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. } \underline{119}, \\ 1981 \text{ (1960)}. \end{array} \right.$



DIFFERENTIAL ELASTIC

T Z MASS  
1 3



FEB. 1965

ANG-1-3-1

10 X 10 TO THE 1/4 INCH

T            Z            MASS  
               1            3

$E_0 = 2.0$  MeV

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE $\theta$	$\sigma(\theta)$ mb/sr	$P(\theta)$
1.0	167	0.4990
0.9	147	0.4392
0.8	129	0.3855
0.7	115	0.3436
0.6	103	0.3078
0.5	94	0.2809
0.4	88	0.2629
0.3	86	0.2570
0.2	87	0.2600
0.1	91.5	0.2734
0.0	98.5	0.2943
-0.1	109.5	0.3272
-0.2	125	0.3735
-0.3	145	0.4333
-0.4	170	0.5080
-0.5	200	0.5976
-0.6	237	0.7082
-0.7	279	0.8337
-0.8	328	0.9801
-0.9	393	1.174
-1.0	475	1.419

SUM = 3346.5            9.9995

$\times \sin \theta d\theta =$  334.65            0.99995

$\times d\phi =$  2.103 barns

(Comparison with curve),  $\sigma_{TOT} =$  2.12 barns

(Seagrave's integral),  $\sigma_{el} =$  2.10  $\pm$  0.06 barns

DATA REFERENCE

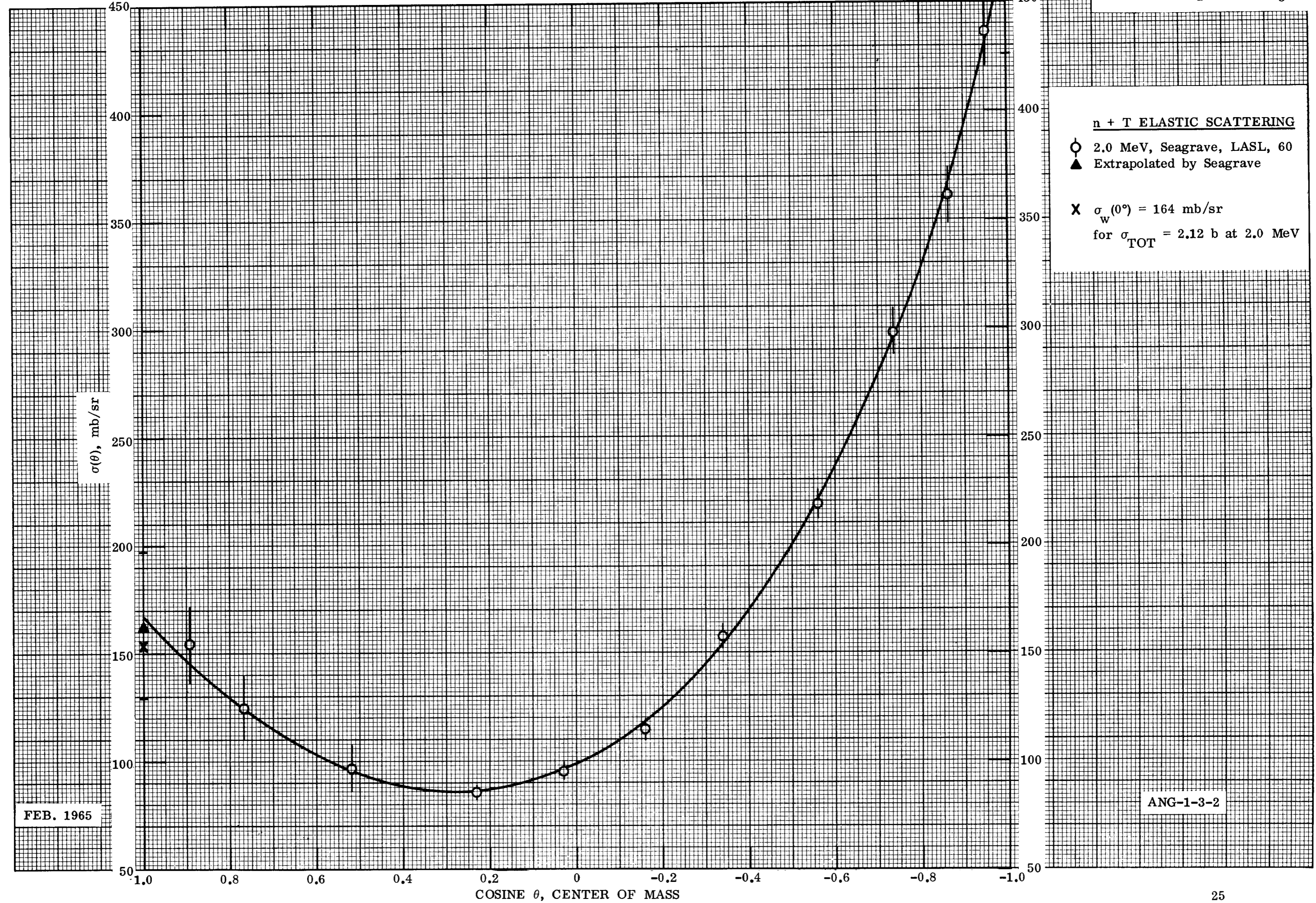
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

1.  $\left. \begin{array}{l} \circ \\ \blacktriangle \end{array} \right\}$  J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. 119,  
 1981 (1960).

DIFFERENTIAL ELASTIC

T            Z            MASS  
                 1            3



10 X 10 TO THE 1/2 INCH

FEB. 1965

ANG-1-3-2

T            Z            MASS  
               1            3

$E_0 = 3.5$  MeV

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE $\theta$	$\sigma(\theta)$ mb/sr	$P(\theta)$
1.0	403	1.064
0.9	360	0.9504
0.8	317	0.8369
0.7	271	0.7154
0.6	227	0.5993
0.5	186	0.4910
0.4	153	0.4039
0.3	126	0.3326
0.2	105	0.2772
0.1	89	0.2350
0.0	80.5	0.2125
-0.1	78	0.2059
-0.2	82.5	0.2178
-0.3	93	0.2455
-0.4	110	0.2904
-0.5	134	0.3538
-0.6	165	0.4356
-0.7	206	0.5438
-0.8	262	0.6917
-0.9	332	0.8765
-1.0	418	1.104
SUM =		3787.5
× sin $\theta$ d $\theta$ =		378.75
× d $\phi$ =		2.380 barns

(Comparison with curve),  $\sigma_{TOT} = 2.435$  barns

(Seagrave's integral),  $\sigma_{el} = 2.41 \pm 0.07$  barns

DATA REFERENCE

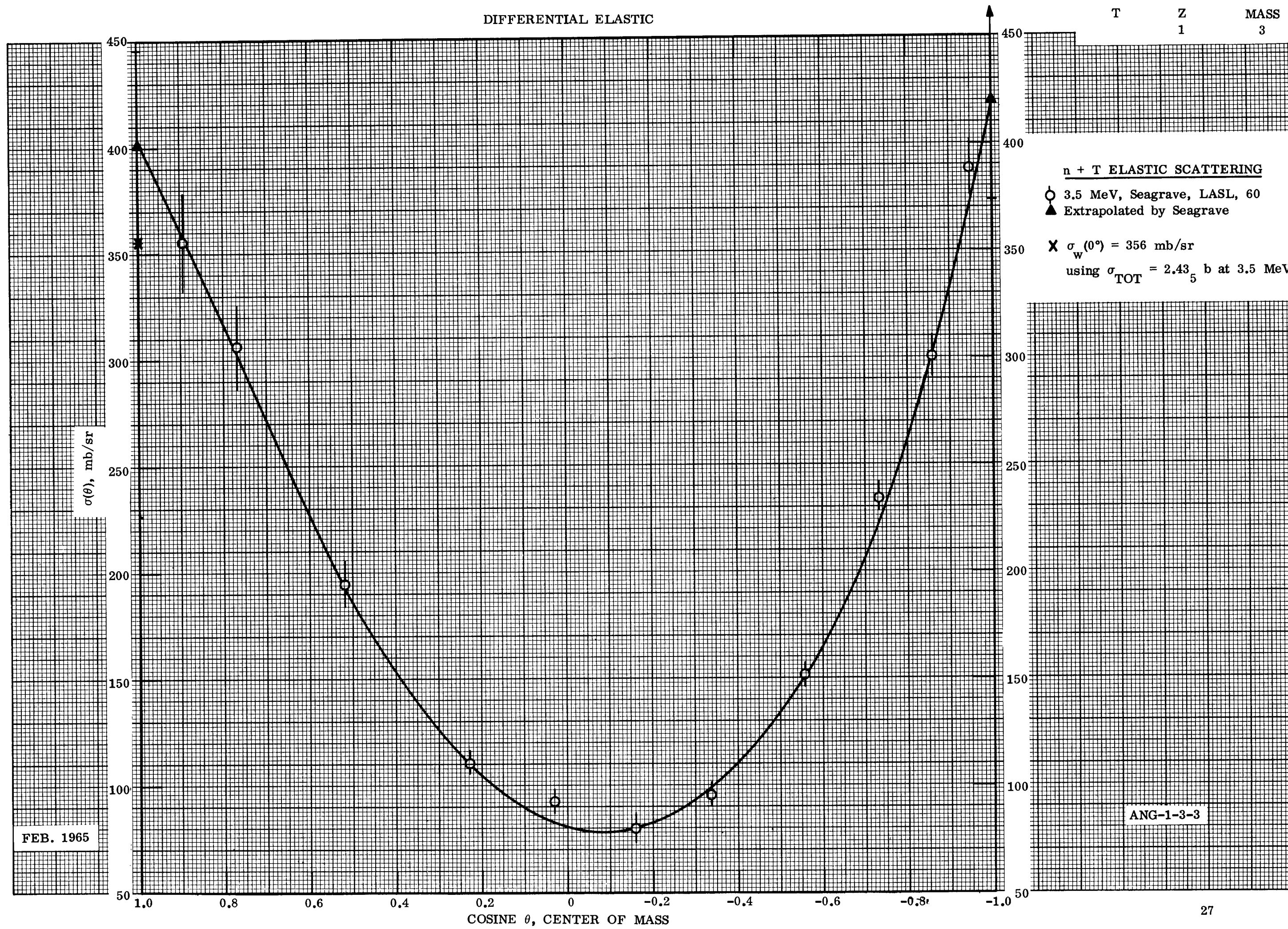
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

- |                        |   |   |
|------------------------|---|---|
| $\circ$<br>$\triangle$ | } | J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. <u>119</u> ,<br>1981 (1960). |
|------------------------|---|---|

DIFFERENTIAL ELASTIC

T Z MASS  
1 1 3



n + T ELASTIC SCATTERING

- 3.5 MeV, Seagrave, LASL, 60
- ▲ Extrapolated by Seagrave
- ✕  $\sigma_w(0^\circ) = 356$  mb/sr  
using  $\sigma_{TOT} = 2.43_5$  b at 3.5 MeV

FEB. 1965

ANG-1-3-3

10 X 10 TO THE 1/8 INCH

T            Z            MASS  
               1            3

$E_0 = 6.0$  MeV

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

<u>COSINE</u> <u><math>\theta</math></u>	<u><math>\sigma(\theta)</math></u> <u>mb/sr</u>	<u>P(<math>\theta</math>)</u>
1.0	458	1.480
0.9	403	1.303
0.8	353	1.141
0.7	299	0.9665
0.6	247	0.7985
0.5	197	0.6368
0.4	155	0.5011
0.3	123	0.3976
0.2	97	0.3136
0.1	77	0.2489
0.0	62	0.2004
-0.1	50	0.1616
-0.2	43	0.1390
-0.3	42	0.1358
-0.4	47	0.1519
-0.5	61	0.1972
-0.6	80	0.2586
-0.7	105	0.3394
-0.8	136	0.4396
-0.9	175	0.5657
-1.0	<u>225</u>	<u>0.7273</u>

SUM = 3093.5            9.9998

$\times \sin \theta d\theta = 309.35$             0.99998

$\times d\phi = 1.944$  barns

(Comparison with curve),  $\sigma_{TOT} = 2.03$  barns

(Seagrave's integral),  $\sigma_{el} = 1.95 \pm 0.06$  barns

DATA REFERENCE

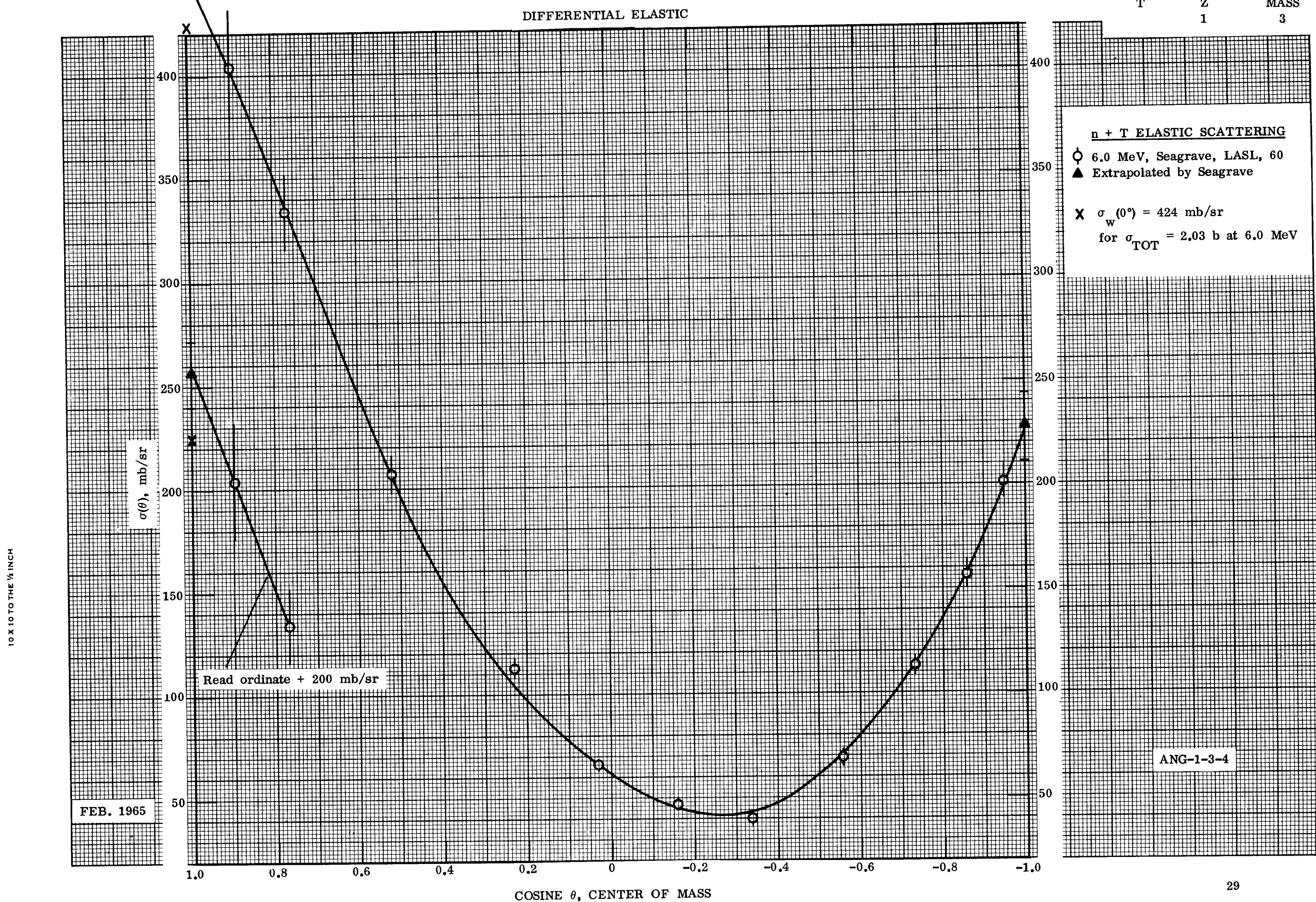
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

- |                             |   |   |
|-----------------------------|---|---|
| $\circ$<br>$\blacktriangle$ | } | J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. <u>119</u> ,<br>1981 (1960). |
|-----------------------------|---|---|

DIFFERENTIAL ELASTIC

T Z MASS  
1 3



DATA REFERENCES

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

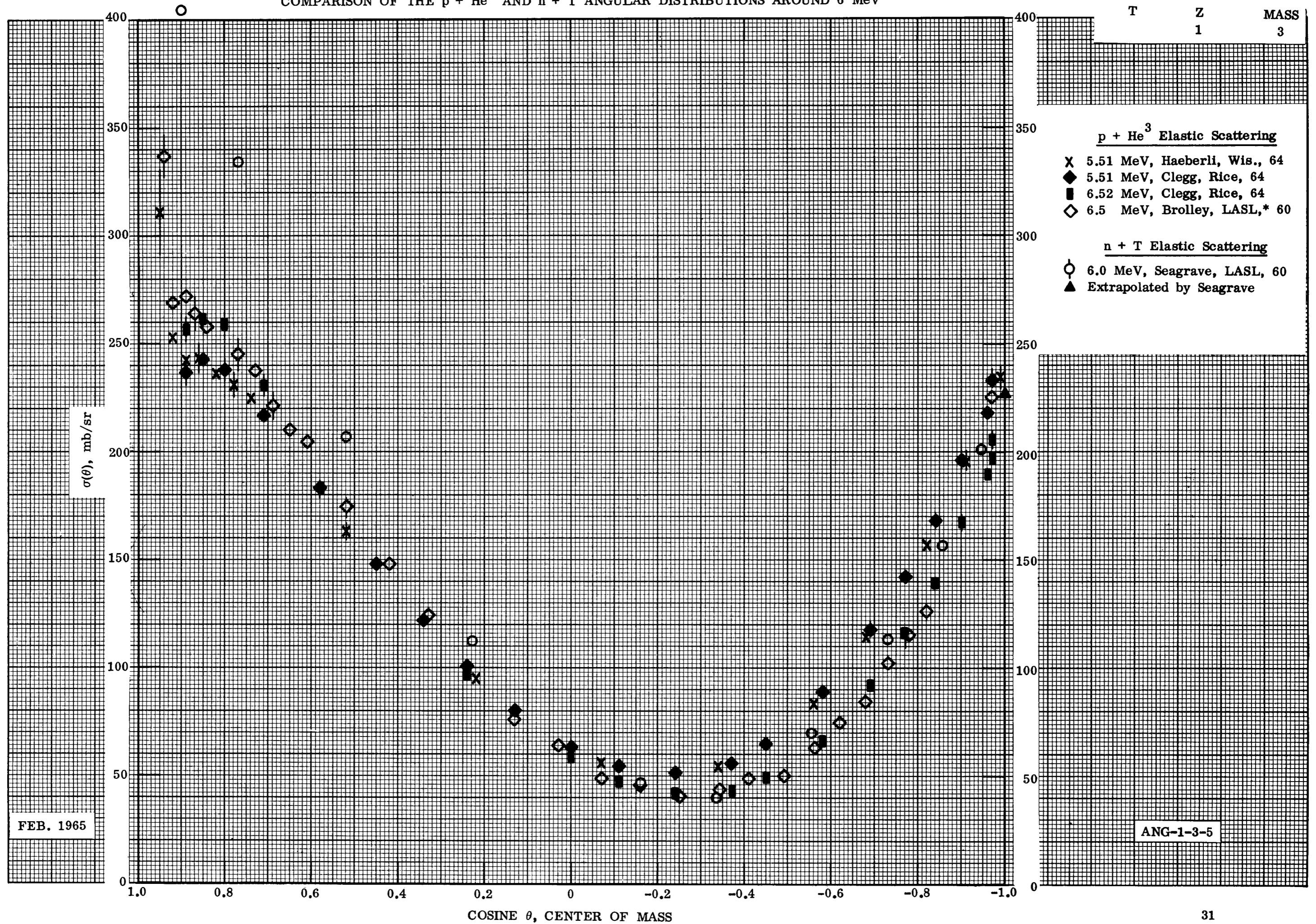
1.  $\left. \begin{array}{l} \circ \\ \blacktriangle \end{array} \right\}$  J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. 119,  
1981 (1960).

p + He<sup>3</sup> ELASTIC SCATTERING:

2. X D. G. McDonald, W. Haeberli, and L. W. Morrow, Phys. Rev. 133B,  
1178 (1964).
3.  $\left. \begin{array}{l} \blacklozenge \\ \blacksquare \end{array} \right\}$  T. B. Clegg, A. C. L. Barnard, J. B. Swint, and J. L. Weil, Nucl.  
Phys. 50, 621 (1964).
4.  $\diamond$  J. E. Brolley, Jr., T. M. Putnam, L. Rosen, and L. Stewart, Phys.  
Rev. 117, 1307 (1960). The data obtained from the measurements  
on the He<sup>3</sup> recoil nuclei were not used in this analysis.



COMPARISON OF THE  $p + \text{He}^3$  AND  $n + \text{T}$  ANGULAR DISTRIBUTIONS AROUND 6 MeV



10 X 10 TO THE 1/4 INCH

T            Z            MASS  
               1               3

$E_0 = 8.5 \text{ MeV}$

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE $\theta$	$\sigma(\theta)$ mb/sr	$P(\theta)$
1.0	350	1.485
0.9	321	1.362
0.8	288	1.222
0.7	245	1.040
0.6	203	0.8615
0.5	166	0.7045
0.4	133	0.5645
0.3	104	0.4414
0.2	81.5	0.3459
0.1	62.5	0.2653
0.0	48	0.2037
-0.1	36.8	0.1562
-0.2	28.6	0.1214
-0.3	23.5	0.09973
-0.4	25.2	0.1069
-0.5	31.5	0.1337
-0.6	42.3	0.1791
-0.7	59.5	0.2525
-0.8	85	0.3607
-0.9	118.5	0.5029
-1.0	157	0.6663

SUM = 2356.3            9.99953

$\times \sin \theta d\theta =$  235.63            0.999953

$\times d\phi =$  1.481 barns

(Comparison with curve),  $\sigma_{el} =$  1.535 barns

DATA REFERENCES

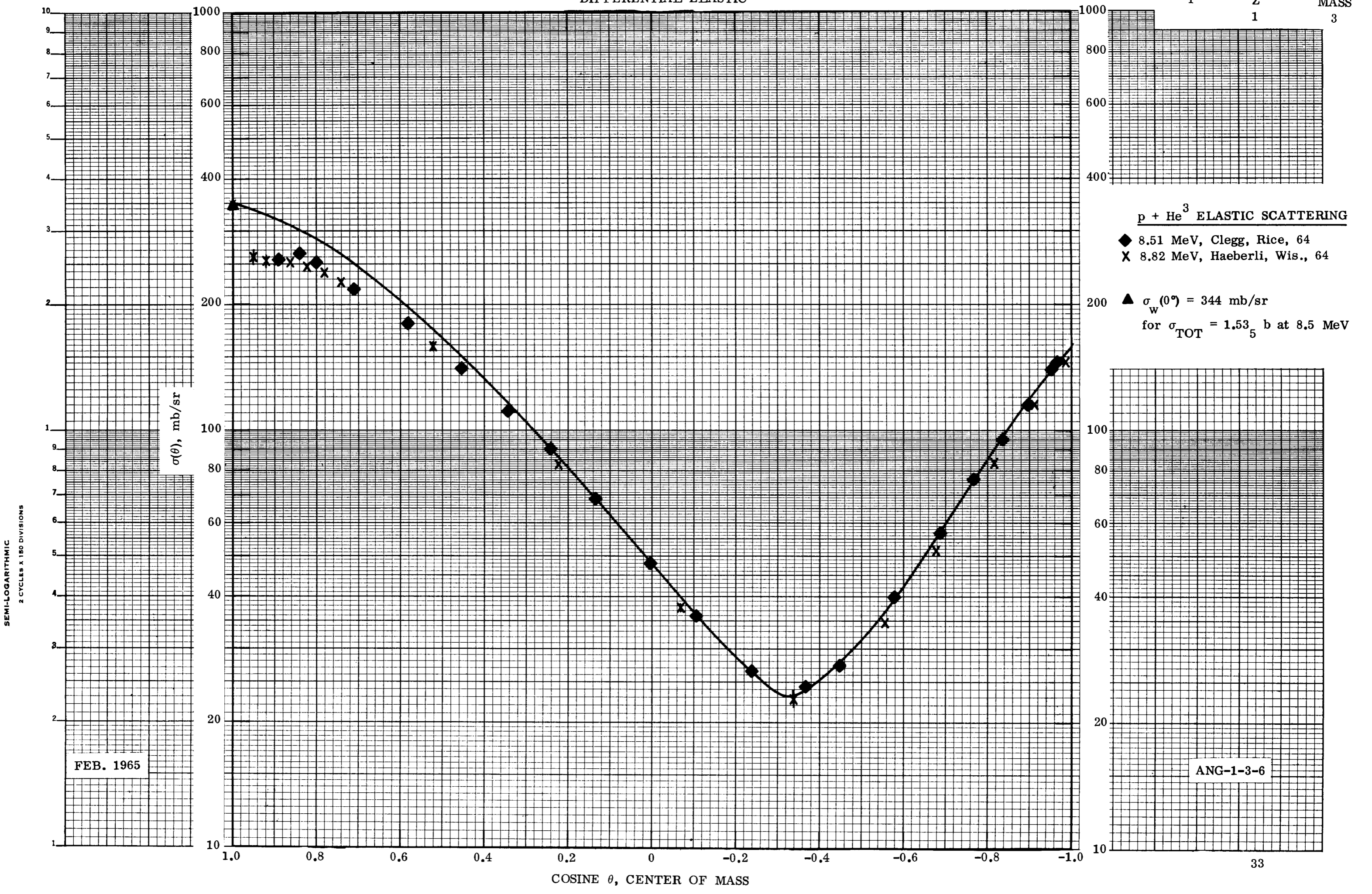
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He<sup>3</sup> ELASTIC SCATTERING:

1. ✕ D. G. McDonald, W. Haeberli, and L. W. Morrow, Phys. Rev. 133B, 1178 (1964).
2. ◆ T. B. Clegg, A. C. L. Barnard, J. B. Swint, and J. L. Weil, Nucl. Phys. 50, 621 (1964).

DIFFERENTIAL ELASTIC

T Z MASS  
1 3



SEMI-LOGARITHMIC  
2 CYCLES X 180 DIVISIONS

FEB. 1965

ANG-1-3-6

T        Z        MASS  
           1        3

$E_0 = 9.5 \text{ MeV}$

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE $\theta$	$\sigma(\theta)$ mb/sr	$P(\theta)$
1.0	318	1.478
0.9	295	1.371
0.8	264	1.227
0.7	230	1.069
0.6	194	0.9015
0.5	157	0.7296
0.4	127	0.5902
0.3	99	0.4601
0.2	77	0.3578
0.1	58.5	0.2718
0.0	44	0.2045
-0.1	33	0.1534
-0.2	25.2	0.1171
-0.3	20.6	0.09573
-0.4	20	0.09294
-0.5	24.2	0.1125
-0.6	33.5	0.1557
-0.7	49	0.2277
-0.8	72	0.3346
-0.9	100	0.4647
-1.0	140	0.6506

SUM = 2152.0        10.00117

$\times \sin \theta \, d\theta =$  215.20        1.000117

$\times d\phi =$  1.352 barns

(Comparison with curve),  $\sigma_{el} =$  1.377 barns

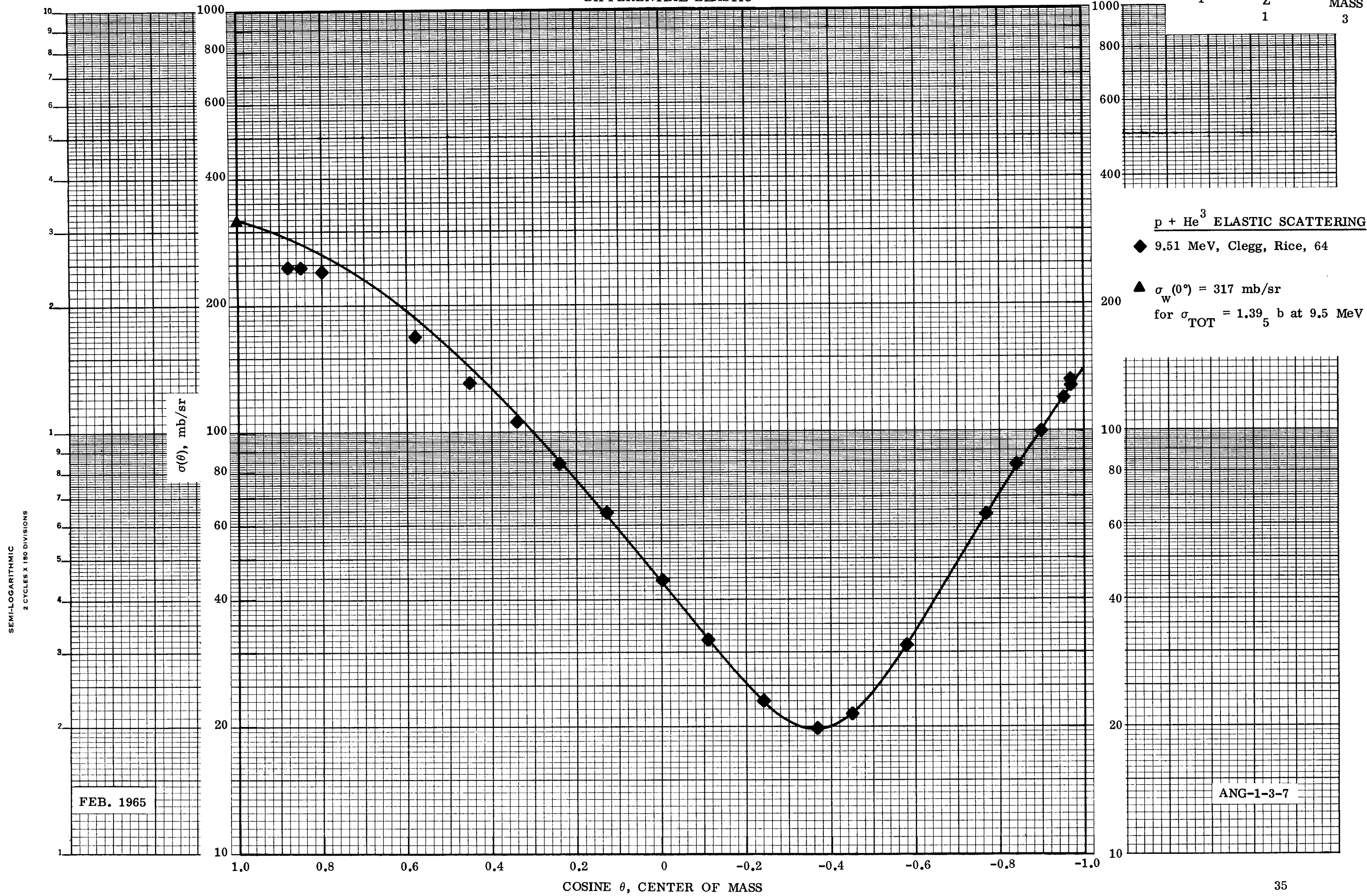
DATA REFERENCE

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He<sup>3</sup> ELASTIC SCATTERING:

- ◆ T. B. Clegg, A. C. L. Barnard, J. B. Swint, and J. L. Weil, Nucl. Phys. 50, 621 (1964).

DIFFERENTIAL ELASTIC



T            Z            MASS  
               1            3

$E_0 = 9.75$  MeV

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE $\theta$	$\sigma(\theta)$ mb/sr	$P(\theta)$
1.0	309	1.476
0.9	285	1.361
0.8	257	1.228
0.7	225	1.075
0.6	193	0.9220
0.5	161	0.7691
0.4	130	0.6210
0.3	100	0.4777
0.2	76	0.3631
0.1	57	0.2723
0.0	42	0.2006
-0.1	30.5	0.1457
-0.2	23.5	0.1123
-0.3	18.5	0.08837
-0.4	18	0.08599
-0.5	22.5	0.1075
-0.6	32	0.1529
-0.7	47	0.2245
-0.8	67.5	0.3224
-0.9	92.5	0.4419
-1.0	<u>122</u>	<u>0.5828</u>
SUM = 2093.5		10.00076
$\times \sin \theta d\theta =$		209.35      1.000076
$\times d\phi =$		1.315 barns
(Comparison with curve), $\sigma_{el} =$		1.331 barns

DATA REFERENCE

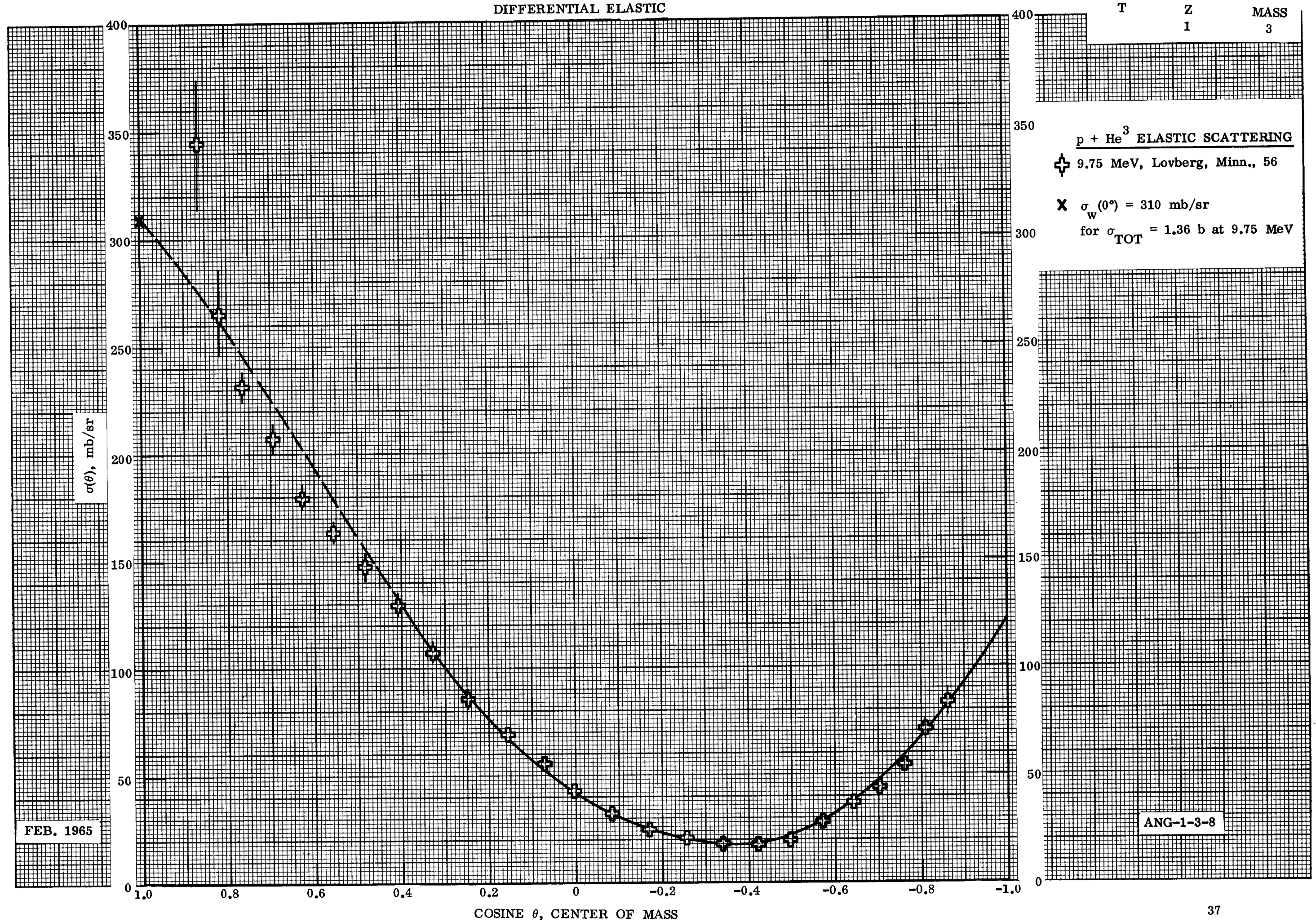
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He<sup>3</sup> ELASTIC SCATTERING:

1.  $\oplus$  Ralph H. Lovberg, Phys. Rev. 103, 1393 (1956).

ANG-1-3-8

DIFFERENTIAL ELASTIC



T            Z            MASS  
               1            3

$E_0 = 10.4$  MeV

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE $\theta$	$\sigma(\theta)$ mb/sr	$P(\theta)$
1.0	293	1.486
0.9	271	1.374
0.8	243	1.232
0.7	212	1.075
0.6	183	0.9281
0.5	151	0.7658
0.4	120	0.6086
0.3	94	0.4767
0.2	71.9	0.3646
0.1	54	0.2739
0.0	40.5	0.2054
-0.1	30	0.1521
-0.2	22.2	0.1126
-0.3	17.9	0.09078
-0.4	17	0.08621
-0.5	19.5	0.09889
-0.6	26.8	0.1359
-0.7	40.5	0.2054
-0.8	61	0.3094
-0.9	89	0.4514
-1.0	122	0.6187

SUM = 1971.8            9.99908

$\times \sin \theta d\theta =$  197.18            0.999908

$\times d\phi =$  1.239 barns

(Comparison with curve),  $\sigma_{el} =$  1.222 barns (total elastic)

DATA REFERENCES

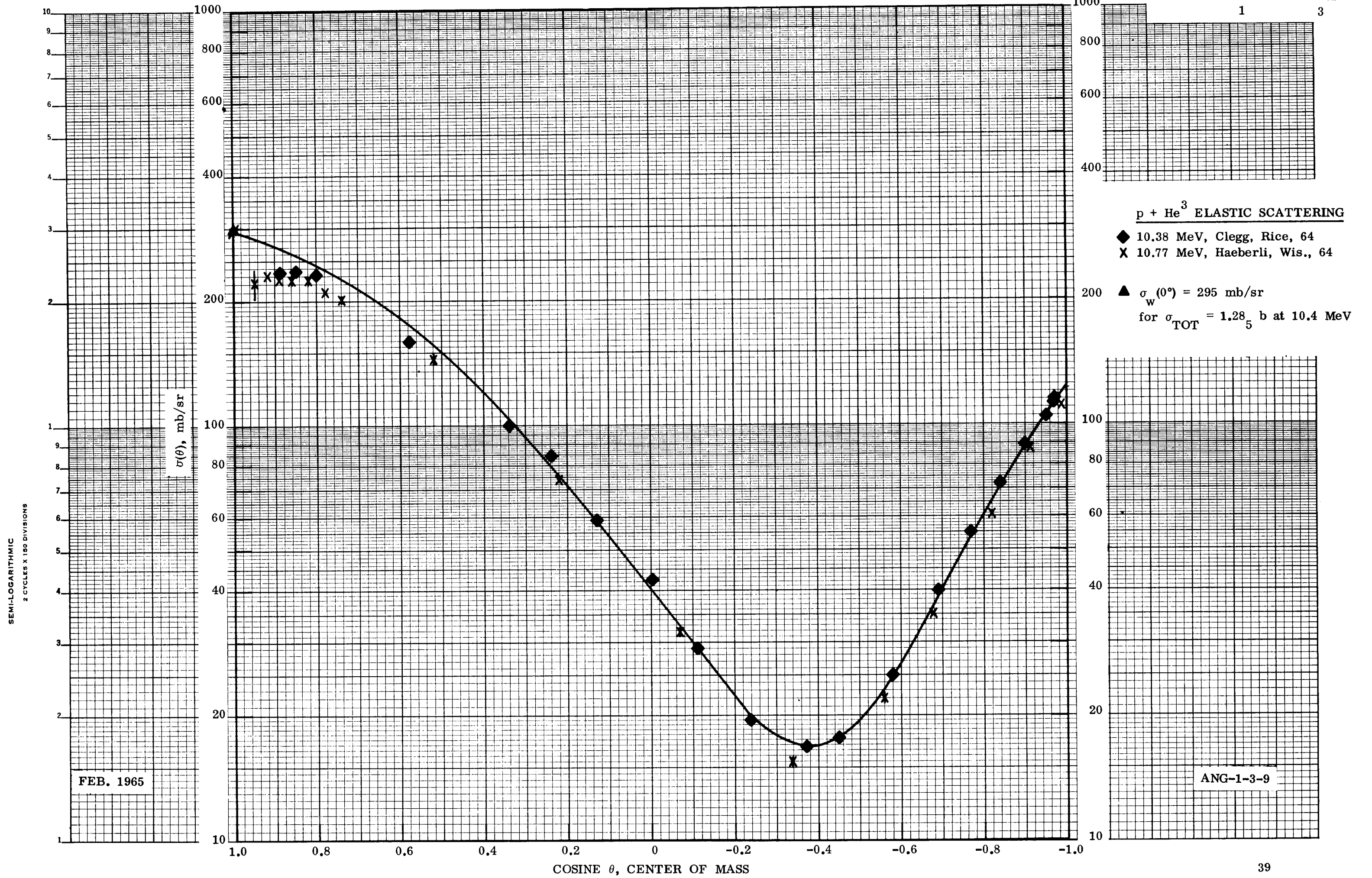
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He<sup>3</sup> ELASTIC SCATTERING:

1. X D. G. McDonald, W. Haeberli, and L. W. Morrow, Phys. Rev. 133B, 1178 (1964).
2. ◆ T. B. Clegg, A. C. L. Barnard, J. B. Swint, and J. L. Weil, Nucl. Phys. 50, 621 (1964).



DIFFERENTIAL ELASTIC



T        Z        MASS  
       1        3

$E_0 = 11.5 \text{ MeV}$

DATA REFERENCE

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

<u>COSINE</u> <u><math>\theta</math></u>	<u><math>\sigma(\theta)</math></u> <u>mb/sr</u>	<u><math>P(\theta)</math></u>
1.0	270	1.609
0.9	237	1.413
0.8	205	1.222
0.7	176	1.049
0.6	149	0.8882
0.5	123	0.7332
0.4	100	0.5961
0.3	80	0.4769
0.2	62.5	0.3726
0.1	48	0.2861
0.0	36.5	0.2176
-0.1	26.8	0.1598
-0.2	19.8	0.1180
-0.3	14.6	0.08703
-0.4	12.5	0.07451
-0.5	15.3	0.09120
-0.6	22	0.1311
-0.7	33	0.1967
-0.8	50.5	0.3010
-0.9	77	0.4590
-1.0	<u>108</u>	<u>0.6438</u>

SUM = 1677.5        9.99944

$\times \sin \theta d\theta = 167.75$         0.999944

$\times d\phi = 1.054$  barns

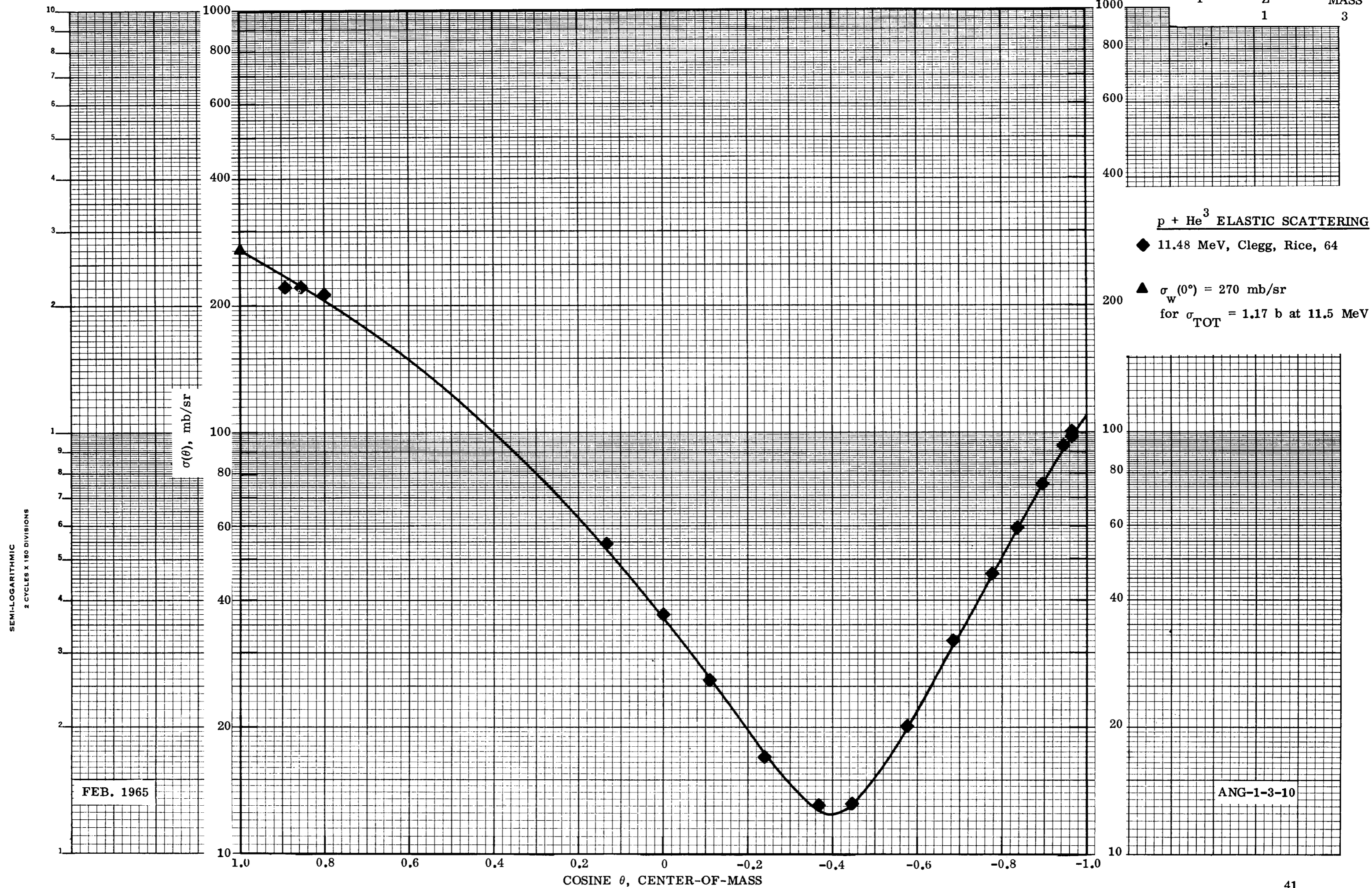
(Comparison with curve),  $\sigma_{el} = 1.061$  barns

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He<sup>3</sup> ELASTIC SCATTERING:

- ◆ T. B. Clegg, A. C. L. Barnard, J. B. Swint, and J. L. Weil, Nucl. Phys. 50, 621 (1964).

DIFFERENTIAL ELASTIC



T            Z            MASS  
               1            3

$E_0 = 14.1$  MeV

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

<u>COSINE</u> <u><math>\theta</math></u>	<u><math>\sigma(\theta)</math></u> <u>mb/sr</u>	<u><math>P(\theta)</math></u>
1.0	235	1.717
0.9	201	1.468
0.8	172	1.256
0.7	145	1.059
0.6	121	0.8839
0.5	101	0.7378
0.4	82	0.5990
0.3	64.5	0.4712
0.2	50.5	0.3689
0.1	38.3	0.2798
0.0	28.7	0.2096
-0.1	21.3	0.1556
-0.2	15.8	0.1154
-0.3	11.7	0.08547
-0.4	9.6	0.07013
-0.5	10.9	0.07962
-0.6	16.3	0.1191
-0.7	25.2	0.1841
-0.8	38.2	0.2791
-0.9	57.2	0.4178
-1.0	<u>82.5</u>	<u>0.6027</u>

SUM = 1368.9            9.99932  
 ×  $\sin \theta d\theta$  = 136.89            0.999932  
 ×  $d\phi$  = 860 millibarns  
 (Comparison with curve),  $\sigma_{el}$  = 841 millibarns

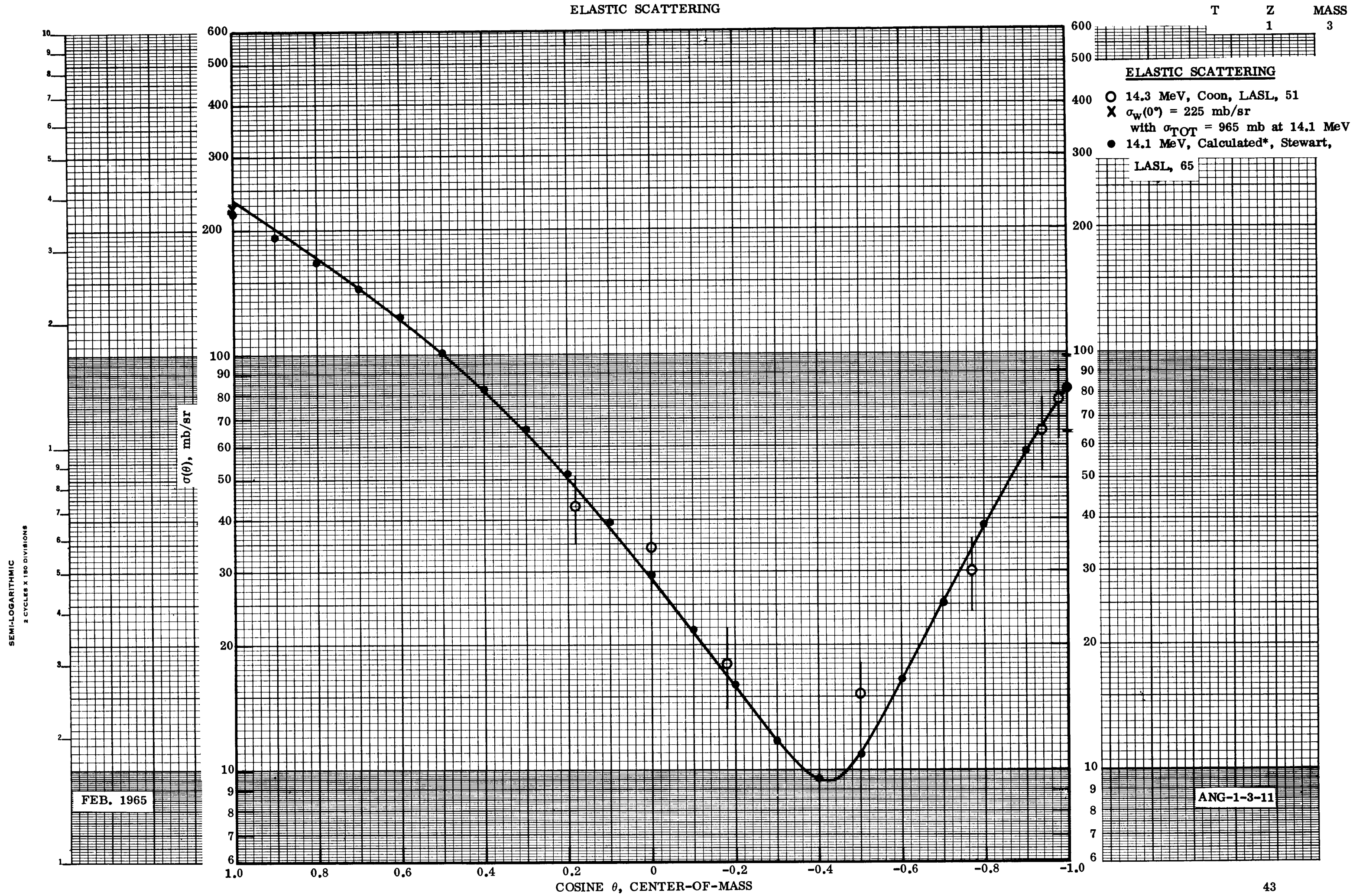
DATA REFERENCES

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

ELASTIC SCATTERING:

1. ○ J. H. Coon, C. K. Bockelman, and H. H. Barschall, Phys. Rev. 81, 33 (1951). The cross sections shown are the values suggested by Seagrave and published in BNL-400, Second Edition.
2. ● These points represent an interpolation (linear with energy) between the 11.5-MeV and 19.4-MeV n+T curves which were obtained from the p+He<sup>3</sup> measurements. Before being plotted, the interpolated points were reduced by approximately 7.5% to give better agreement with the total elastic scattering at this energy.

ELASTIC SCATTERING



T            Z            MASS  
               1            3

$E_0 = 19.4$  MeV

EVALUATED ANGULAR DISTRIBUTIONS  
 OF  
 NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE $\theta$	$\sigma(\theta)$ mb/sr	$P(\theta)$
1.0	162	1.579
0.9	146	1.423
0.8	131	1.277
0.7	115	1.121
0.6	100	0.9747
0.5	84	0.8187
0.4	67.5	0.6579
0.3	53.5	0.5215
0.2	41.	0.3996
0.1	30.5	0.2973
0.0	22.3	0.2174
-0.1	16.3	0.1589
-0.2	11.9	0.1160
-0.3	8.5	0.08285
-0.4	5.8	0.05653
-0.5	4.4	0.04289
-0.6	9.2	0.08967
-0.7	15.5	0.1511
-0.8	23.5	0.2291
-0.9	34.5	0.3363
-1.0	49.	0.4776

SUM = 1025.9            9.99975

× sin  $\theta$  d $\theta$  = 102.59    0.999975

× d $\phi$  = 645 millibarns

(Comparison with curve),  $\sigma_{el}$  = 639 millibarns

DATA REFERENCE

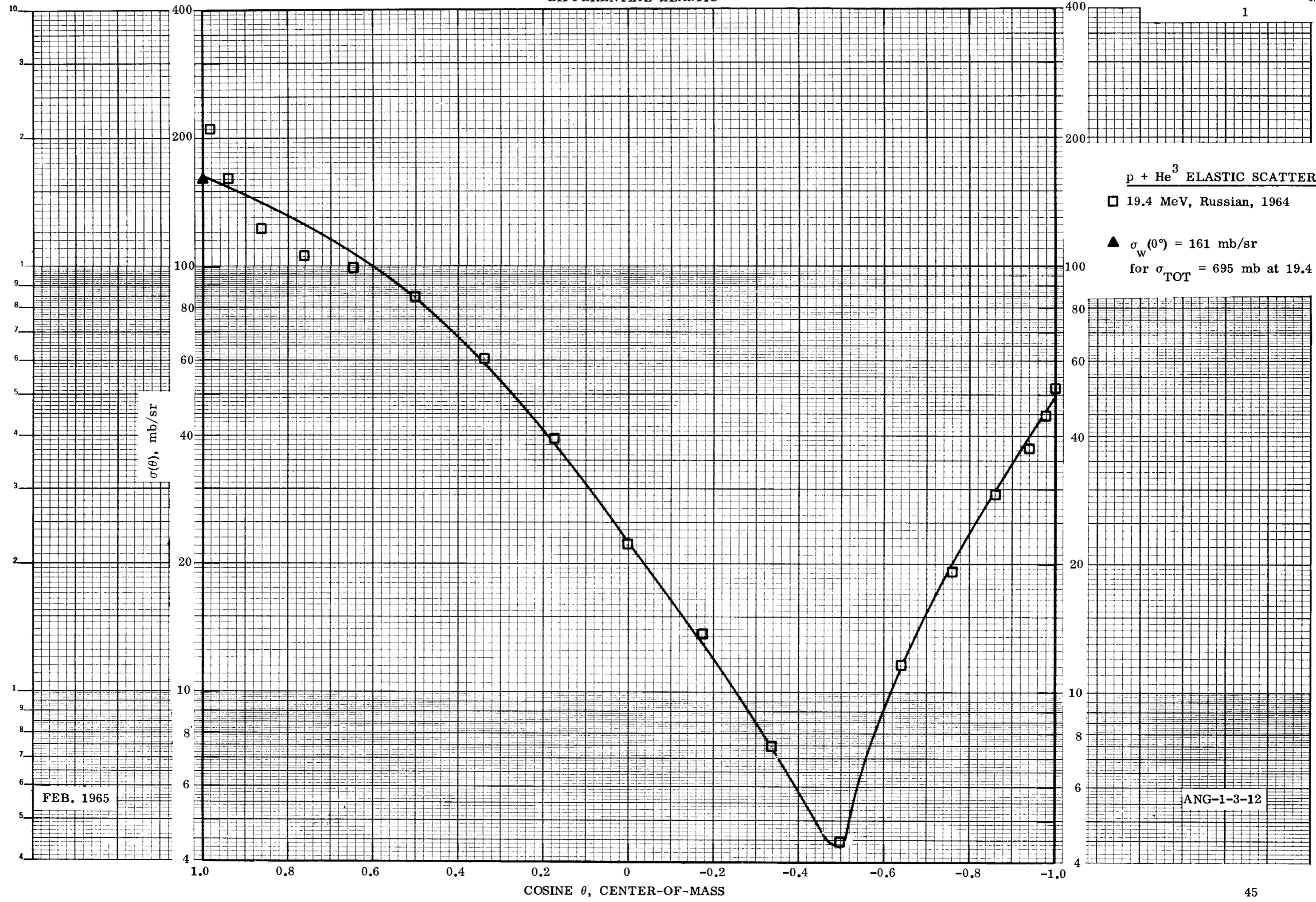
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He<sup>3</sup> ELASTIC SCATTERING:

1. □ R. A. Vanetsian and E. D. Fedchenko, Translation: Soviet Journal of Atomic Energy, 2, 141 (1957). These points were taken from the smooth curve in the journal. The graph was extremely small and plotted on a semi-log basis. Neither the angles nor the cross sections are reproduced with any degree of accuracy.

DIFFERENTIAL ELASTIC

T Z MASS  
1 3



p + He<sup>3</sup> ELASTIC SCATTERING

□ 19.4 MeV, Russian, 1964

▲  $\sigma_w(0^\circ) = 161$  mb/sr

for  $\sigma_{TOT} = 695$  mb at 19.4 MeV

FEB. 1965

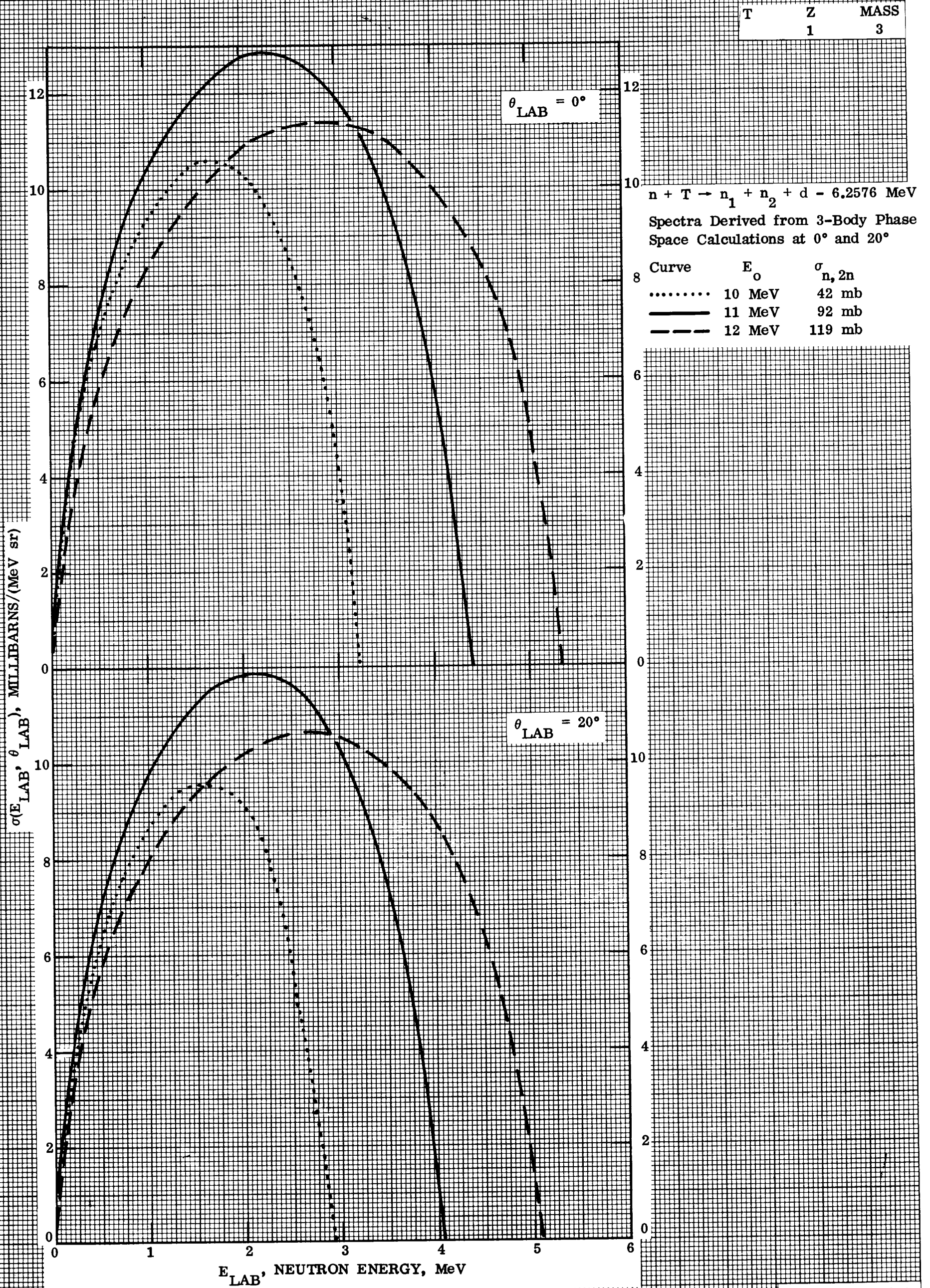
ANG-1-3-12





## APPENDIX





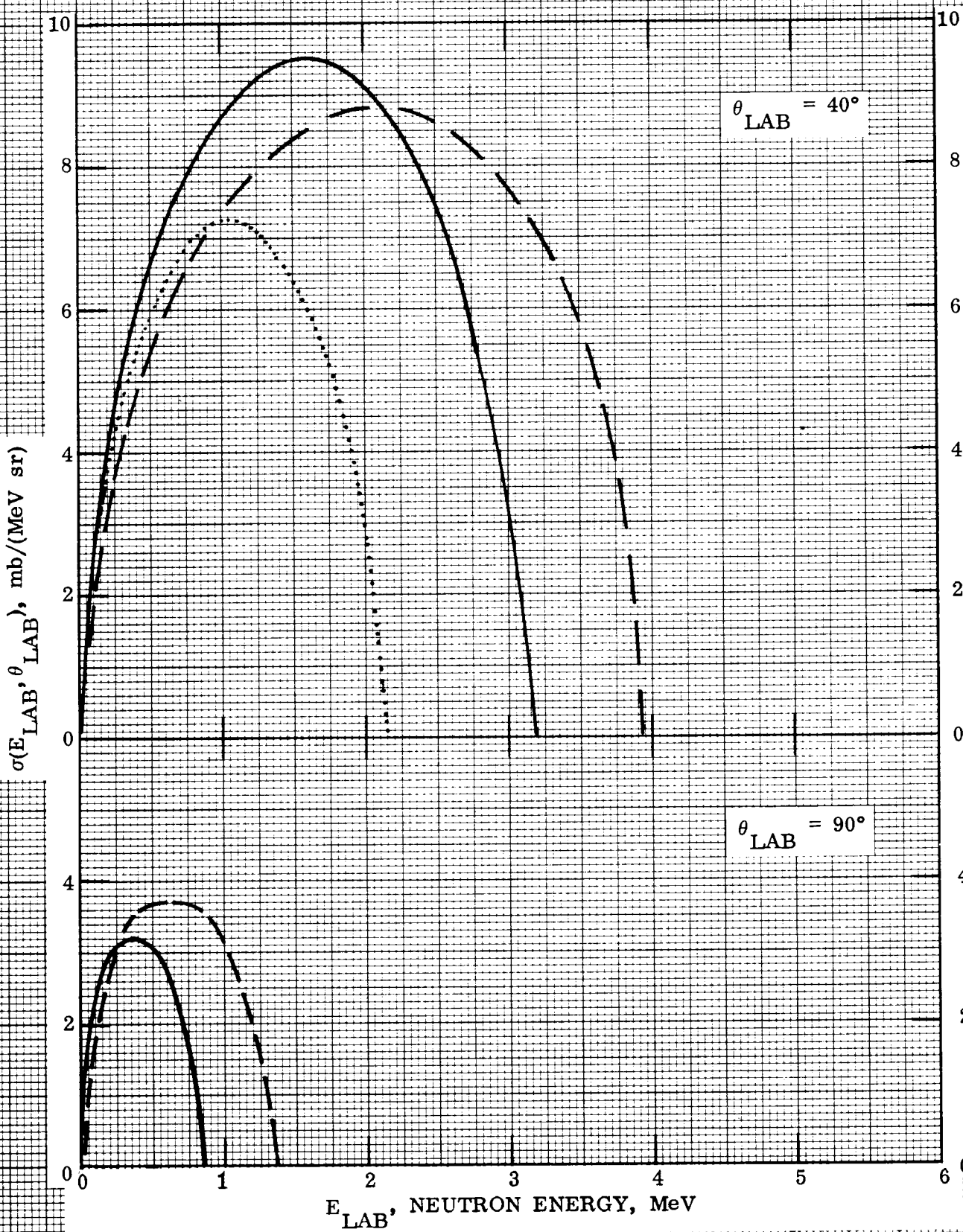
T	Z	MASS
1	1	3



$n + T \rightarrow n_1 + n_2 + d - 6.2576 \text{ MeV}$   
 Spectra Derived from 3-Body Phase  
 Space Calculations at  $40^\circ$  and  $90^\circ$

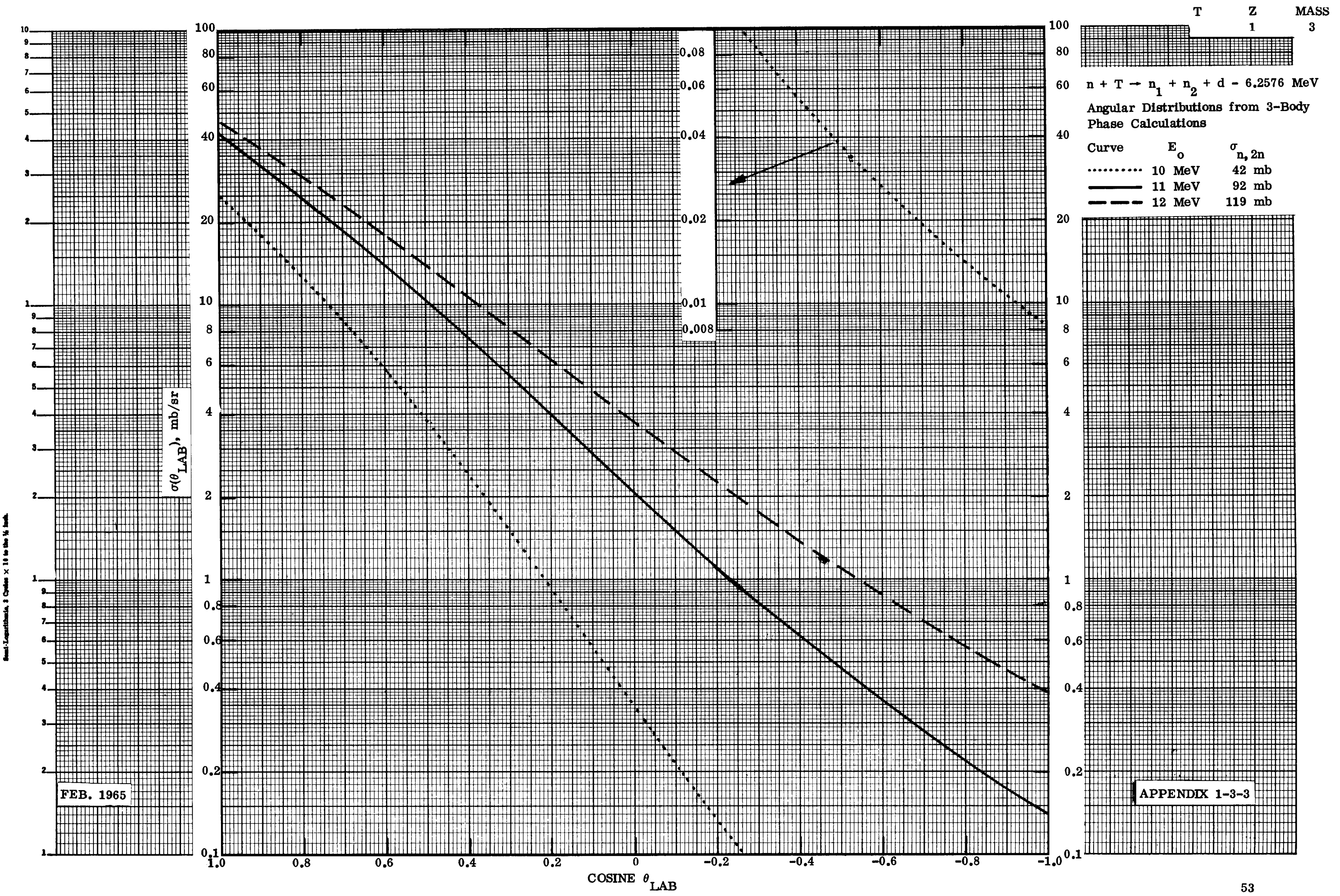
T	Z	MASS
	1	3

Curve	$E_o$	$\sigma_{n,2n}$
.....	10 MeV	42 mb
————	11 MeV	91.5 mb
-----	12 MeV	114 mb



APPENDIX 1-3-2





Semi-Logarithmic, 8 Cycles X 10 to the 1/2 inch

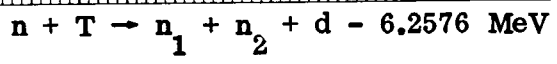
T	Z	MASS
1	1	3

$n + T \rightarrow n_1 + n_2 + d - 6.2576 \text{ MeV}$   
 Angular Distributions from 3-Body  
 Phase Calculations

Curve	$E_o$	$\sigma_{n, 2n}$
.....	10 MeV	42 mb
————	11 MeV	92 mb
-----	12 MeV	119 mb



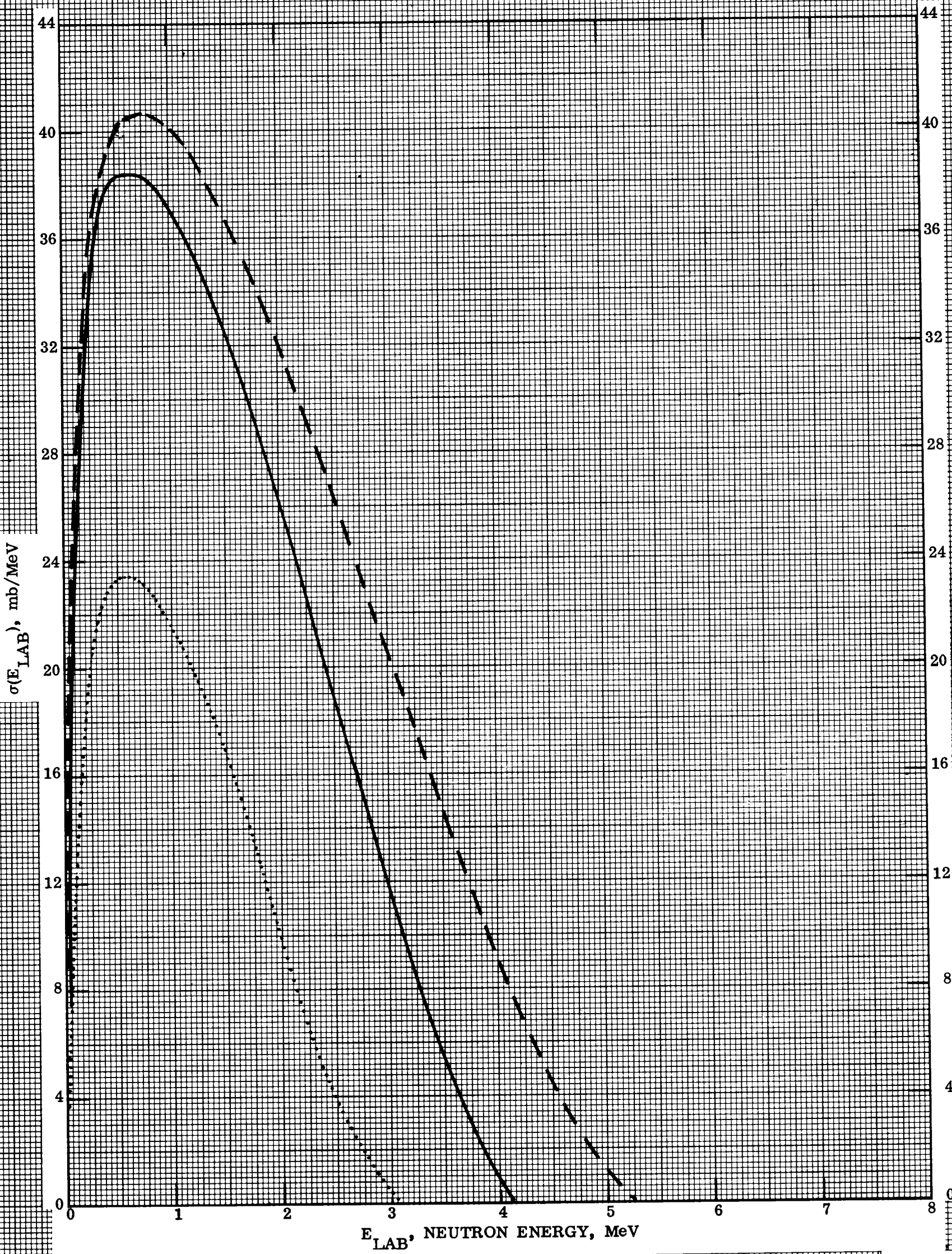




Spectra Derived from 3-Body Phase Space Calculations

Curve	$E_0$	$\sigma_{n,2n}$
.....	10 MeV	42 mb
————	11 MeV	91.5 mb
— — — —	12 MeV	119 mb

T	Z	MASS
	1	3

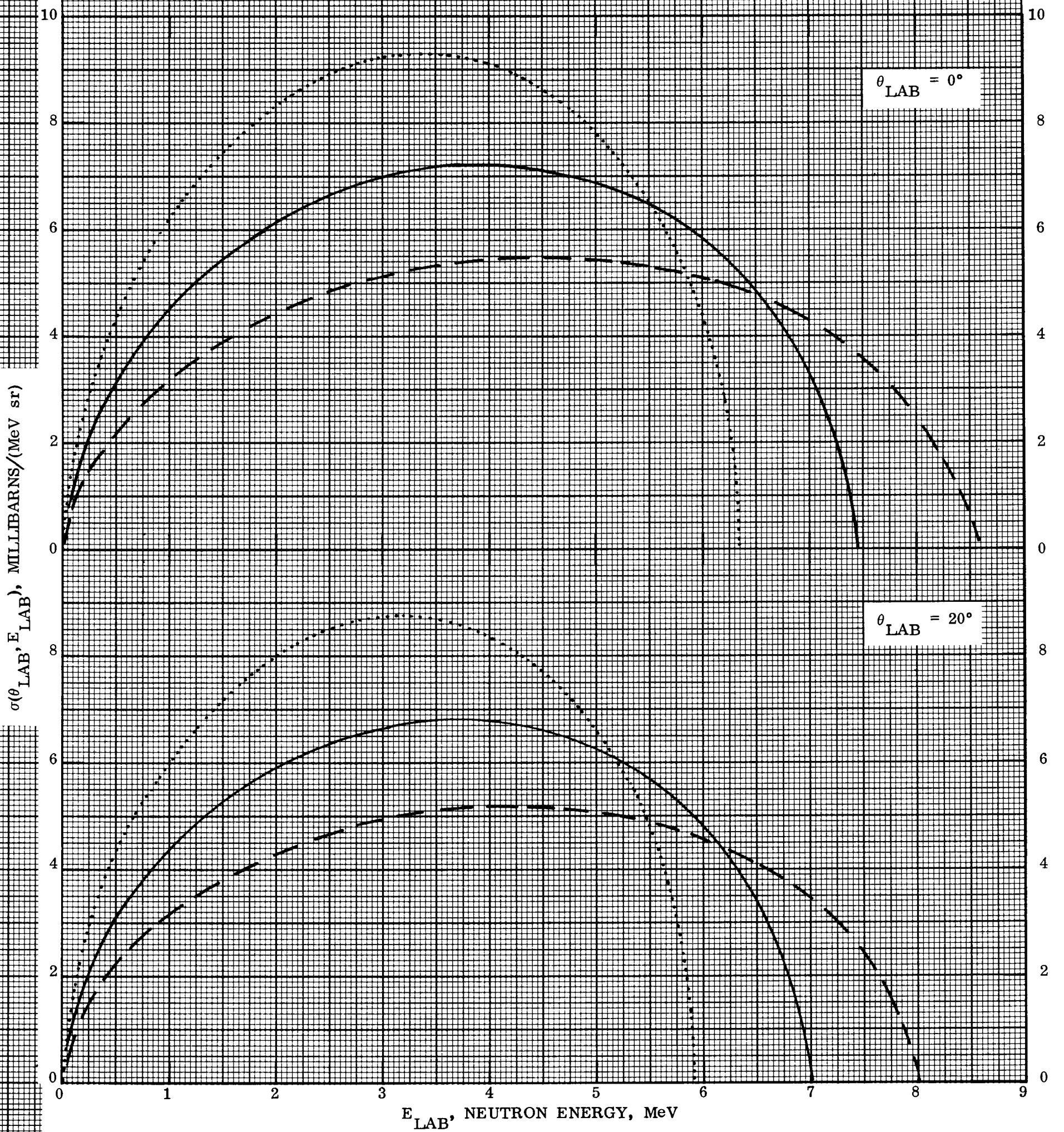




$n + T \rightarrow n_1 + n_2 + d - 6.2576 \text{ MeV}$   
 Spectra Derived from 3-Body Phase Space  
 Calculations at  $0^\circ$  and  $20^\circ$

T	Z	MASS
	1	3

Curve	$E_0$	$\sigma_{n,2n}$
.....	13 MeV	129 mb
————	14 MeV	125 mb
-----	15 MeV	114.5 mb

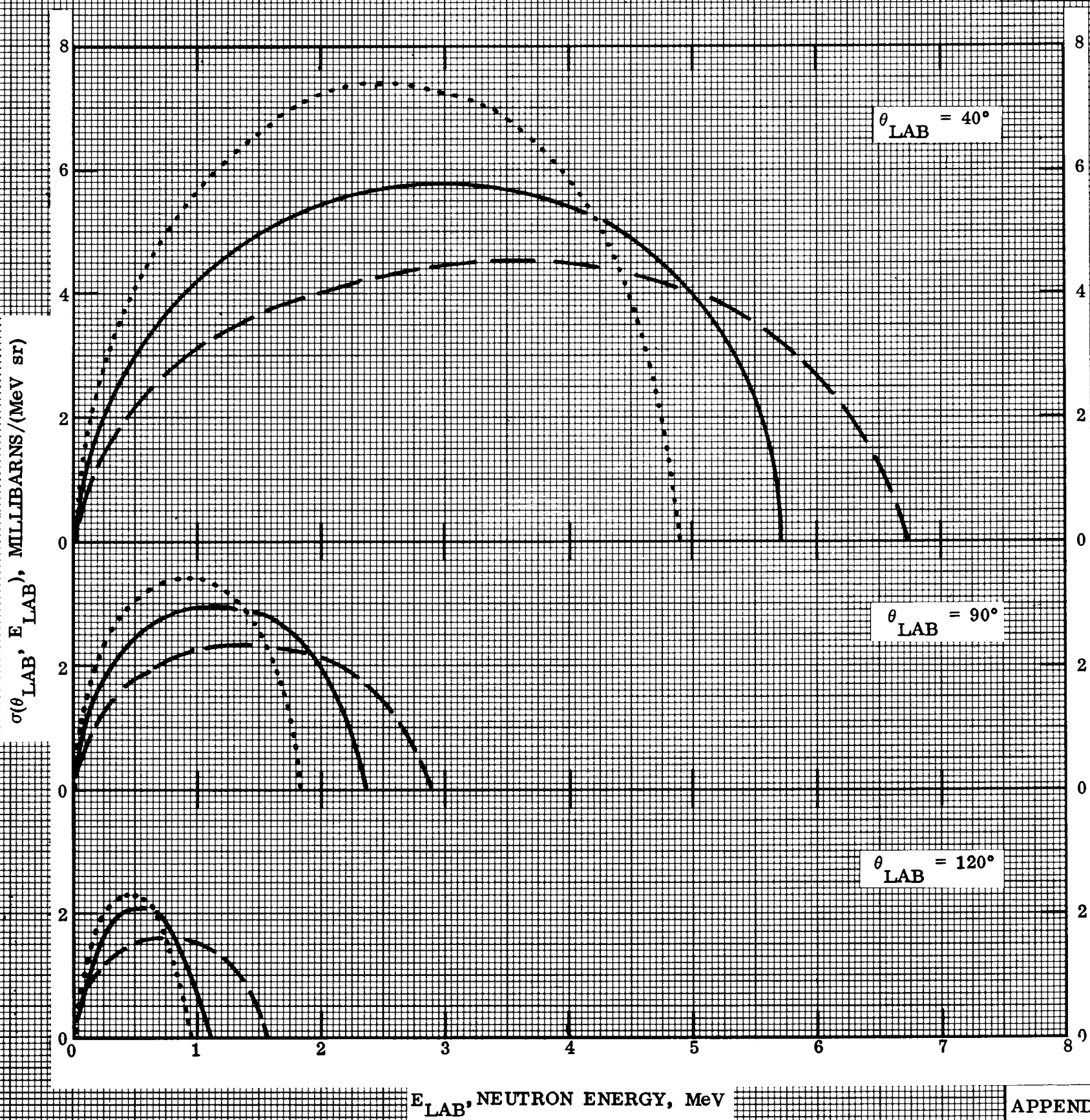




$n + T \rightarrow n_1 + n_2 + d - 6.2576 \text{ MeV}$   
 Spectra Derived from 3-Body Phase Space  
 Calculations at 40°, 90°, and 120°

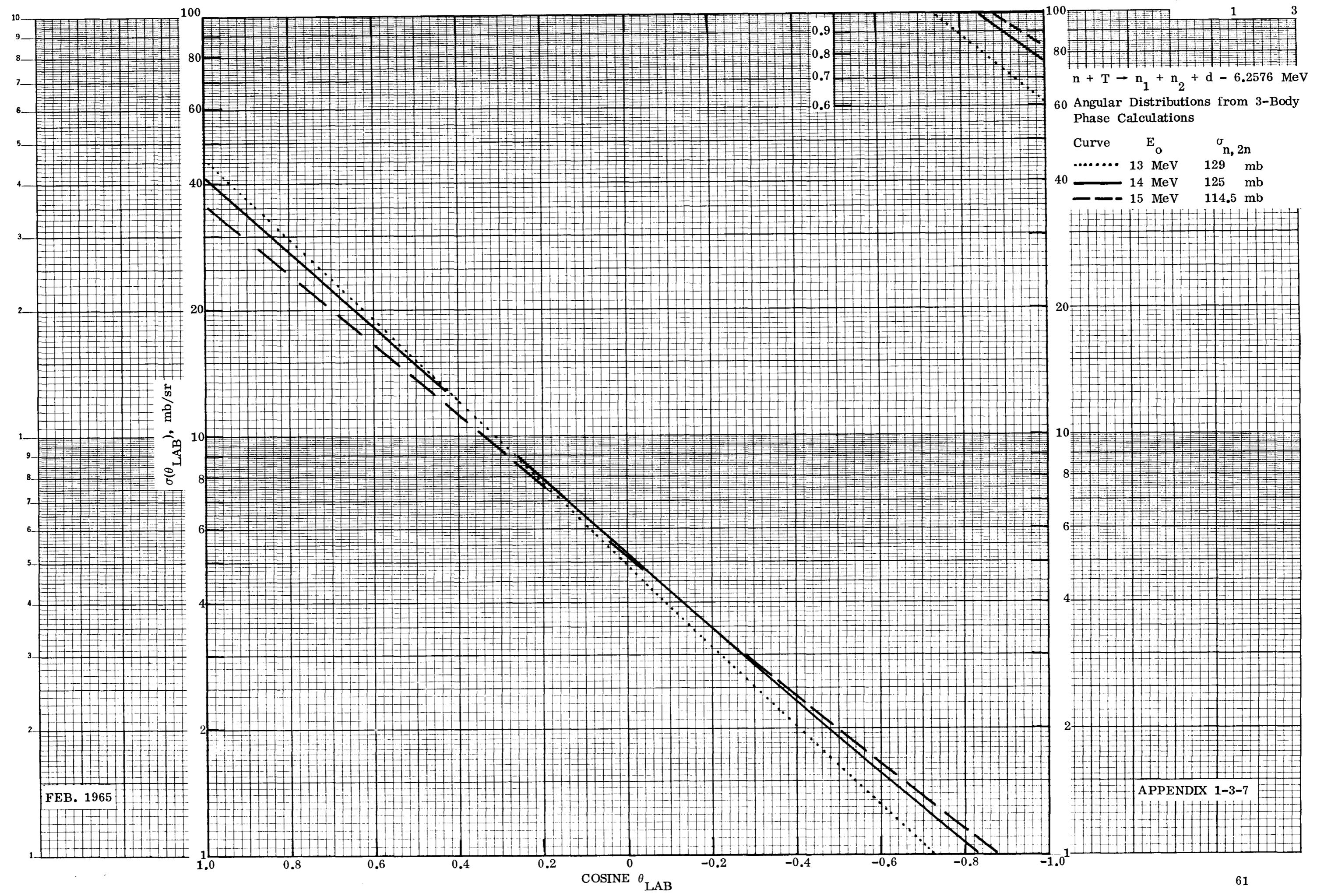
Curve	$E_o$	$\sigma_{n,2n}$
.....	13 MeV	129 mb
————	14 MeV	125 mb
-----	15 MeV	114.5 mb

T	Z	MASS
1	1	3





SEMI-LOGARITHMIC  
2 CYCLES X 180 DIVISIONS



FEB. 1965

APPENDIX 1-3-7

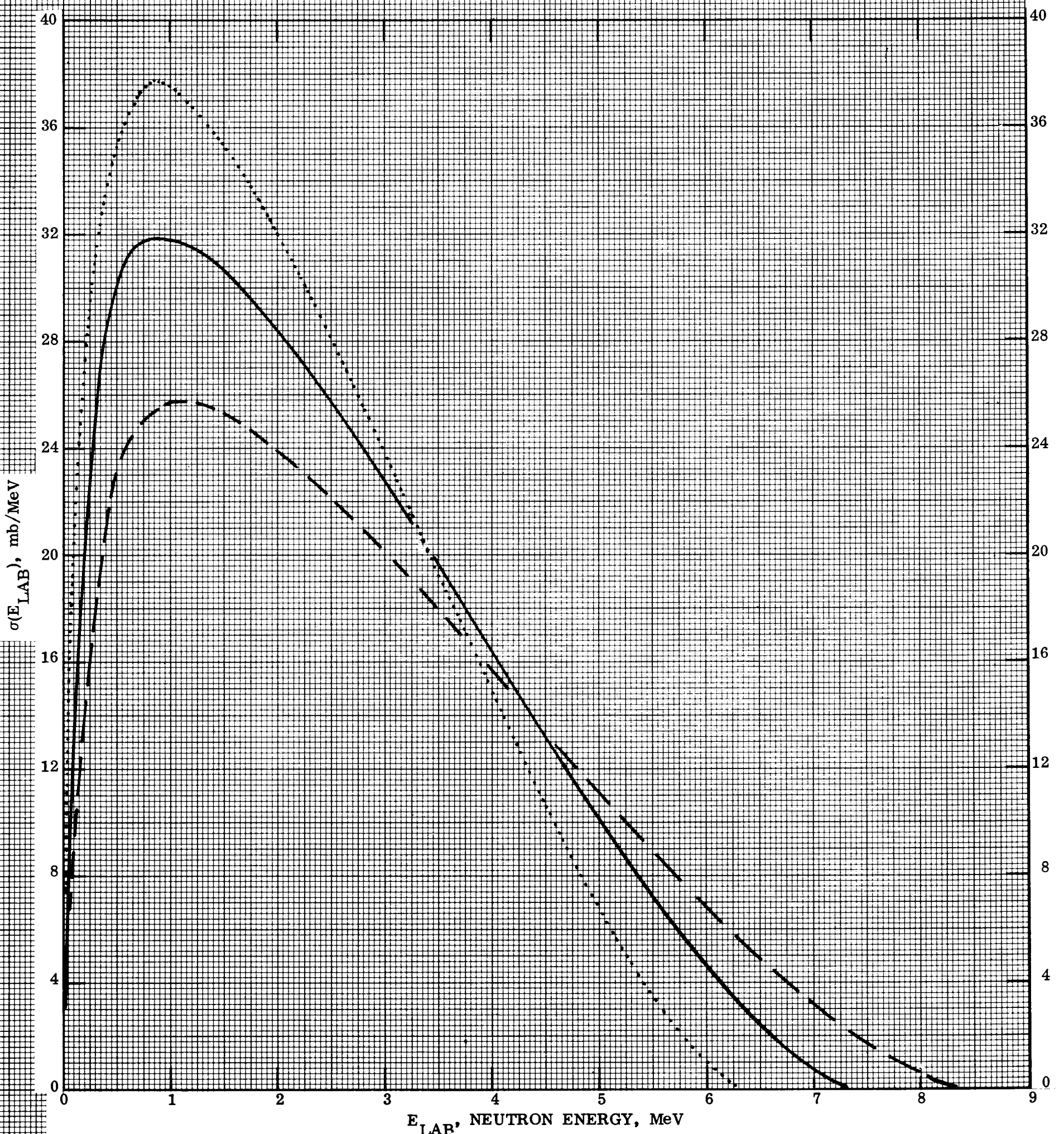




$n + T \rightarrow n_1 + n_2 + d - 6.2576 \text{ MeV}$   
 Spectra Derived from 3-Body Phase Space  
 Calculations

T	Z	MASS
	1	3

Curve	$E_0$	$\sigma_{n,2n}$
.....	13 MeV	129 mb
————	14 MeV	125 mb
— · — ·	15 MeV	114.5 mb



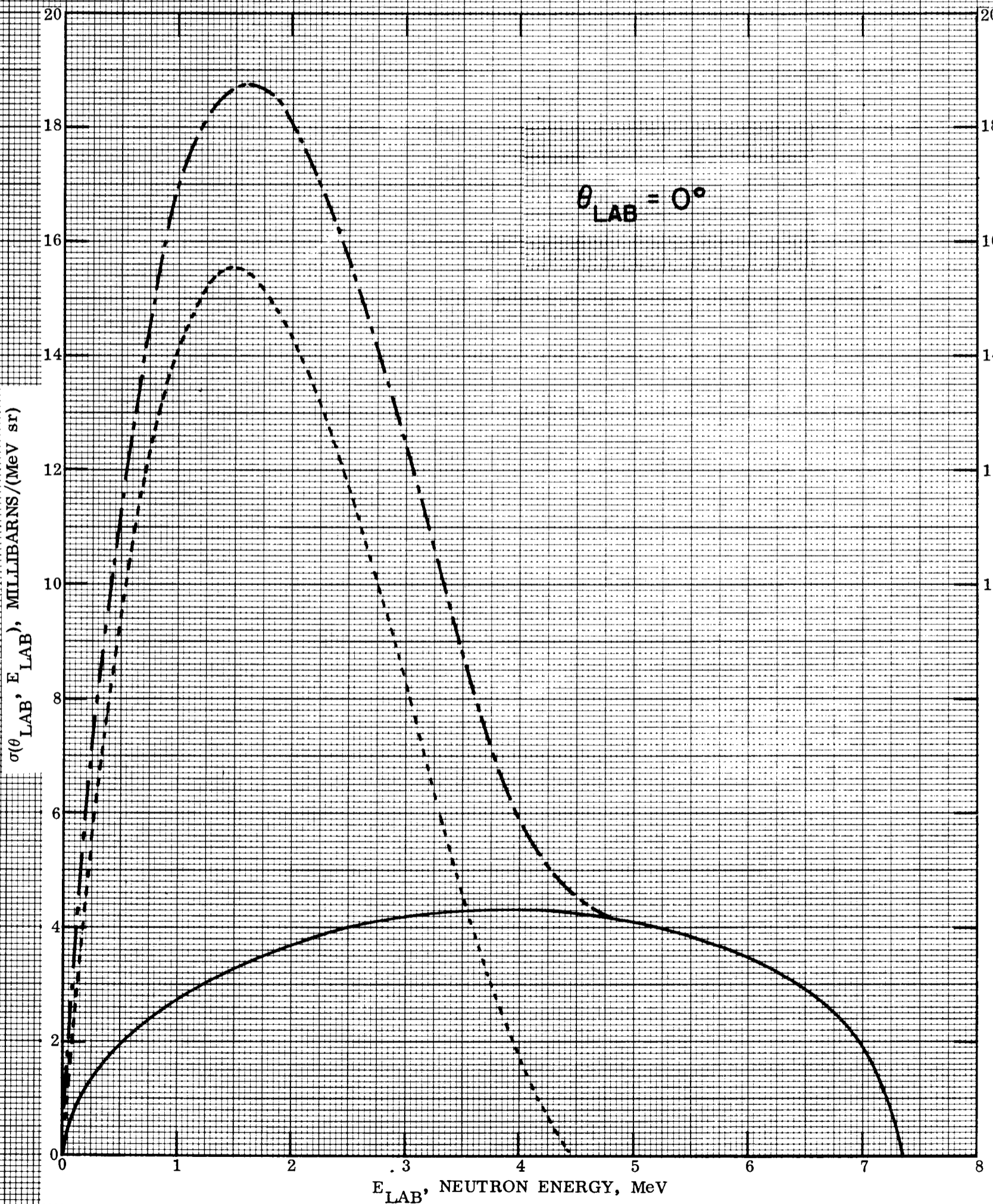


$n + T \rightarrow 2n + d - 6.2576 \text{ MeV}$   
 $n + T \rightarrow 3n + p - 8.4823 \text{ MeV}$   
 14-MeV Spectra Derived from 3- and  
 4-Body Phase Space Calculations at  $0^\circ$

T	Z	MASS
	1	3

Curve

- $\sigma_{n,2n} = 75 \text{ mb}$
- - -  $\sigma_{n,3n} = 50 \text{ mb}$
- · - · - Total = 125 mb





T	Z	MASS
	1	3

$n + T \rightarrow 2n + d - 6.2576 \text{ MeV}$   
 $n + T \rightarrow 3n + p - 8.4823 \text{ MeV}$   
 14-MeV Spectra Derived from 3- and  
 4-Body Phase Space Calculations at  
 20° and 40°

Curve

- $\sigma_{n, 2n} = 75 \text{ mb}$
- - -  $\sigma_{n, 3n} = 50 \text{ mb}$
- · - · Total = 125 mb

$\sigma(\theta_{\text{LAB}}, E_{\text{LAB}})$ , MILLIBARNS/(MeV sr)

$\theta_{\text{LAB}} = 20^\circ$

$\theta_{\text{LAB}} = 40^\circ$

$E_{\text{LAB}}$ , NEUTRON ENERGY, MeV

APPENDIX 1-3-10

FEB. 1965

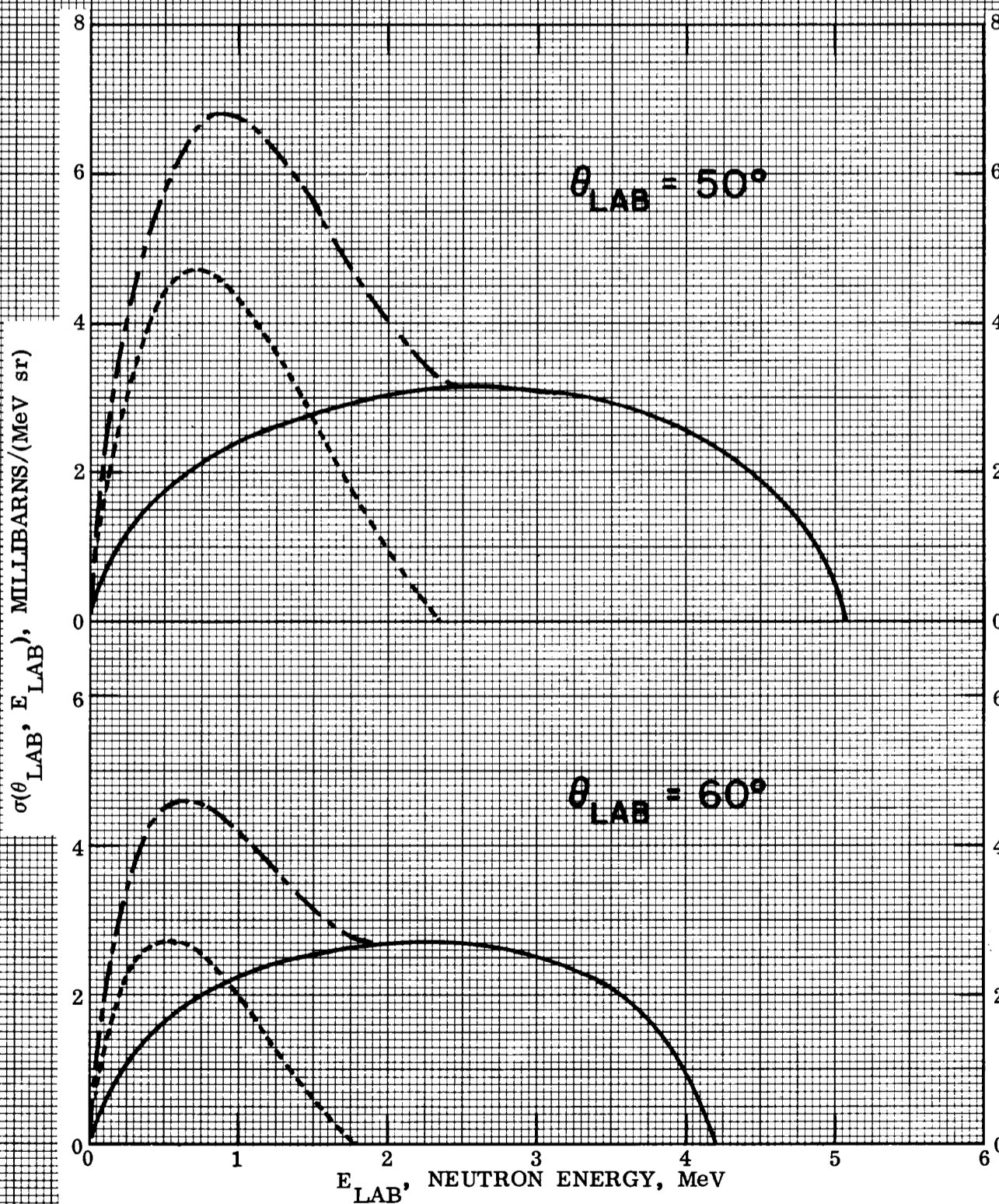


$n + T \rightarrow 2n + d - 6.2576 \text{ MeV}$   
 $n + T \rightarrow 3n + p - 8.4823 \text{ MeV}$   
 14-MeV Energy Spectra Derived from a  
 Combination 3- and 4-Body Phase Space  
 Calculations at  $50^\circ$  and  $60^\circ$

T	Z	MASS
	1	3

Curve

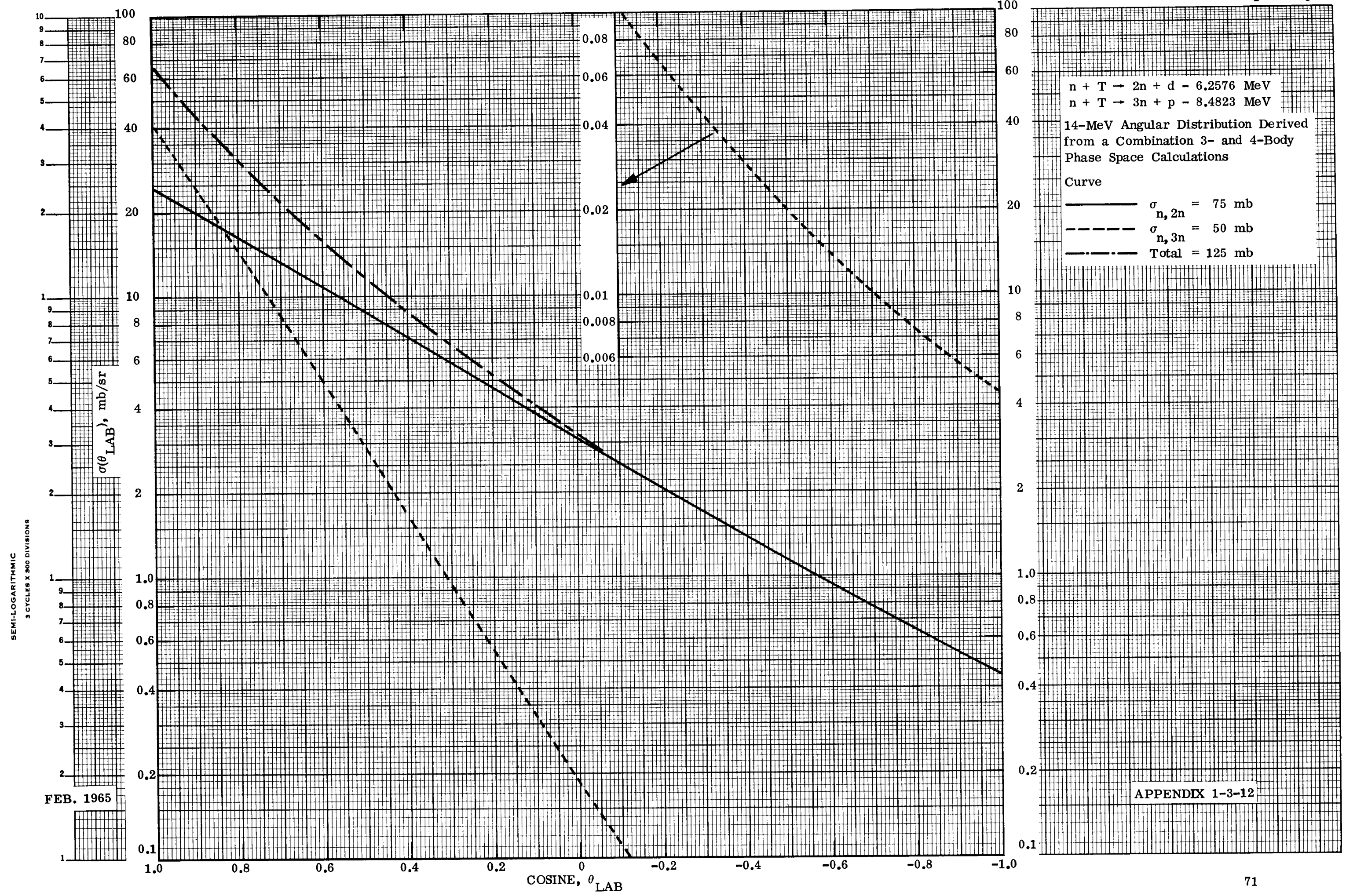
- $\sigma_{n,2n} = 75 \text{ mb}$
- - -  $\sigma_{n,3n} = 50 \text{ mb}$
- · - · - Total = 125 mb



APPENDIX 1-3-11









$n + T \rightarrow 2n + d - 6.2576 \text{ MeV}$   
 $n + T \rightarrow 3n + p - 8.4823 \text{ MeV}$   
 14-MeV Energy Spectra Derived from  
 3- and 4-Body Phase Space Calculations

T	Z	MASS
	1	3

Curve  
 —  $\sigma_{n,2n} = 75 \text{ mb}$   
 - - -  $\sigma_{n,3n} = 50 \text{ mb}$   
 - · - · - Total = 125 mb

