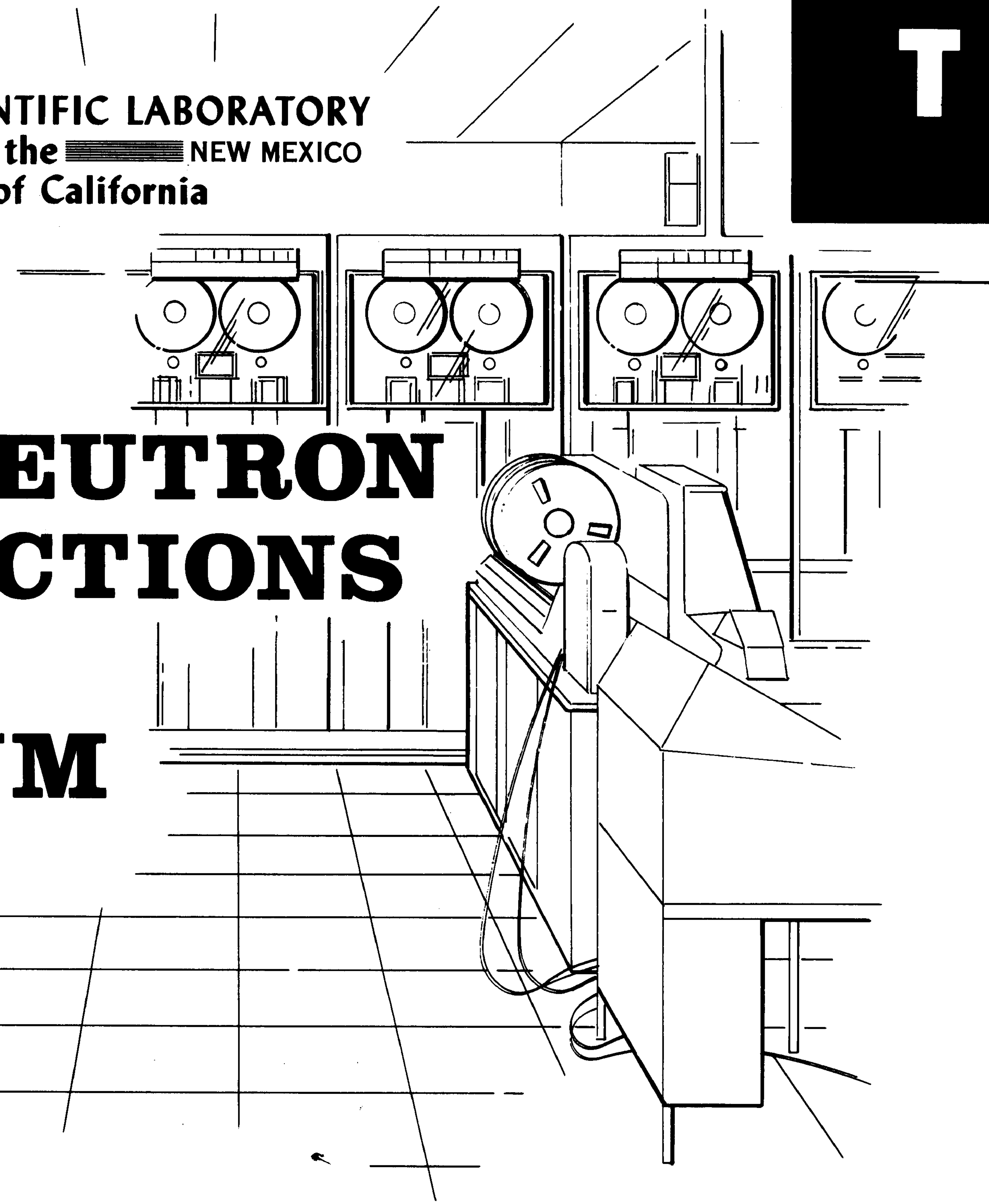
LA-3270

C.3

LOS ALAMOS SCIENTIFIC LABORATORY
LOS ALAMOS of the NEW MEXICO
University of California

T

EVALUATED NEUTRON CROSS SECTIONS FOR TRITIUM



UNITED STATES ATOMIC ENERGY COMMISSION / CONTRACT W-7405-ENG. 36 / AEC RESEARCH & DEVELOPMENT REPORT

Printed in USA. Price $3.00. Available from the

Clearinghouse for Federal Scientific
and Technical Information,
National Bureau of Standards,
U. S. Department of Commerce,
Springfield, Virginia

Report Written: February 1965
Report Distributed: April 1965

LA-3270
UC-34, PHYSICS
TID-4500 (38th Ed.)

LOS ALAMOS SCIENTIFIC LABORATORY
LOS ALAMOS of the NEW MEXICO
University of California

EVALUATED NEUTRON CROSS SECTIONS FOR TRITIUM

by

LEONA STEWART

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_{mass} (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.[1] 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[2] 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.[3] In 1951, data over a limited angular region at 14.3 MeV were published by Coon et al.[4] 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 $p+He^3$. Data from Rice,[5] Wisconsin,[6] Los Alamos,[7] Minnesota,[8] and Russia[9] were spread over the energy region from 4.5 to 19.4 MeV. The $p+He^3$ data were, therefore, used to extend the differential cross sections to higher energies and to obtain an estimate of the total nonelastic contribution from:

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

[1]See references listed on page 9.

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

Since

$$\sigma(0°) = \left|f_R(0°)\right|^2 + \left|f_I(0°)\right|^2 ,$$

it follows that

$$\sigma(0°) \geq \left|f_I(0°)\right|^2$$

where $f_R(0°)$ and $f_I(0°)$ are the real and imaginary parts, respectively, of the complex scattering amplitude at zero degrees.

It is easily proven[11] that

$$f_I(0°) = \frac{k\sigma_{TOT}}{4\pi} ,$$

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

$$\sigma_W \equiv \frac{k^2\left(\sigma_{TOT}\right)^2}{(4\pi)^2} ;$$

where

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

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,

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

with σ_{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 σ_{NON}.

4. Capture

At thermal energies Imhof et al[12] have measured:

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

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

5. n, 2n
6. n, 3n

Recently, the energy spectrum of the charged particles emitted at 4.8° when tritium is bombarded by 14.4-MeV neutrons was published by the Zagreb group.[13] 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° 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.[14] The deuteron spectrum shows a pronounced peak at 0°, with a cross section at the maximum of ~32 mb/sr MeV^{-1}. The values drop to approximately zero as the deuteron energy decreases to ~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+T scattering, but only recently has the treatment been extended to include the inelastic channels. Gammel and MacKellar[15] calculated the ratio of the first Born approximation for inelastic to that for elastic scattering at 14 MeV. They reported σ_{NON} = 343 mb and "from an order of magnitude estimate," $\sigma_{n,3n}$ = 0.4 mb.

At 14 MeV, σ_{TOT} = 975 mb; and σ_{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 $\sigma_{NON} = 343$ 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 $p+He^3$ 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:

$$N(E_i)\, dE_i = \text{Constant}(E_i)^{1/2} \left[E_i(\max) - E_i\right]^{\frac{3}{2}n-4} dE_i ,$$

by assuming equal probability in phase space.[16] $E_i(\max)$ 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)	$\sigma_{TOT} = \sigma_{el} + \sigma_{NON}$	Summary: Graphs:	Table 1 TOT-1-3-1 TOT-1-3-2 TOT-1-3-3
b)	$\sigma_{el} = \int \sigma(\theta)\, d\Omega$ (Evaluated) exp. Seagrave	Summary: Graphs:	Table 1 TOT-1-3-1 TOT-1-3-2 TOT-1-3-3
c)	$\sigma_{NON} = \sigma_{n,\gamma} + \sigma_{n,2n} + \sigma_{n,3n}$ (Evaluated only)	Summary: Graph:	Table 1 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 $p+He^3$ with $n+T$ scattering around 6 MeV — Graph: ANG-1-3-5

g) E_n = 8.5 MeV (obtained from $p+He^3$) — Graph: ANG-1-3-6

h) E_n = 9.5 MeV (obtained from $p+He^3$) — Graph: ANG-1-3-7

i) E_n = 9.75 MeV (obtained from $p+He^3$) — Graph: ANG-1-3-8

j) E_n = 10.4 MeV (obtained from $p+He^3$) — Graph: ANG-1-3-9

k) E_n = 11.5 MeV (obtained from $p+He^3$) — Graph: ANG-1-3-10

l) 14 MeV region (Comparison of the predicted 14.1-MeV differential cross sections using the $p+He^3$ data with the 14.3-MeV distributions measured by Coon, et al.) — Graph: ANG-1-3-11

m) E_n = 19.4 MeV (obtained from $p+He^3$) — Graph: ANG-1-3-12

3. Breakup Cross Sections

About the time this analysis was completed, John Anderson[17] 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[18] 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[19] and MacKellar assumed that the triton "looks something like n+d."

Measurements are in progress at Los Alamos on the differential cross sections for $p+He^3$ 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; $\sigma_{n,2n} = \sigma_{NON}$

	E_0	θ_n(lab)	
1)	10 11 12	0° 20°	Appendix-1-3-1
2)	10 11 12	40° 90°	Appendix-1-3-2
3)	10 11 12	Angular distributions integrated over energy	Appendix-1-3-3
4)	10 11 12	Energy distributions integrated over angle	Appendix-1-3-4
5)	13 14 15	0° 20°	Appendix-1-3-5
6)	13 14 15	40° 90° 120°	Appendix-1-3-6
7)	13 14 15	Angular distributions integrated over energy	Appendix-1-3-7
8)	13 14 15	Energy distributions integrated over angle	Appendix-1-3-8

b) Combination 3-body and 4-body at 14 MeV

	θ_n(lab)		
1)	0°	3-body 4-body Sum	Appendix-1-3-9

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

References

1. Los Alamos Physics and Cryogenics Groups, Nucl. Phys. 12, 291 (1959).
2. L. H. Katsaurov, P. M. Musallian, and B. M. Popov, Soviet J. of Atomic Energy, Supp. 5, 71 (1957).
3. J. D. Seagrave, et al, Phys. Rev. 119, 1981 (1960).
4. J. H. Coon, et al, Phys. Rev. 81, 33 (1951).
5. T. B. Clegg, et al, Nucl. Phys. 50, 621 (1964).
6. W. Haeberli, et al, Phys. Rev. 133, B1178 (1964).
7. J. E. Brolley, Jr., et al, Phys. Rev. 117, 1307 (1960). Data at back angles where the He^3 particles were observed were ignored in this analysis.
8. R. H. Lovberg, Phys. Rev. 103, 1393 (1956).
9. R. A. Vanetsian and E. D. Fedchenko, Soviet J. of Atomic Energy, Trans. 2, 141 (1957); and K. P. Artemov, S. P. Kalinin and L. H. Samoilov, JETP 10, 474 (1960). The latter data were not used, since they covered the 5- to 10-MeV energy region and were not available in tabular form.
10. G. C. Wick, Atti Acad. d'Ital., 13, 1203 (1943).
11. See, for instance: Ta-You Wu and Takashi Ohmura, Quantum Theory of Scattering, Englewood Cliffs, N. J., Prentice Hall, Inc., 1962, pp. 7 and 256.
12. W. L. Imhof, et al, Lockheed Missiles and Space Co., Nuclear Physics Div. Report SWC-TDR-62-26 (1962).
13. M. Cerineo, K. Ilakovac, I. Slaus, P. Tomas, and V. Valkovic, Phys. Rev. 133, B1948 (1964); see also, I. Slaus, et al, Progress in Fast Neutron Physics, Chicago, Ill., The University of Chicago Press, 1963, p. 61.
14. V. Ajdacick, M. Cerineo, B. Lalovic, G. Paic, I. Slaus and P. Tomas, Phys. Rev. Letters 14, 442 (1965); and

    V. Ajdacick, M. Cerineo, B. Lalovic, G. Paic, I. Slaus and P. Tomas, Phys. Rev. Letters 14, 444 (1965).
15. J. L. Gammel and A. D. MacKellar, Phys. Rev. 133, B1476 (1964).
16. Many papers have been written on these distribution functions; only two will be quoted here: A. D. Fokker, H. D. Kloosterman, and F. J. Belinfante, Physica 1, 705 (1933-34); E. Fermi, Elementary Particles, New Haven, Conn., Yale University Press, 1951, p. 44.
17. John D. Anderson, LRL, private communication, 1965.
18. C. H. Holbrow, R. R. Borchers, and C. H. Poppe, Bull. Am. Phys. Soc. 6, 429 (1961).
19. John Gammel, Texas A and M, private communication, 1965.

TABLE I

EVALUATED NEUTRON CROSS SECTIONS SCATTERED FROM TRITIUM

(TABULAR DATA FROM GRAPHS)

ASSUMPTIONS:

a) At thermal energies $\sigma_{n,\gamma} \leq 6.7\ \mu b$; therefore the capture cross section is neglected at all energies.

b) For simplicity, $\sigma_{NON} = \sigma_{n,2n}$; therefore $\sigma_{n,3n} = 0$.

	E_0	σ_{TOT} Barns	σ_{el} Barns	σ_{NON} Barns	$\sigma_{n,\gamma}$	$\sigma_{n,2n}$ Barns	$\sigma_{n,3n}$ Barns
eV	0.0253	1.3	1.3	0	0	0	0
	.	↓	↓	↓	↓	↓	↓
	.						
	.						
	.						
keV	100	1.3	1.3				
	150	1.3	1.3				
	200	1.315	1.315				
	250	1.325	1.325				
	300	1.35	1.35				
	350	1.37	1.37				
	400	1.40	1.40				
	450	1.425	1.425				
	500	1.45	1.45				
	550	1.48	1.48				
	600	1.51	1.51				
	650	1.53	1.53				
	700	1.56	1.56				
	800	1.61	1.61				
	900	1.65	1.65				
MeV	1.0	1.70	1.70				
	1.25	1.795	1.795				
	1.5	1.895	1.895				
	1.75	2.015	2.015				
	2.0	2.12	2.12				
	2.25	2.21	2.21				
	2.5	2.295	2.295				
	2.75	2.35	2.35				
	3.0	2.40	2.40				
	3.2	2.42	2.42				
	3.5	2.435	2.435				
	3.7	2.44	2.44				
	4.0	2.41	2.41				
	4.2	2.38	2.38				
	4.5	2.335	2.335	↓	↓	↓	↓

E_0 MeV	σ_{TOT} Barns	σ_{el} Barns	σ_{NON} Barns	$\sigma_{n,\gamma}$	$\sigma_{n,2n}$ Barns	$\sigma_{n,3n}$ Barns
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				
6.0	2.03	2.03				
6.2	1.985	1.985				
6.5	1.925	1.925				
6.7	1.87	1.87				
7.0	1.815	1.815				
7.5	1.705	1.705				
8.0	1.615	1.615				
8.35			↓		↓ (Thresh.)	
8.5	1.535	1.5345	0.0005		0.0005	
9.0	1.46	1.4545	0.0055		0.0055	
9.5	1.395	1.3775	0.0175		0.0175	
9.75	1.36	1.331	0.029		0.029	
10.0	1.33	1.288	0.042		0.042	
10.4	1.285	1.222	0.063		0.063	
10.5	1.275	1.206	0.069		0.069	
11.0	1.22	1.1285	0.0915		0.0915	
11.3						↓ (Thresh.)
11.5	1.17	1.061	0.109		0.109	0
12.0	1.125	1.006	0.119		0.119	
12.5	1.075	0.9495	0.1255		0.1255	
13.0	1.045	0.916	0.129		0.129	
13.5	1.005	0.877	0.128		0.128	
14.0	0.975	0.850	0.125		0.125	
14.1	0.965	0.841	0.124		0.124	
14.3	0.950	0.8275	0.1225		0.1225	
14.5	0.937	0.8165	0.1205		0.1205	
14.6	0.930	0.8105	0.1195		0.1195	
15.0	0.905	0.7905	0.1145		0.1145	
15.5	0.878	0.7700	0.108		0.108	
16.0	0.850	0.749	0.101		0.101	
19.4	0.695	0.639	0.056	↓	0.056	↓

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).

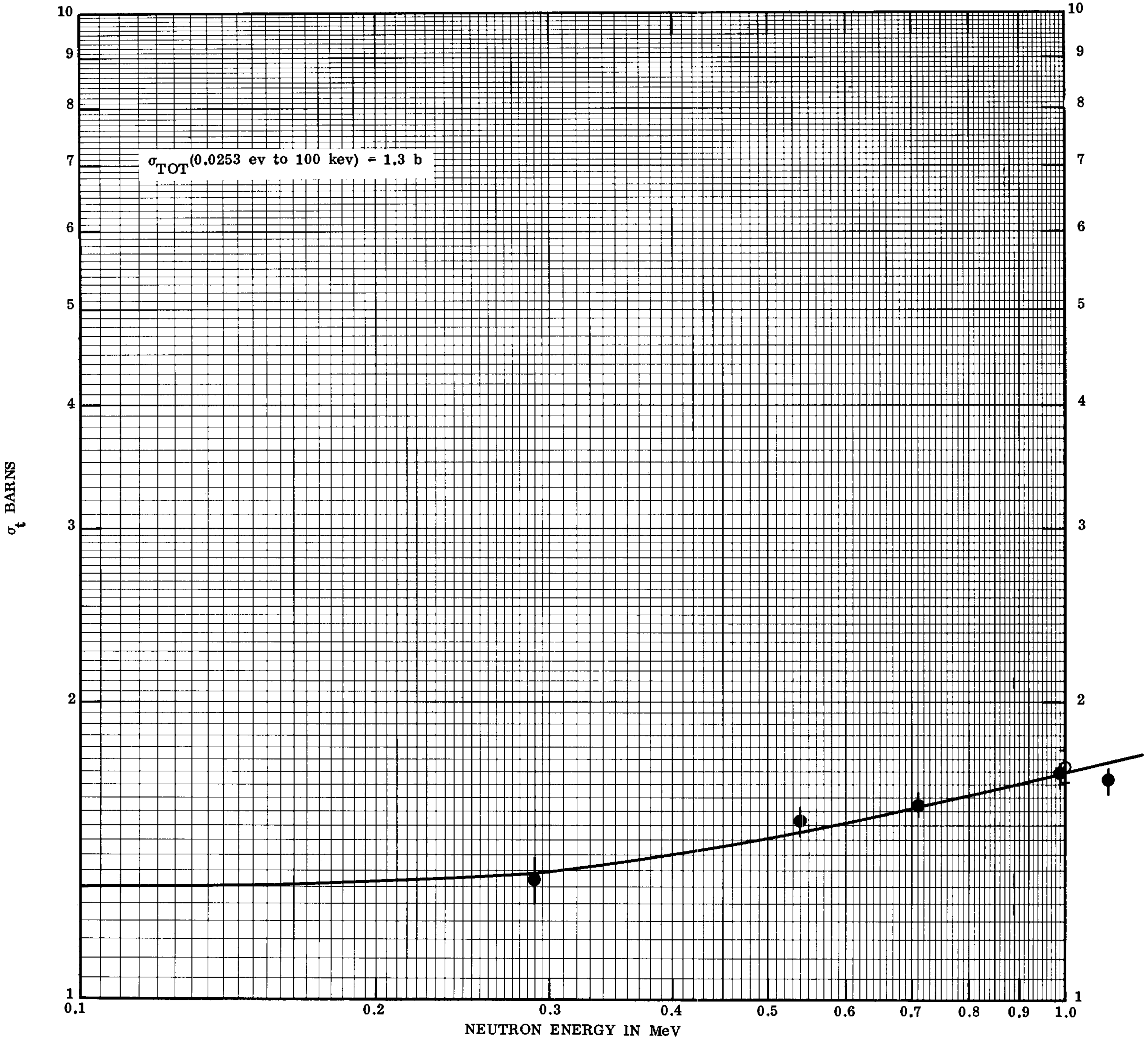
TOTAL ELASTIC CROSS SECTIONS

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

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:

   E_0 = 2.5 MeV, σ_{TOT} = 2.5 ± 0.5 barns

   E_0 = 14 MeV, σ_{TOT} = 0.63 ± 0.17 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.

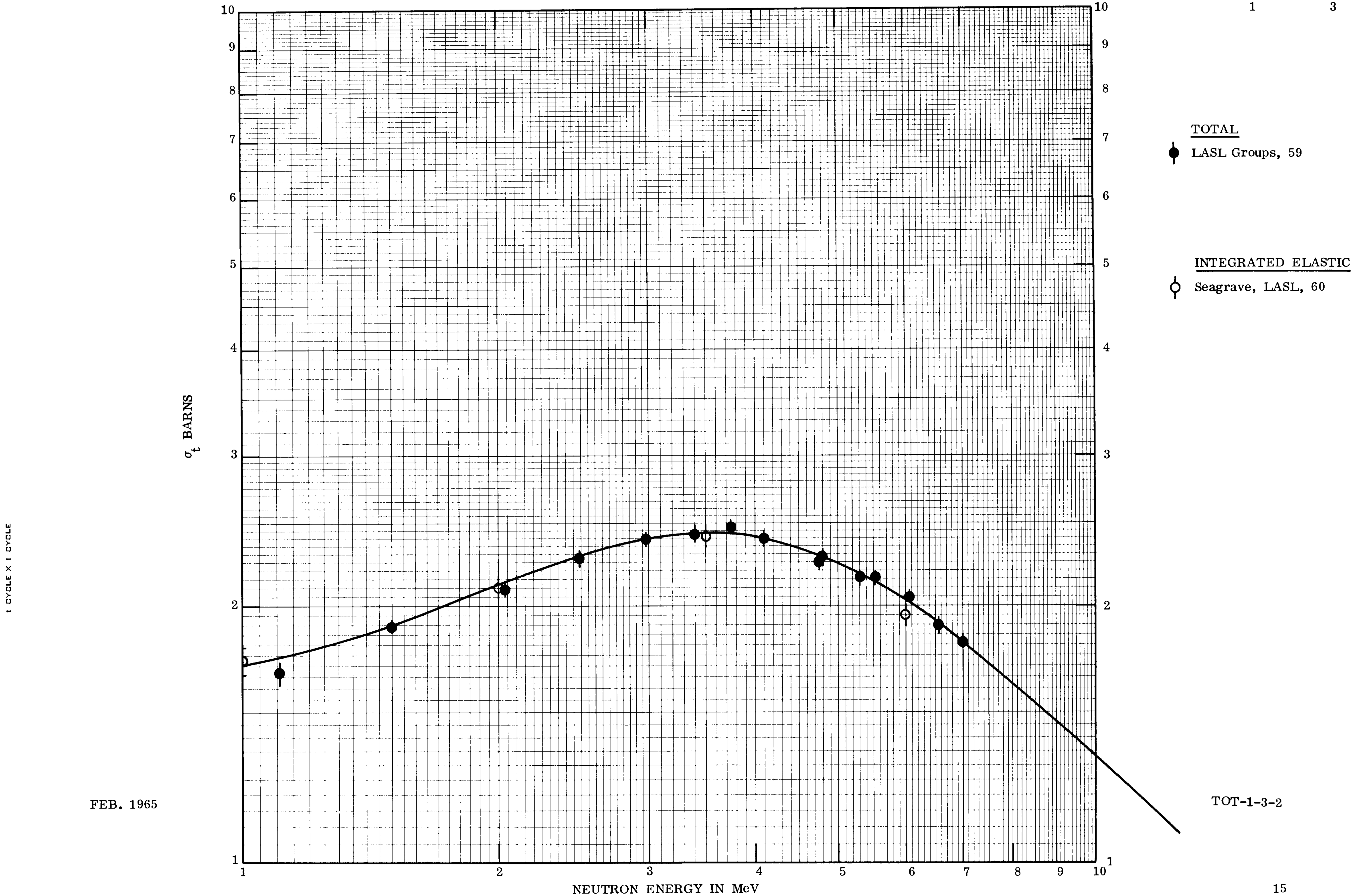
TOTAL ELASTIC CROSS SECTIONS

INTEGRATED ELASTIC:

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

TOTAL

T Z 1 MASS 3



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:

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

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

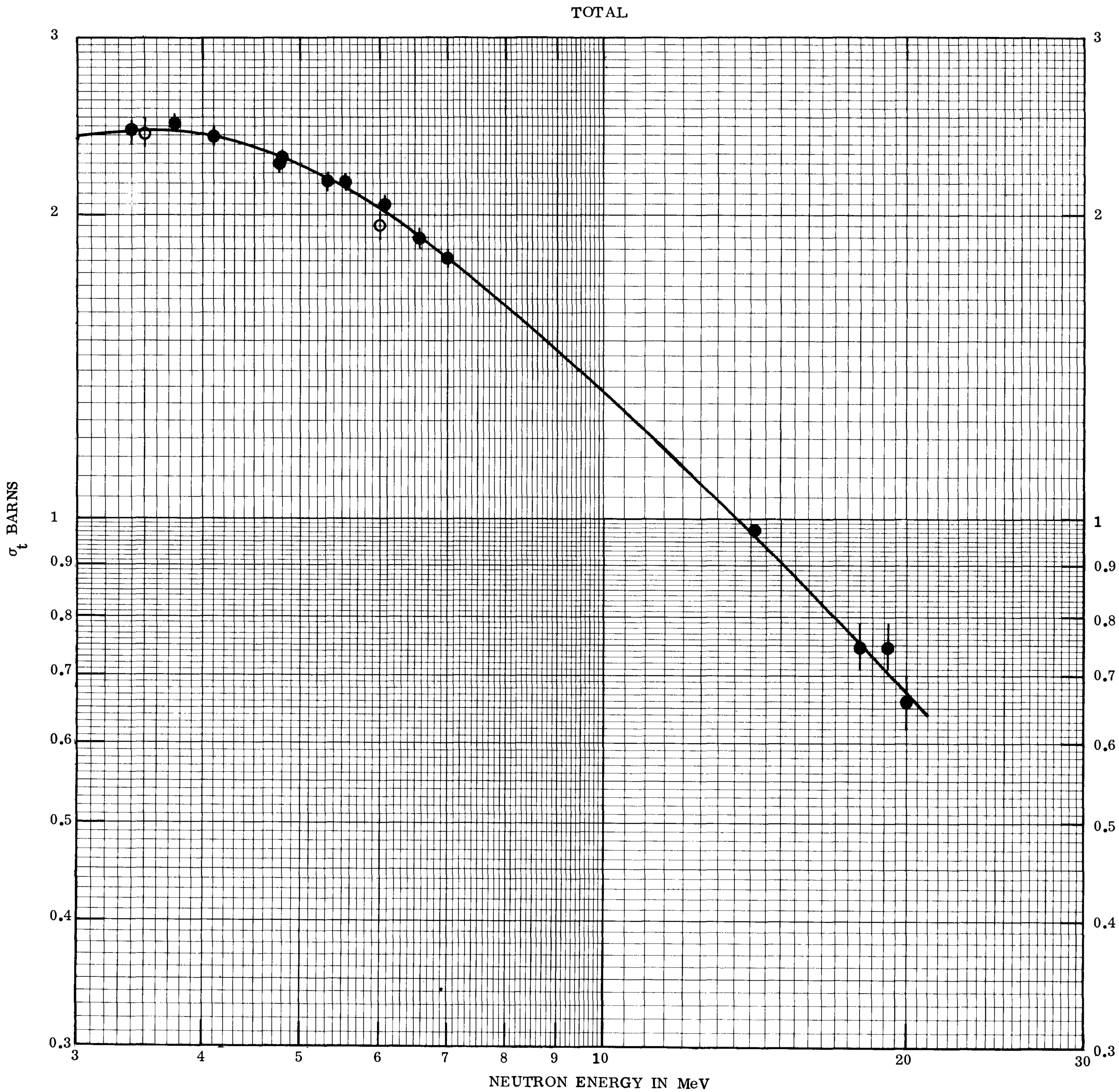
   in Sov. J. Atomic Energy, Supplement #5, 71 (1957). Since a water target containing only 9.2% T_2O was used for this experiment, the data were not included in this evaluation.

TOTAL ELASTIC CROSS SECTIONS

INTEGRATED ELASTIC:

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

T	Z	MASS
	1	3



TOTAL
LASL Groups, 59

INTEGRATED ELASTIC
Seagrave, LASL, 60

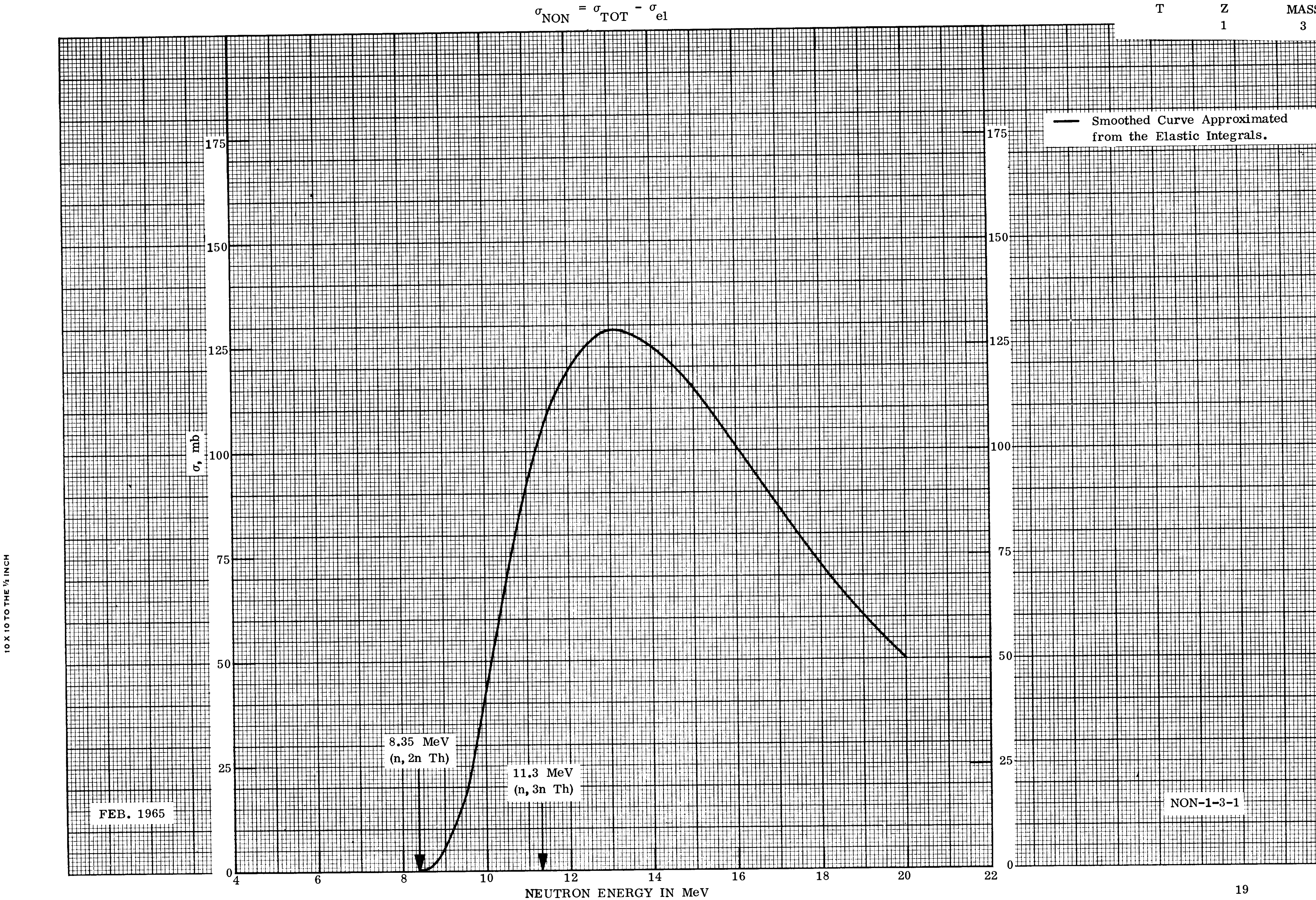
LOGARITHMIC
1 CYCLE X 1 CYCLE

FEB. 1965

TOT-1-3-3

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.



$\sigma_{NON} = \sigma_{TOT} - \sigma_{el}$
T Z MASS
1 3
Smoothed Curve Approximated from the Elastic Integrals.
σ, mb
175
150
125
100
75
50
25
0
4
6
8
10
12
14
16
18
20
22
NEUTRON ENERGY IN MeV
8.35 MeV (n, 2n Th)
11.3 MeV (n, 3n Th)
FEB. 1965
NON-1-3-1
10 X 10 TO THE ½ INCH

T	Z	MASS
	1	3

E_0 = 0.5 MeV

Table II

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ mb/sr	$P(\theta)$
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), σ_{TOT} =	1.45 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

COSINE θ	$\sigma(\theta)$ mb/sr	$P(\theta)$
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), σ_{TOT} =	1.70 barns	
(Seagrave's integral), σ_{el} =	1.72 ± 0.06 barns	

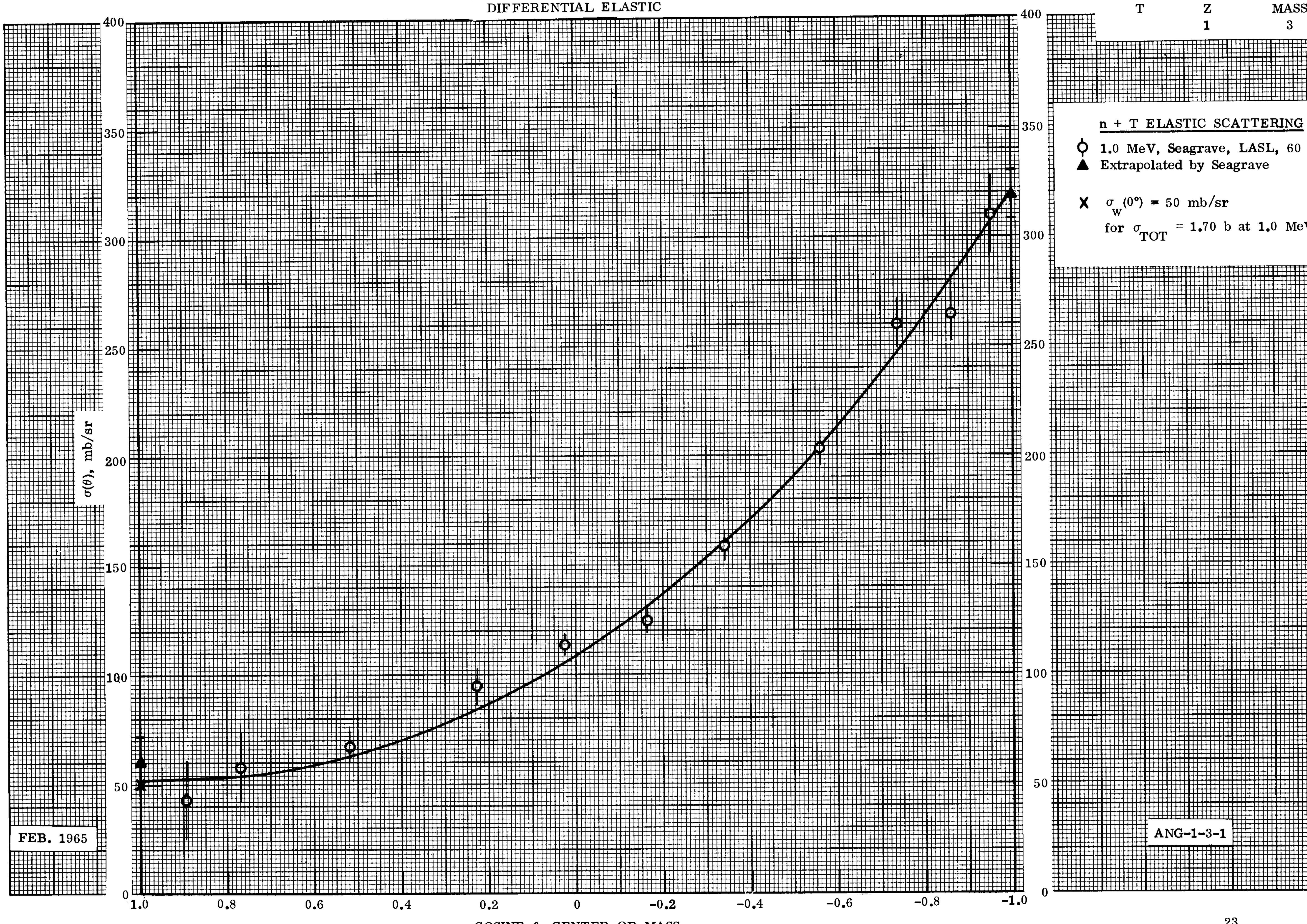
ANG-1-3-1

DATA REFERENCE

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

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



FEB. 1965

ANG-1-3-1

T	Z	MASS
	1	3

E_0 = 2.0 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ 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), σ_{TOT} =	2.12 barns	
(Seagrave's integral), σ_{el} =	2.10 ± 0.06 barns	

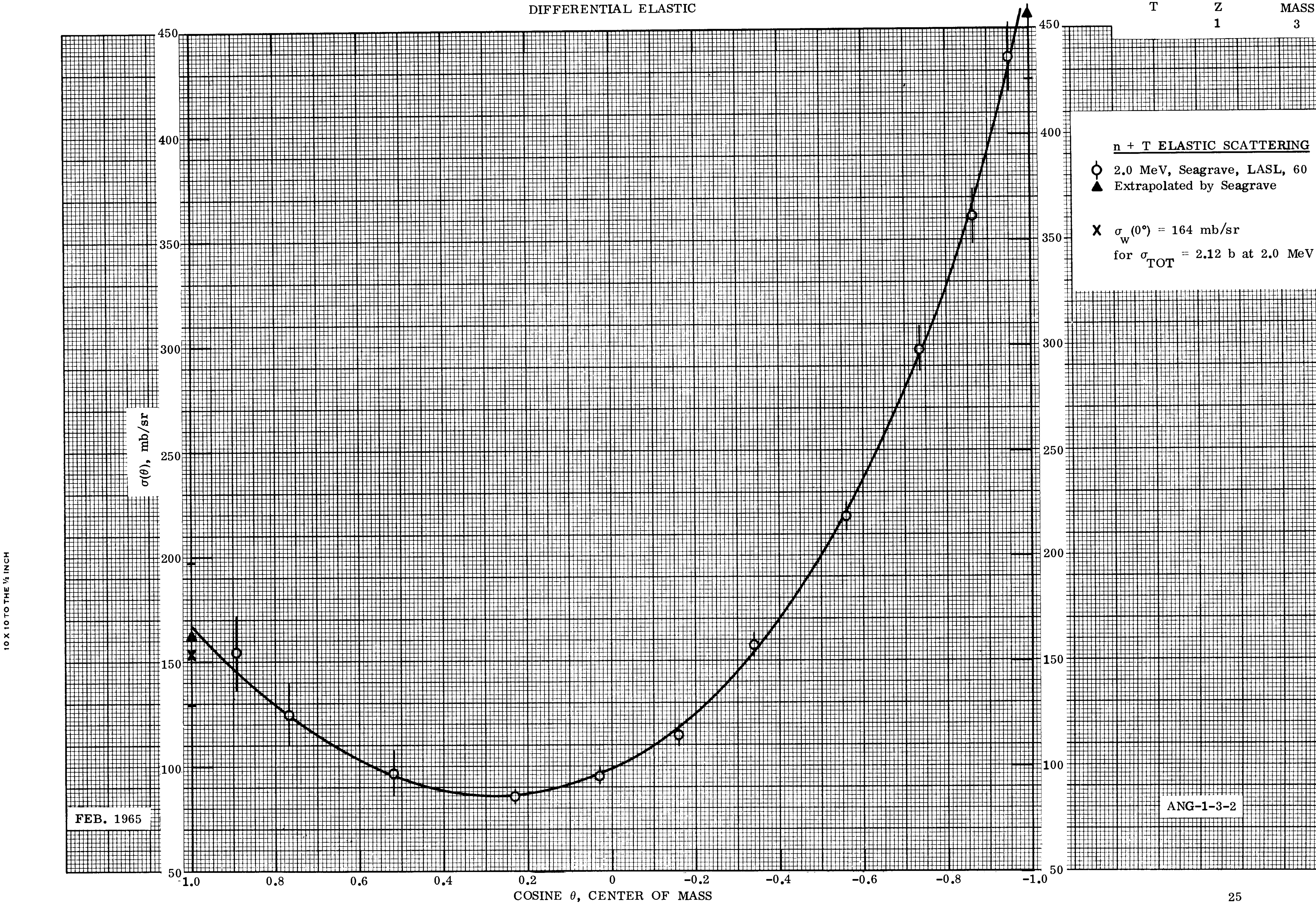
ANG-1-3-2

DATA REFERENCE

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

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


σ(θ), mb/sr
450
400
350
300
250
200
150
100
50
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
COSINE θ, CENTER OF MASS
n + T ELASTIC SCATTERING
2.0 MeV, Seagrave, LASL, 60
Extrapolated by Seagrave
X σw(0°) = 164 mb/sr
for σTOT = 2.12 b at 2.0 MeV
FEB. 1965
ANG-1-3-2
10 X 10 TO THE ½ INCH

T	Z	MASS
	1	3

E_0 = 3.5 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ 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	9.9992
$\times$ sin θ dθ =	378.75	0.99992
$\times$ dϕ =	2.380 barns	
(Comparison with curve), σ_{TOT} =	2.435 barns	
(Seagrave's integral), σ_{el} =	2.41 ± 0.07 barns	

ANG-1-3-3

DATA REFERENCE

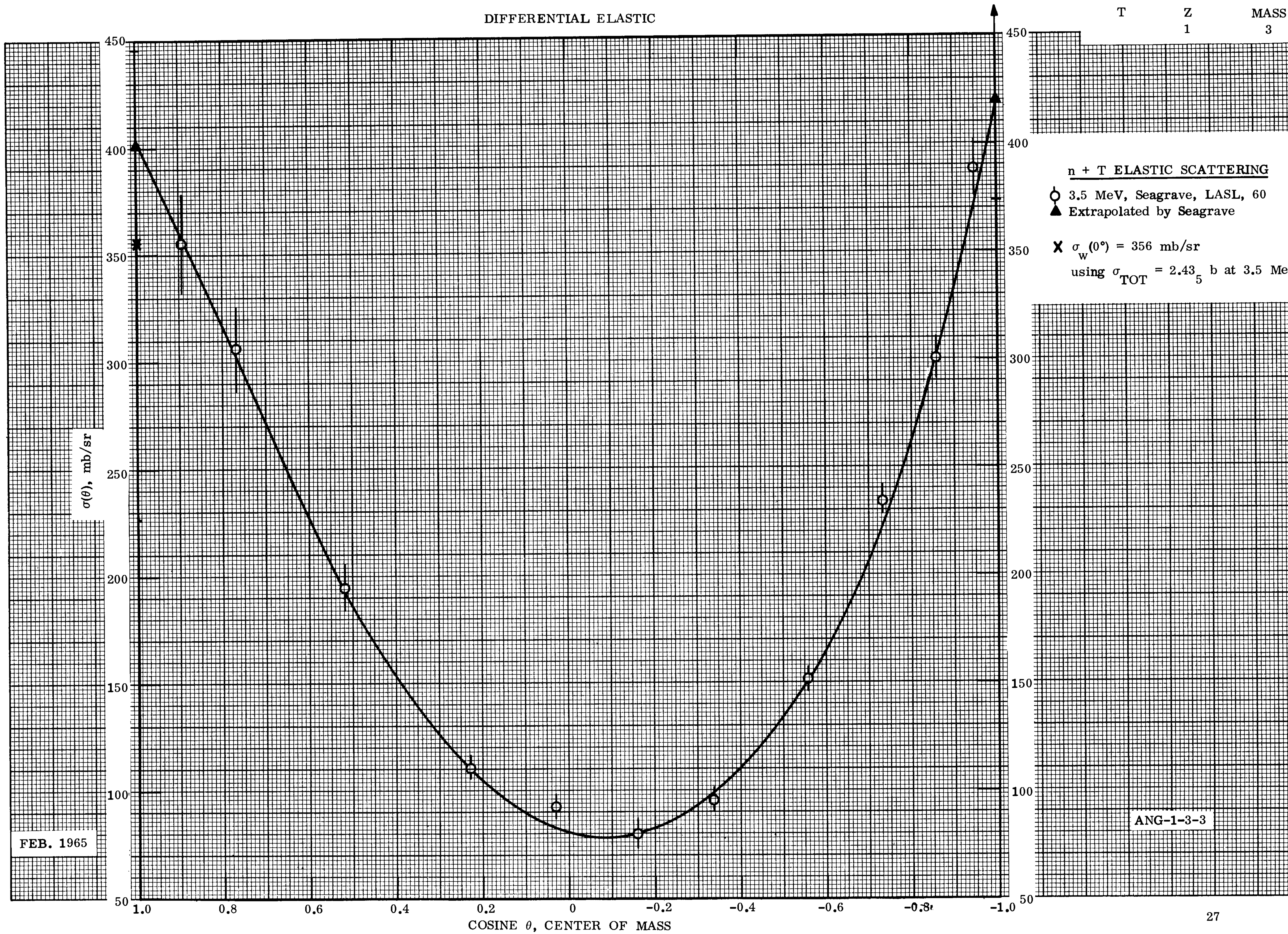
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

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

DIFFERENTIAL ELASTIC

T	Z	MASS
	1	3



FEB. 1965

ANG-1-3-3

10 X 10 TO THE ½ INCH

T	Z	MASS
	1	3

E_0 = 6.0 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ mb/sr	$P(\theta)$
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	225	0.7273
SUM =	3093.5	9.9998
$\times \sin\theta \, d\theta$ =	309.35	0.99998
$\times \, d\phi$ =	1.944 barns	
(Comparison with curve), σ_{TOT} =	2.03 barns	
(Seagrave's integral), σ_{el} =	1.95 ± 0.06 barns	

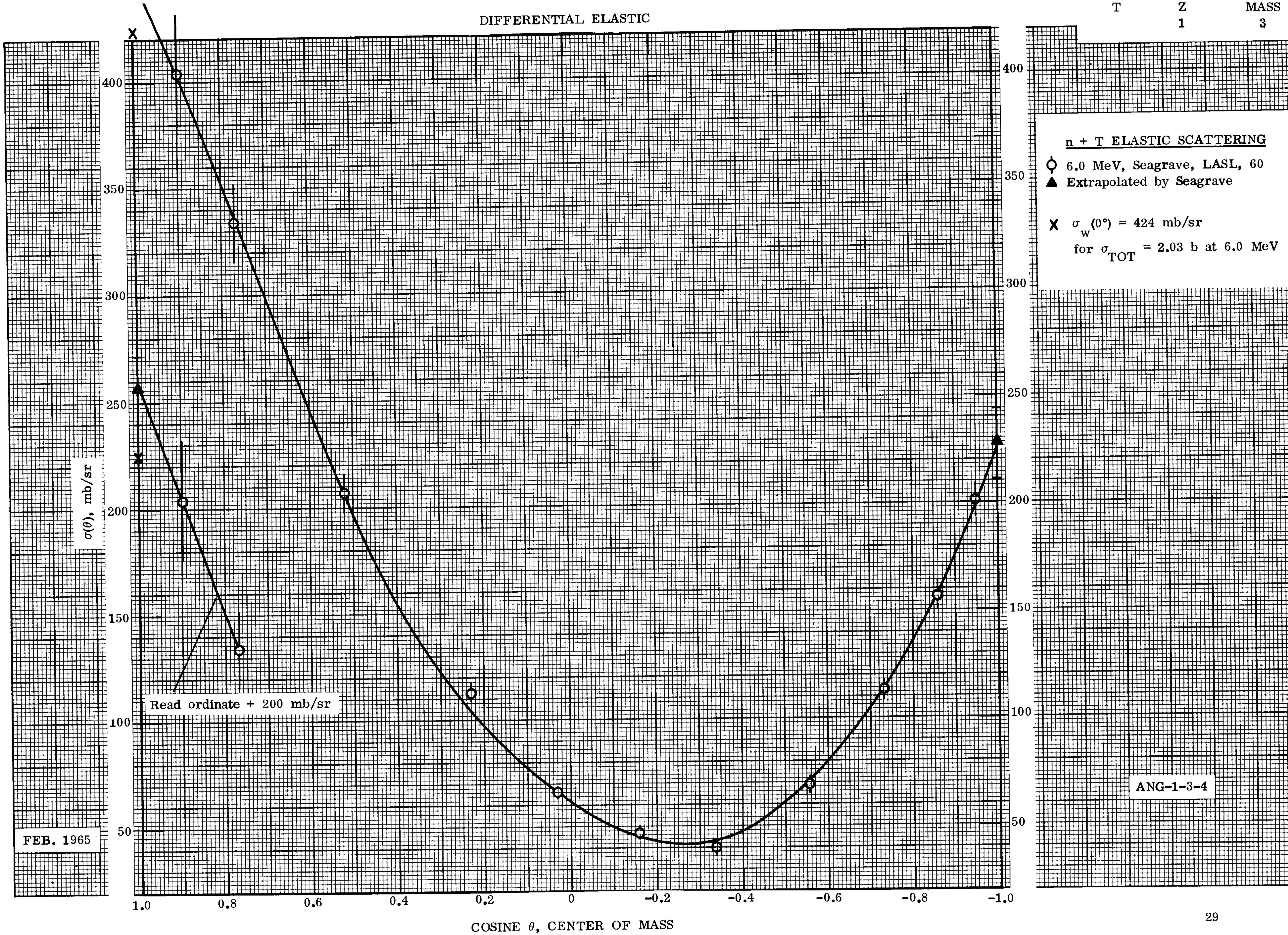
ANG-1-3-4

DATA REFERENCE

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

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


DIFFERENTIAL ELASTIC
n + T ELASTIC SCATTERING
6.0 MeV, Seagrave, LASL, 60
Extrapolated by Seagrave
X $\sigma_W(0°)$ = 424 mb/sr
for σ_{TOT} = 2.03 b at 6.0 MeV
Read ordinate + 200 mb/sr
σ(θ), mb/sr
400
350
300
250
200
150
100
50
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
COSINE θ, CENTER OF MASS
FEB. 1965
ANG-1-3-4

DATA REFERENCES

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

n + T ELASTIC SCATTERING:

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

p + He^3 ELASTIC SCATTERING:

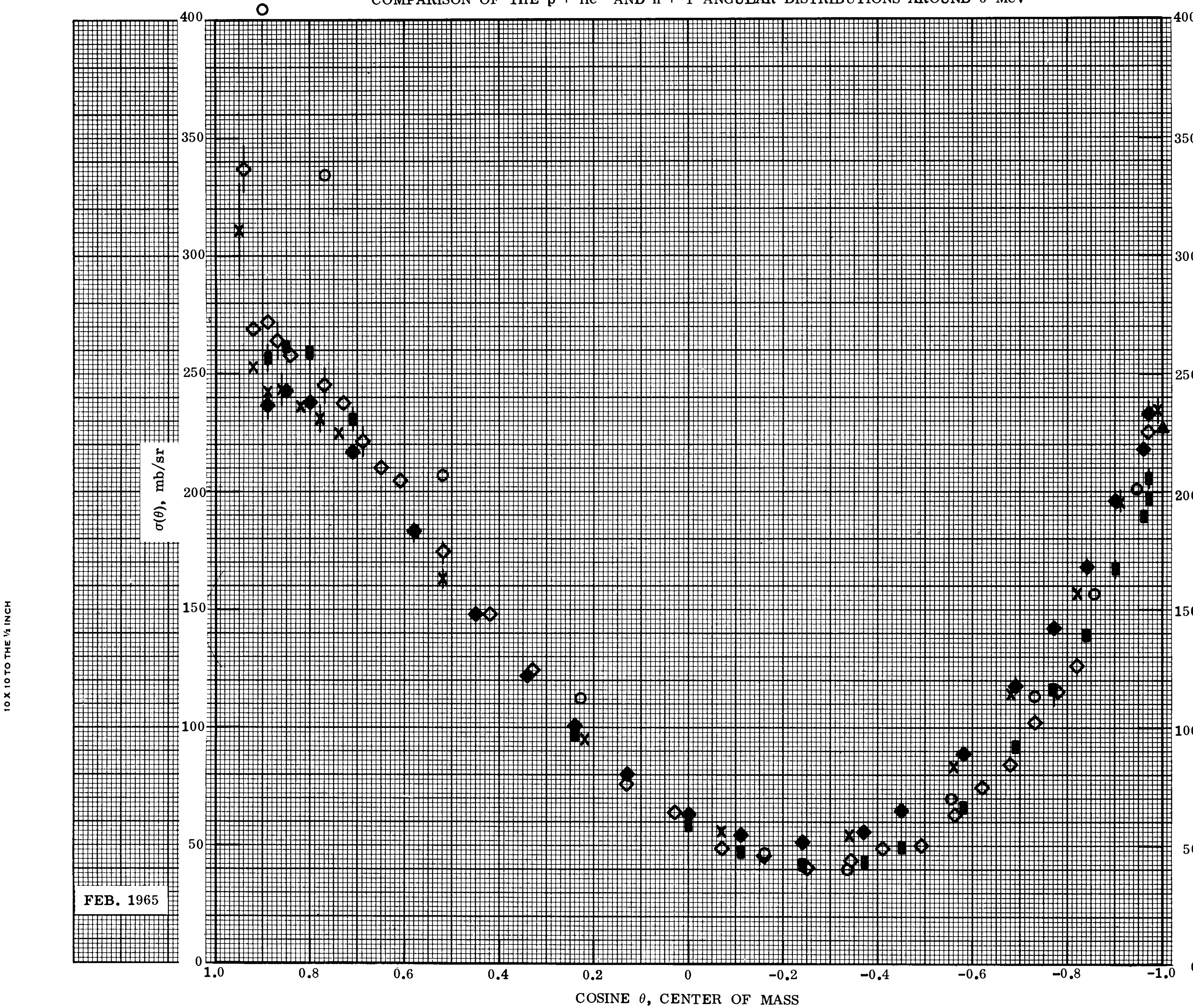
2. X D. G. McDonald, W. Haeberli, and L. W. Morrow, Phys. Rev. 133B, 1178 (1964).

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

4. ◇ 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^3 recoil nuclei were not used in this analysis.

COMPARISON OF THE p + He^3 AND n + T ANGULAR DISTRIBUTIONS AROUND 6 MeV

T Z MASS
1 3



p + He^3 Elastic Scattering

- X 5.51 MeV, Haeberli, Wis., 64
- ◆ 5.51 MeV, Clegg, Rice, 64
- ▮ 6.52 MeV, Clegg, Rice, 64
- ◇ 6.5 MeV, Brolley, LASL,* 60

n + T Elastic Scattering

- ○ 6.0 MeV, Seagrave, LASL, 60
- ▲ Extrapolated by Seagrave

T	Z	MASS
	1	3

E_0 = 8.5 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ 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), σ_{el} =	1.535 barns	

ANG-1-3-6

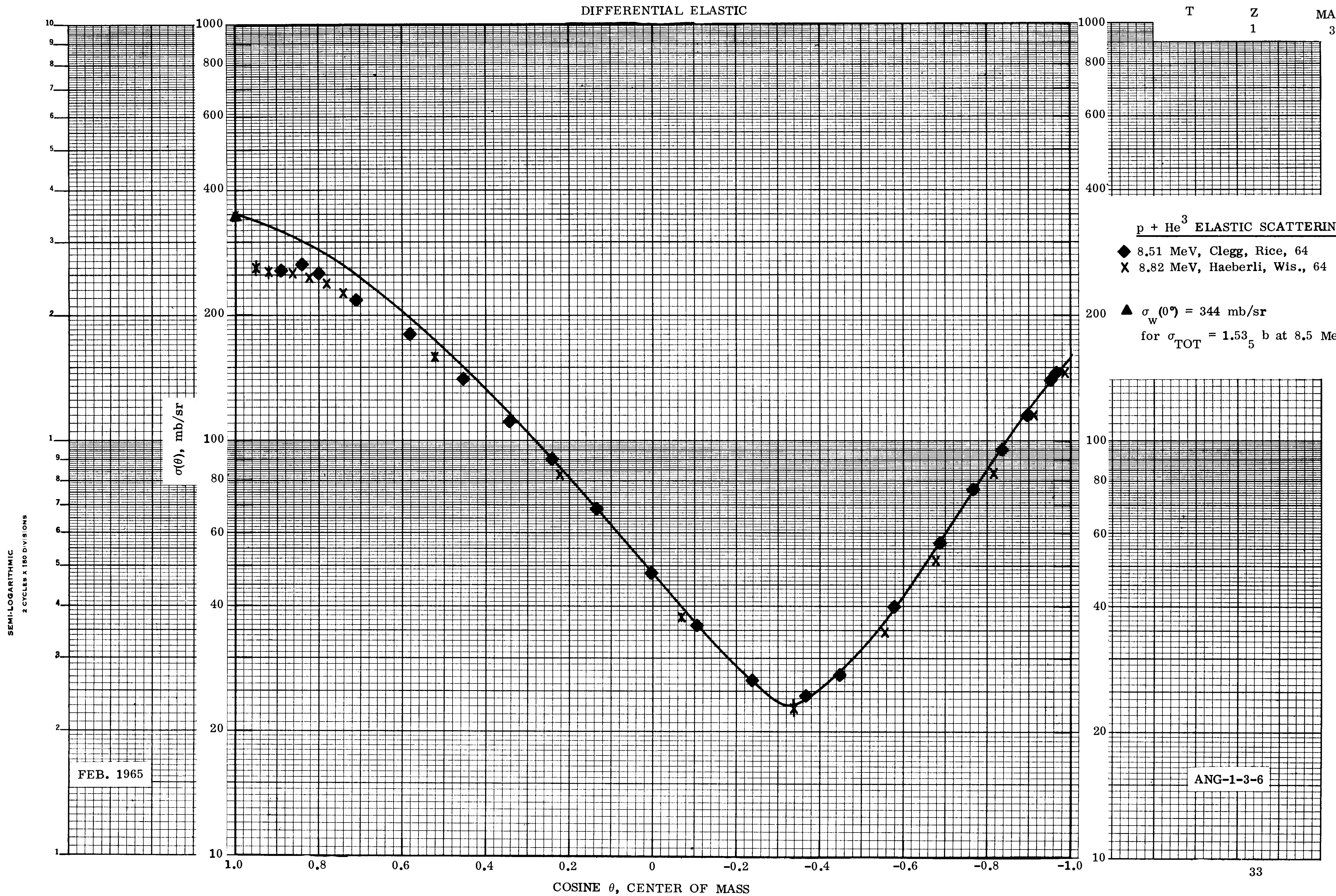
DATA REFERENCES

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He^3 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
1
MASS
3
p + He[3] ELASTIC SCATTERING
◆ 8.51 MeV, Clegg, Rice, 64
X 8.82 MeV, Haeberli, Wis., 64
▲ σw(0°) = 344 mb/sr
for σTOT = 1.53₅ b at 8.5 MeV
σ(θ), mb/sr
COSINE θ, CENTER OF MASS
SEMI-LOGARITHMIC
2 CYCLES X 180 DIVISIONS
FEB. 1965
ANG-1-3-6

T	Z	MASS
	1	3

E_0 = 9.5 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ 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 θ dθ =	215.20	1.000117
$\times$ dϕ =	1.352 barns	
(Comparison with curve), σ_{el} =	1.377 barns	

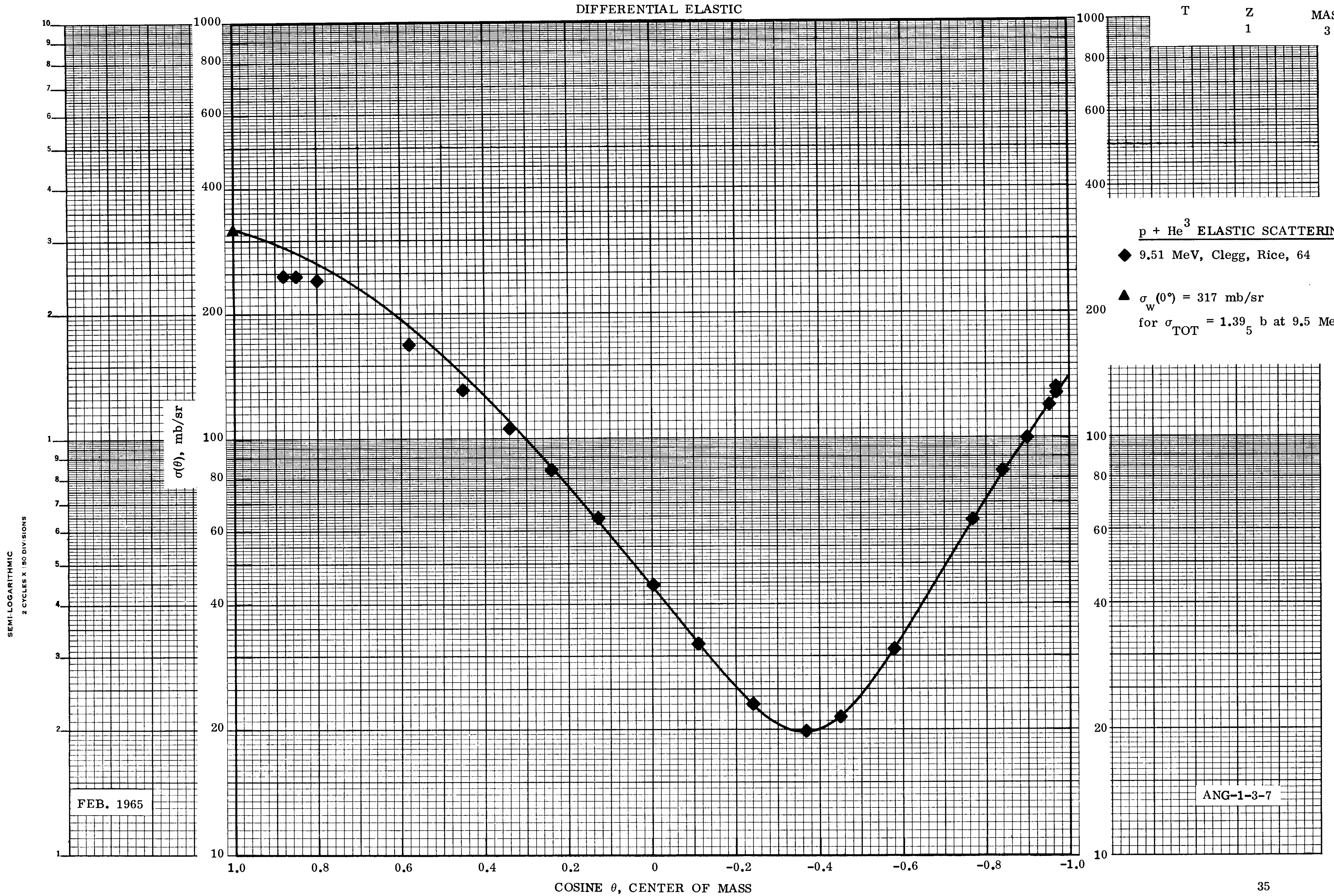
ANG-1-3-7

DATA REFERENCE

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He^3 ELASTIC SCATTERING:

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


DIFFERENTIAL ELASTIC
T
Z 1
MASS 3
p + He3 ELASTIC SCATTERING
9.51 MeV, Clegg, Rice, 64
σw(0°) = 317 mb/sr
for σTOT = 1.395 b at 9.5 MeV
σ(θ), mb/sr
COSINE θ, CENTER OF MASS
FEB. 1965
ANG-1-3-7
SEMI-LOGARITHMIC
2 CYCLES X 150 DIVISIONS

T	Z	MASS
	1	3

E_0 = 9.75 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ 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	122	0.5828
SUM =	2093.5	10.00076
$\times \sin\theta\, d\theta$ =	209.35	1.000076
$\times\, d\phi$ =	1.315 barns	
(Comparison with curve), σ_{el} =	1.331 barns	

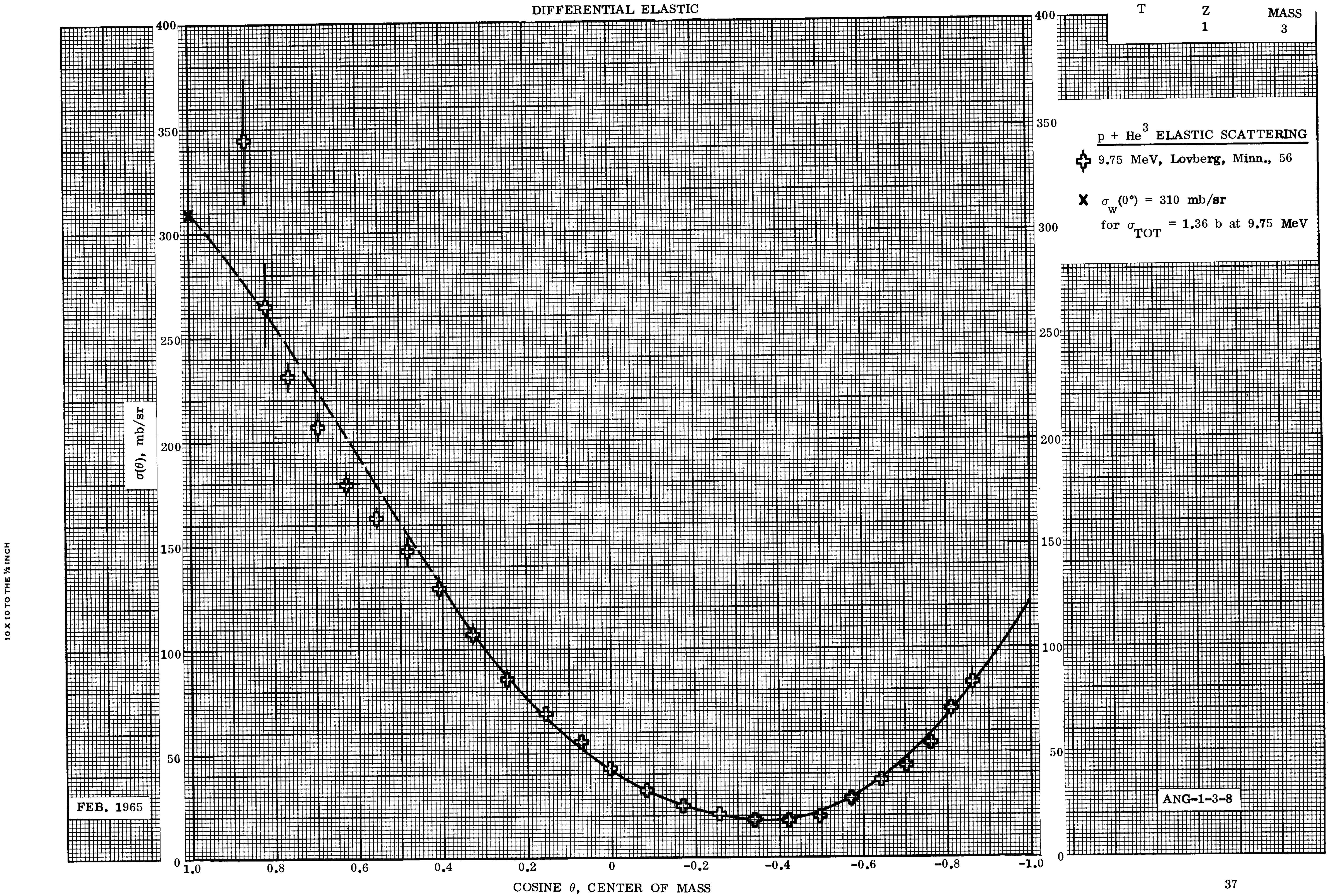
ANG-1-3-8

DATA REFERENCE

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He^3 ELASTIC SCATTERING:

1. ⌖ Ralph H. Lovberg, Phys. Rev. 103, 1393 (1956).


DIFFERENTIAL ELASTIC
T
Z 1
MASS 3
p + He3 ELASTIC SCATTERING
9.75 MeV, Lovberg, Minn., 56
X σw(0°) = 310 mb/sr
for σTOT = 1.36 b at 9.75 MeV
σ(θ), mb/sr
COSINE θ, CENTER OF MASS
FEB. 1965
ANG-1-3-8
10 X 10 TO THE ½ INCH

T	Z	MASS
	1	3

E_0 = 10.4 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ 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), σ_{el} =	1.222 barns (total elastic)	

ANG-1-3-9

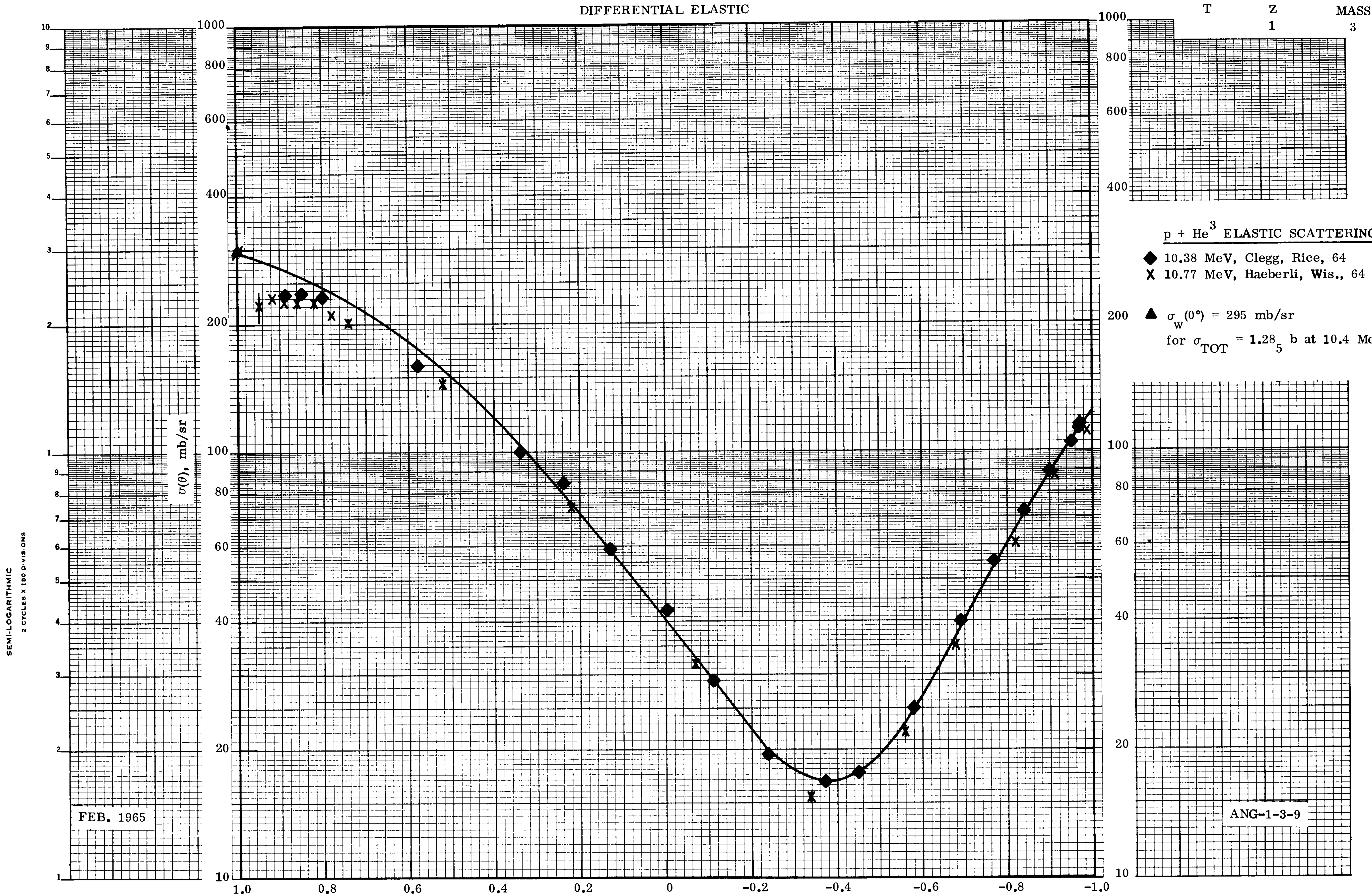
DATA REFERENCES

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He^3 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
p + He3 ELASTIC SCATTERING
10.38 MeV, Clegg, Rice, 64
10.77 MeV, Haeberli, Wis., 64
σw(0°) = 295 mb/sr
for σTOT = 1.285 b at 10.4 MeV
σ(θ), mb/sr
COSINE θ, CENTER OF MASS
1.0 0.8 0.6 0.4 0.2 0 -0.2 -0.4 -0.6 -0.8 -1.0
1000 800 600 400 200 100 80 60 40 20 10
FEB. 1965
ANG-1-3-9
SEMI-LOGARITHMIC
2 CYCLES X 150 DIVISIONS

T	Z	MASS
	1	3

E_0 = 11.5 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ mb/sr	$P(\theta)$
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	108	0.6438
SUM =	1677.5	9.99944
$\times \sin\theta\, d\theta$ =	167.75	0.999944
$\times\, d\phi$ =	1.054 barns	
(Comparison with curve), σ_{el} =	1.061 barns	

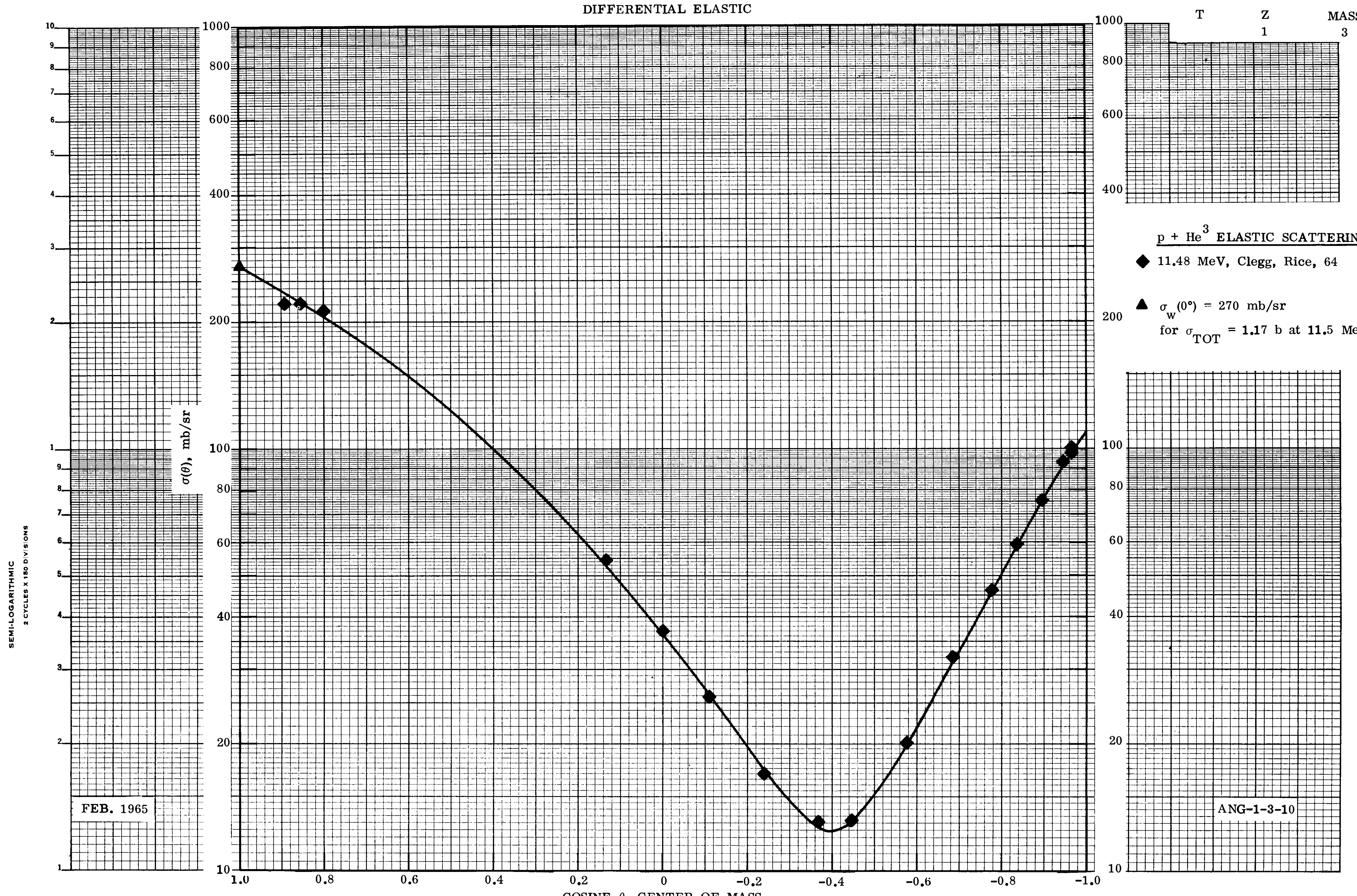
ANG-1-3-10

DATA REFERENCE

ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

p + He^3 ELASTIC SCATTERING:

1. ◆ 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
p + He^3 ELASTIC SCATTERING
◆ 11.48 MeV, Clegg, Rice, 64
▲ $\sigma_w(0°)$ = 270 mb/sr
for σ_{TOT} = 1.17 b at 11.5 MeV
$\sigma(\theta)$, mb/sr
COSINE θ, CENTER-OF-MASS
FEB. 1965
ANG-1-3-10
SEMI-LOGARITHMIC
2 CYCLES X 150 DIVISIONS

T	Z	MASS
	1	3

E_0 = 14.1 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ mb/sr	$P(\theta)$
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	82.5	0.6027
SUM =	1368.9	9.99932
$\times$ sin θ dθ =	136.89	0.999932
$\times$ dϕ =	860 millibarns	
(Comparison with curve), σ_{el} =	841 millibarns	

ANG-1-3-11

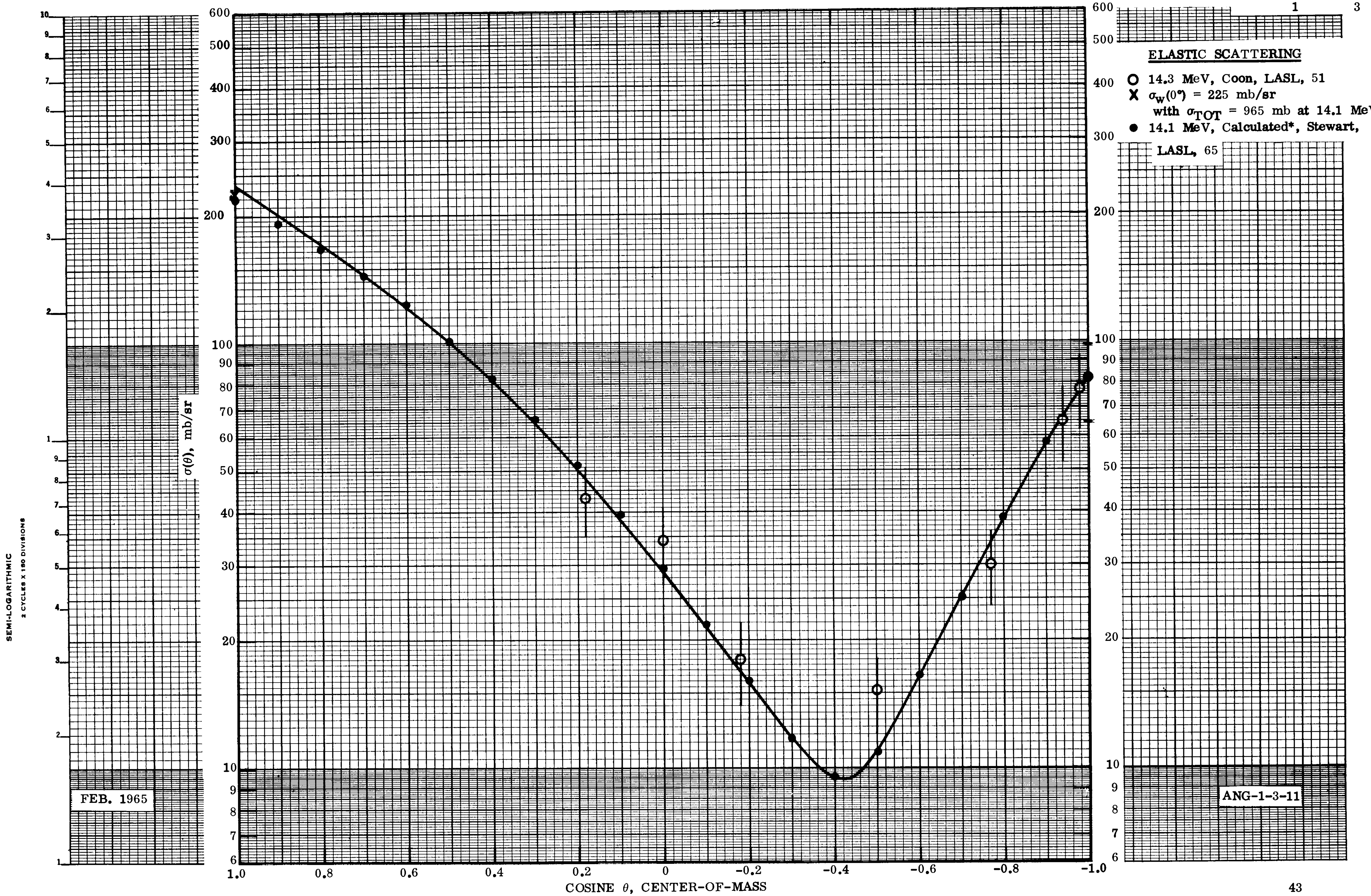
DATA REFERENCES

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^3 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
O 14.3 MeV, Coon, LASL, 51
X $\sigma_W(0°)$ = 225 mb/sr
with σ_{TOT} = 965 mb at 14.1 MeV
● 14.1 MeV, Calculated*, Stewart, LASL, 65
$\sigma(\theta)$, mb/sr
COSINE θ, CENTER-OF-MASS
FEB. 1965
ANG-1-3-11
SEMI-LOGARITHMIC
2 CYCLES X 180 DIVISIONS

E_0 = 19.4 MeV

EVALUATED ANGULAR DISTRIBUTIONS
OF
NEUTRONS ELASTICALLY SCATTERED FROM TRITIUM

COSINE θ	$\sigma(\theta)$ 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
$\times \sin\theta\, d\theta$ =	102.59	0.999975
$\times\, d\phi$ =	645 millibarns	
(Comparison with curve), σ_{el} =	639 millibarns	

ANG-1-3-12

DATA REFERENCE

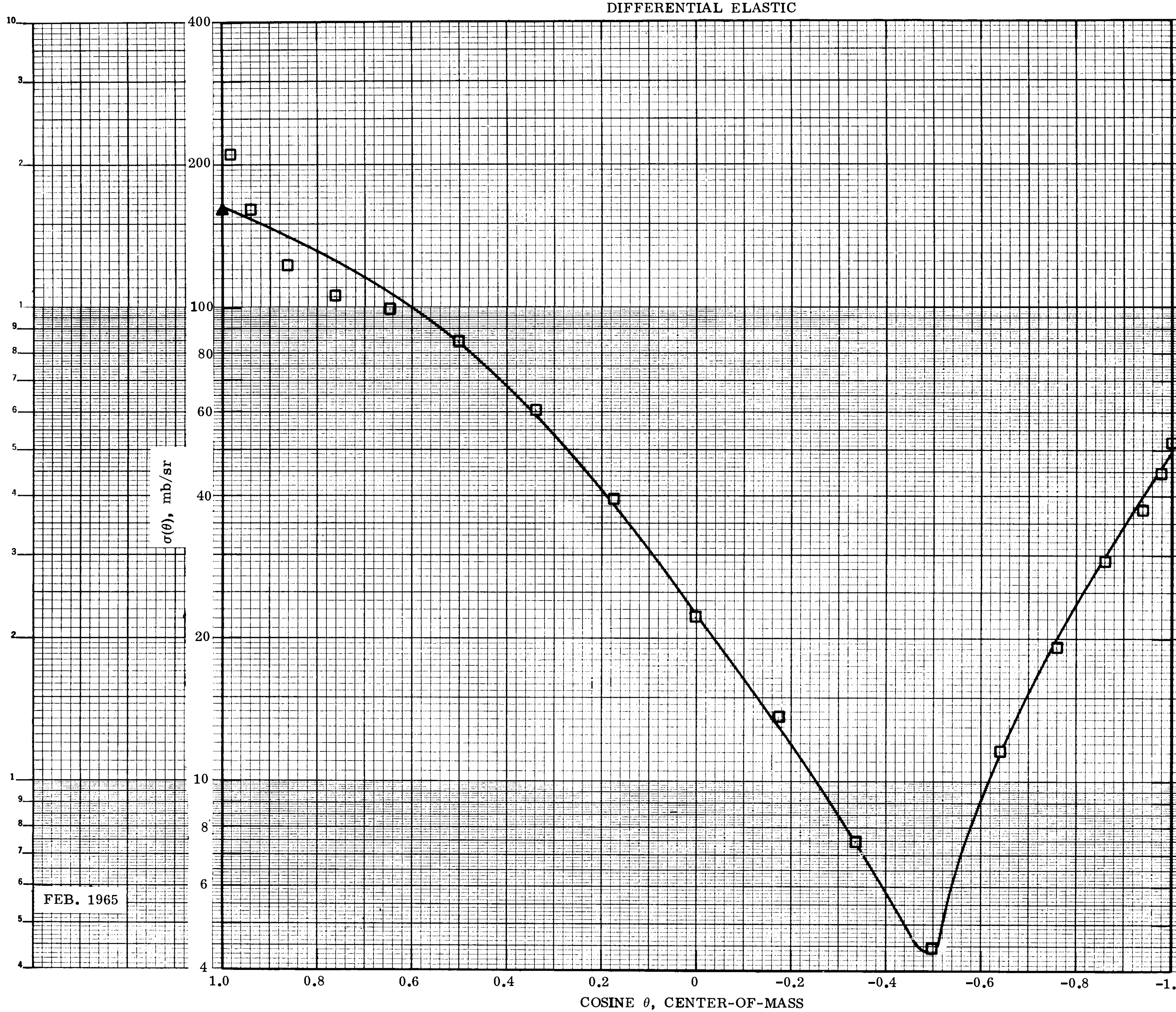
ELASTIC SCATTERING ANGULAR DISTRIBUTIONS

$p + He^3$ 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^3 ELASTIC SCATTERING

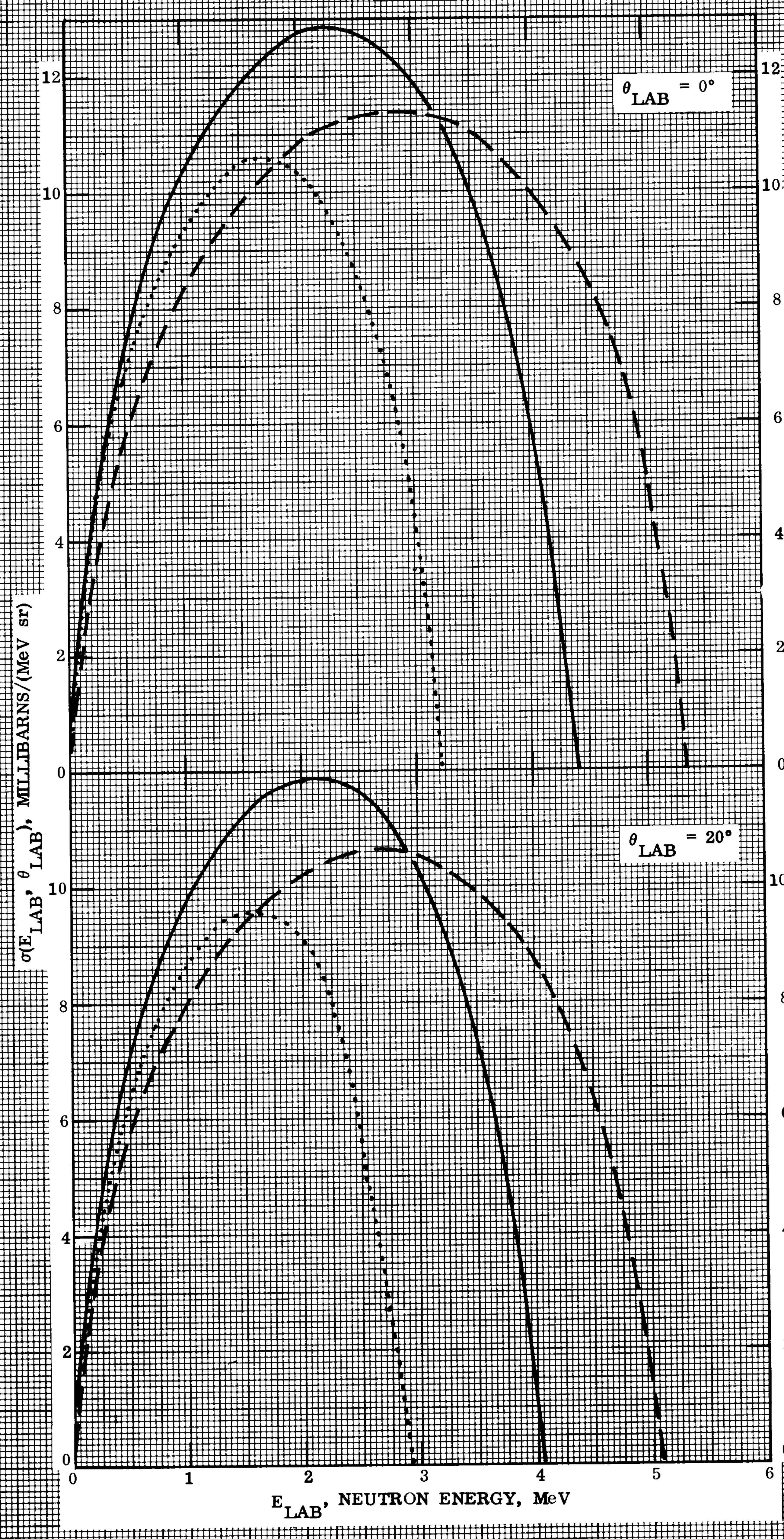
□ 19.4 MeV, Russian, 1964

▲ $\sigma_W(0°)$ = 161 mb/sr
for σ_{TOT} = 695 mb at 19.4 MeV

ANG-1-3-12

APPENDIX

T	Z	MASS
	1	3



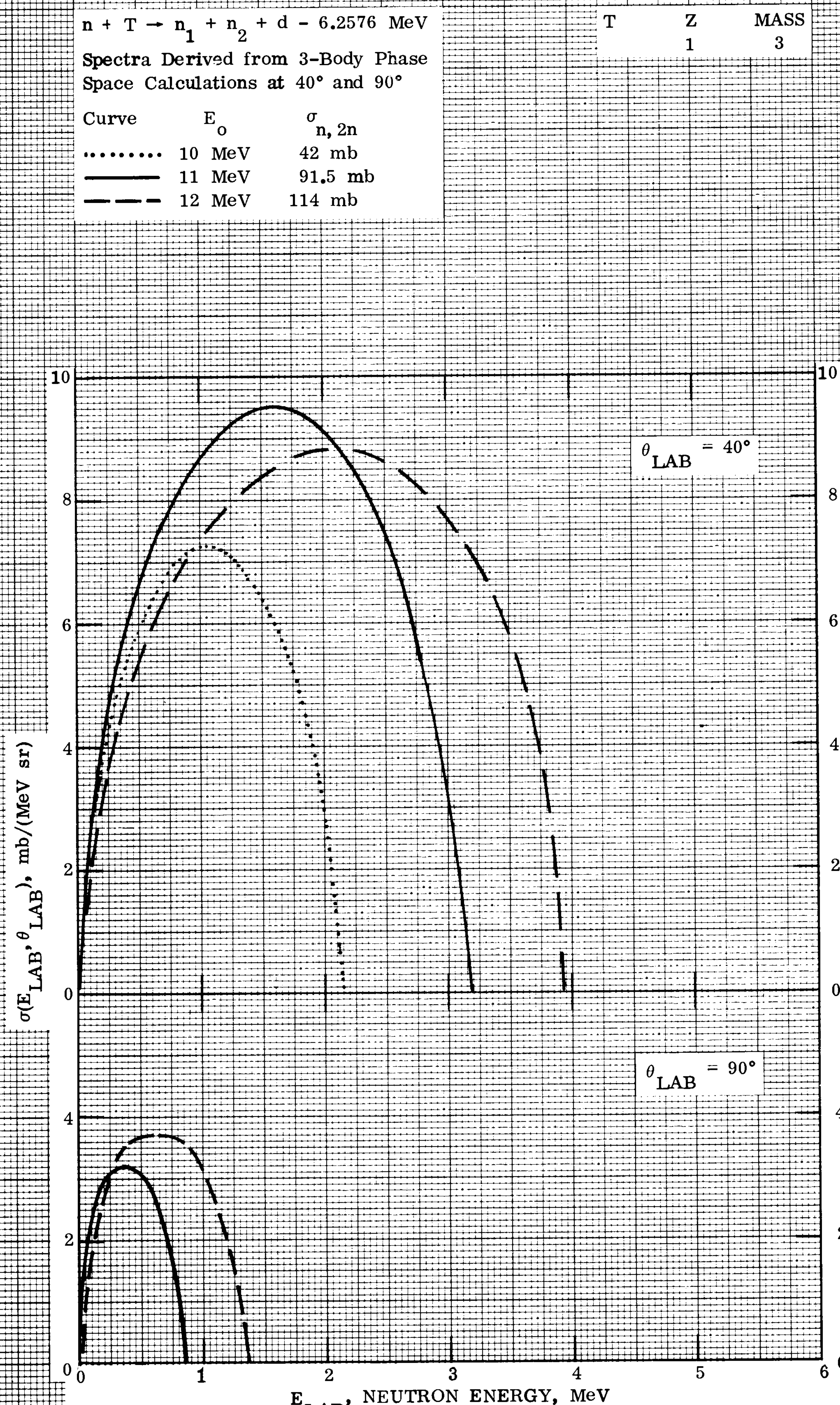
$n + T \rightarrow n_1 + n_2 + d - 6.2576$ MeV

Spectra Derived from 3-Body Phase Space Calculations at 0° and 20°

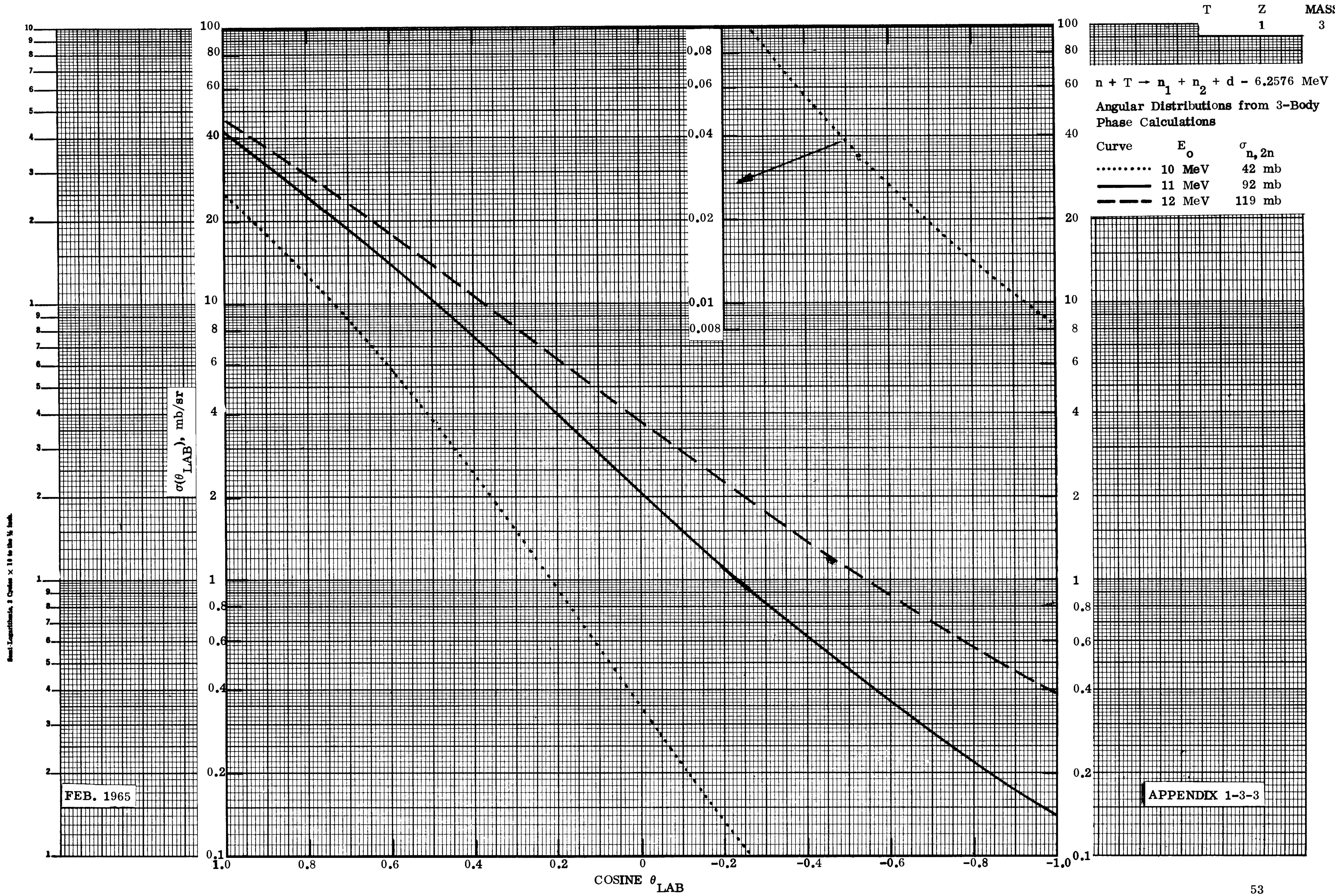
Curve	E_o	$\sigma_{n,2n}$
·········	10 MeV	42 mb
———	11 MeV	92 mb
— — —	12 MeV	119 mb

APPENDIX 1-3-1

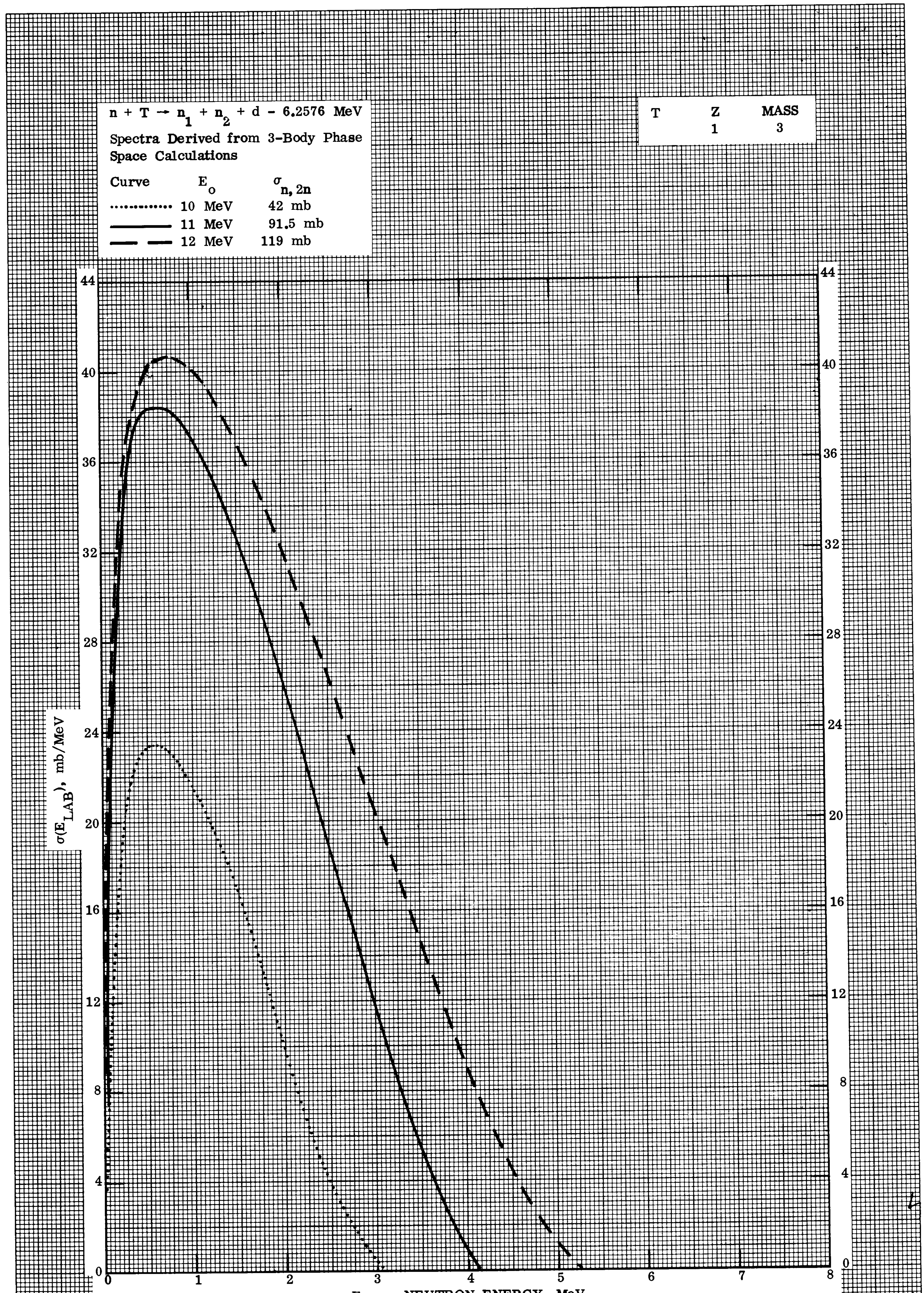
FEB. 1965



APPENDIX 1-3-2

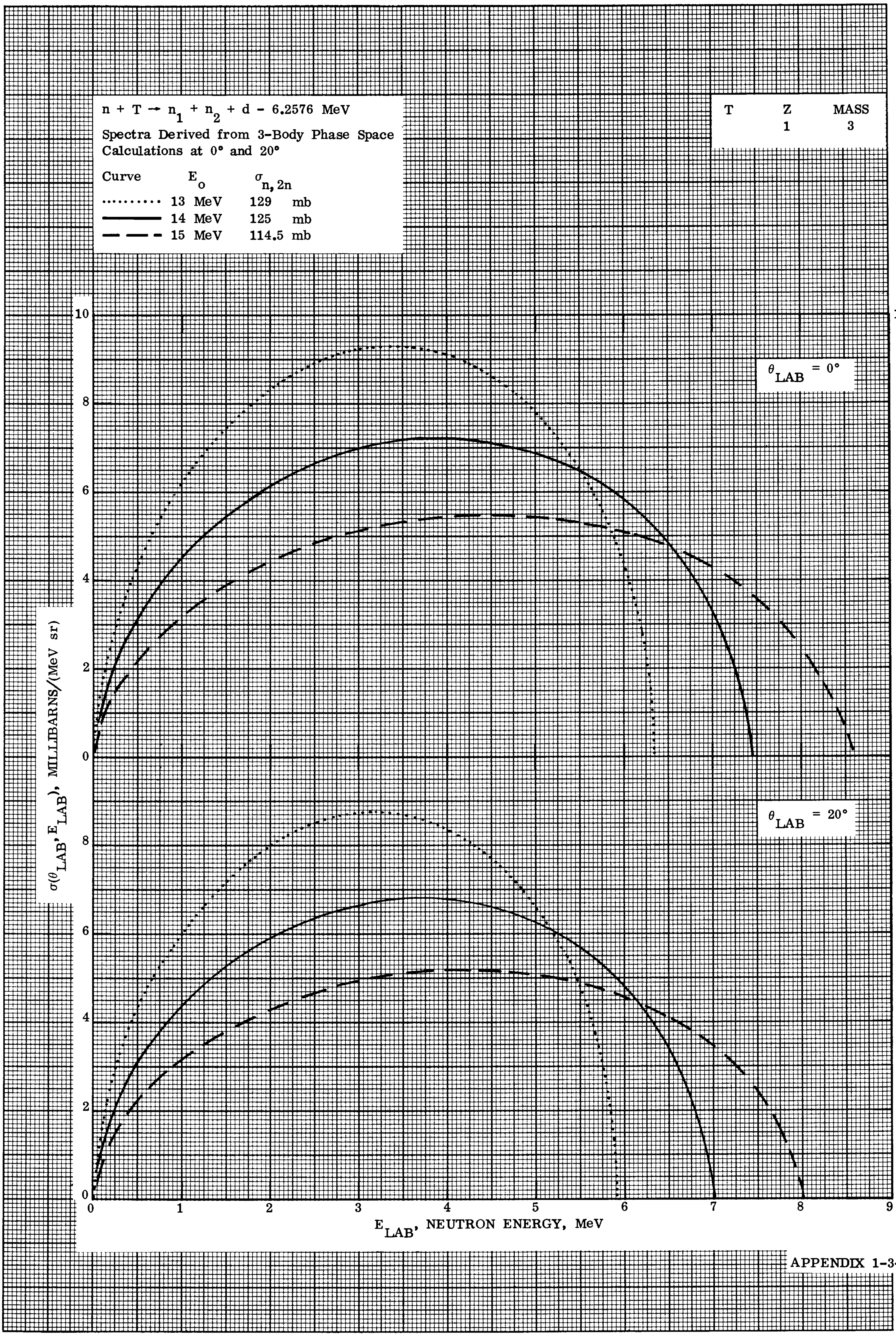

T Z MASS
1 3
n + T → n_1 + n_2 + d - 6.2576 MeV
Angular Distributions from 3-Body Phase Calculations
Curve E_o $\sigma_{n,2n}$
10 MeV 42 mb
11 MeV 92 mb
12 MeV 119 mb
$\sigma(\theta_{LAB})$, mb/sr
COSINE θ_{LAB}
FEB. 1965
APPENDIX 1-3-3

10 X 10 PER HALF INCH

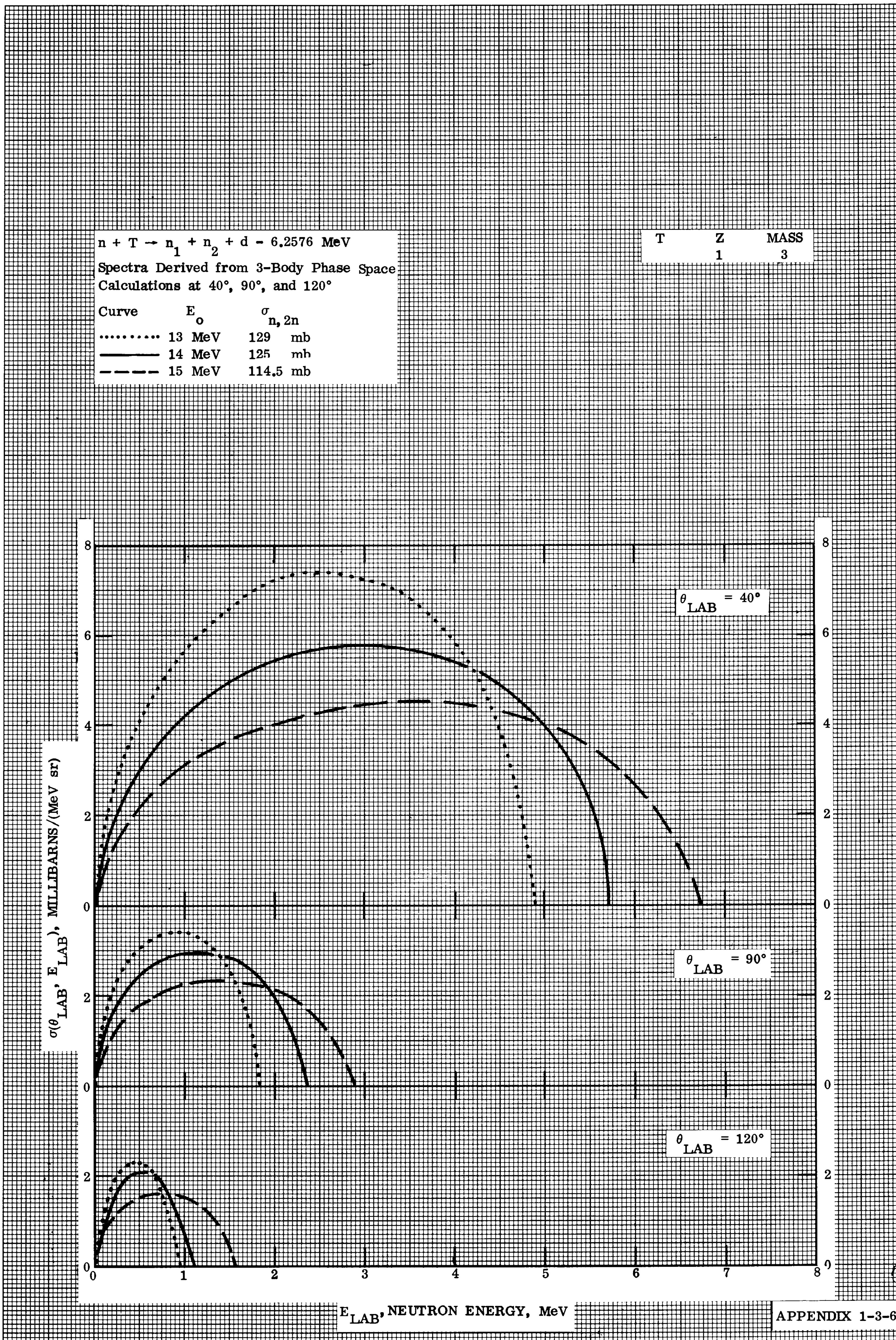


APPENDIX 1-3-4

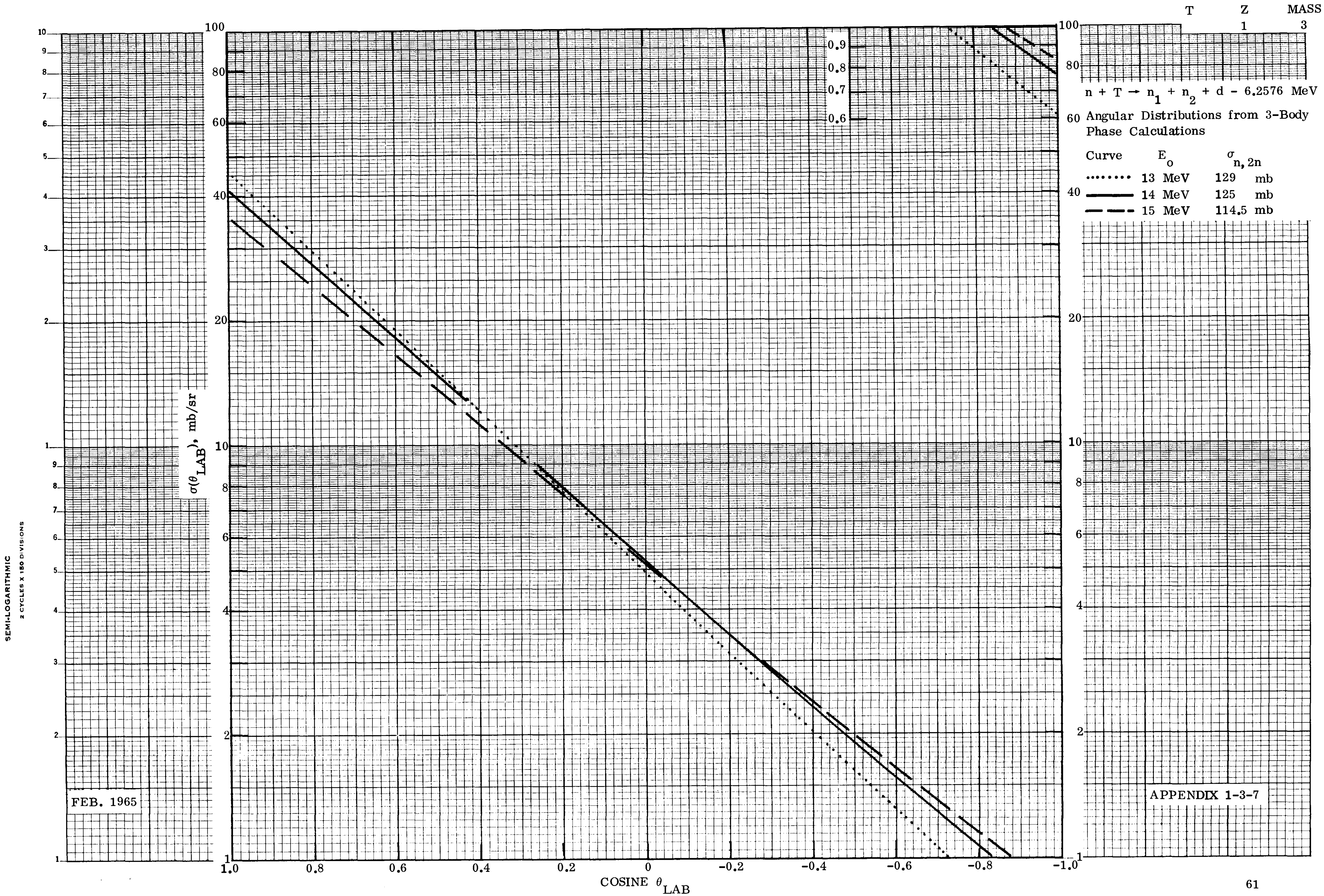
FEB. 1965


n + T → n1 + n2 + d - 6.2576 MeV
Spectra Derived from 3-Body Phase Space Calculations at 0° and 20°
Curve E0 σn, 2n
13 MeV 129 mb
14 MeV 125 mb
15 MeV 114.5 mb
T Z MASS
1 3
θLAB = 0°
θLAB = 20°
σ(θLAB, ELAB), MILLIBARNS/(MeV sr)
ELAB, NEUTRON ENERGY, MeV
0 1 2 3 4 5 6 7 8 9
0 2 4 6 8 10

10 X 10 PER HALF INCH



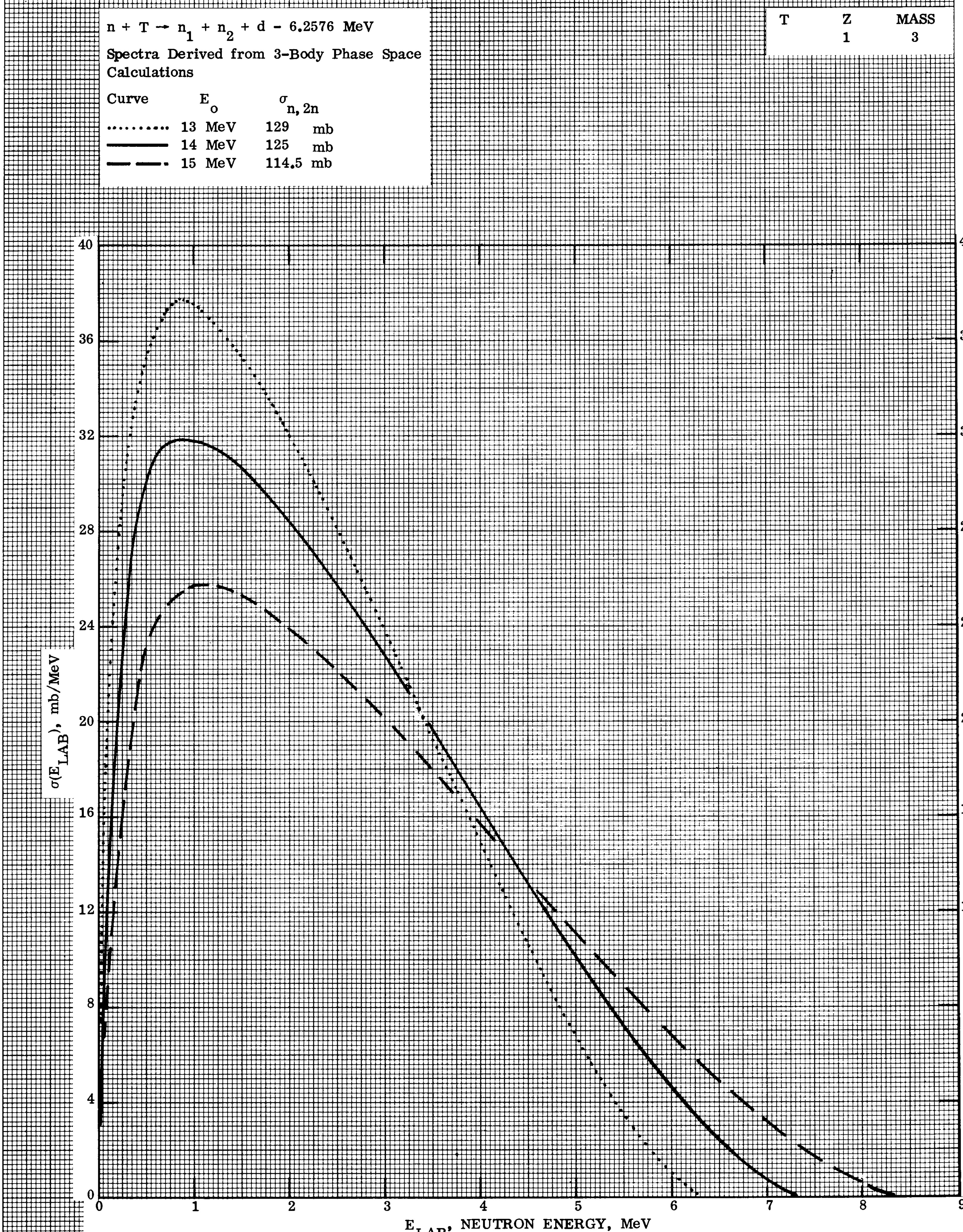
APPENDIX 1-3-6



T Z MASS
1 3
n + T → n1 + n2 + d - 6.2576 MeV
Angular Distributions from 3-Body Phase Calculations
Curve E0 σn,2n
13 MeV 129 mb
14 MeV 125 mb
15 MeV 114.5 mb
σ(θLAB), mb/sr
COSINE θLAB
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
100
80
60
40
20
10
8
6
4
2
1
0.9
0.8
0.7
0.6
SEMI-LOGARITHMIC
2 CYCLES X 180 DIVISIONS
FEB. 1965
APPENDIX 1-3-7

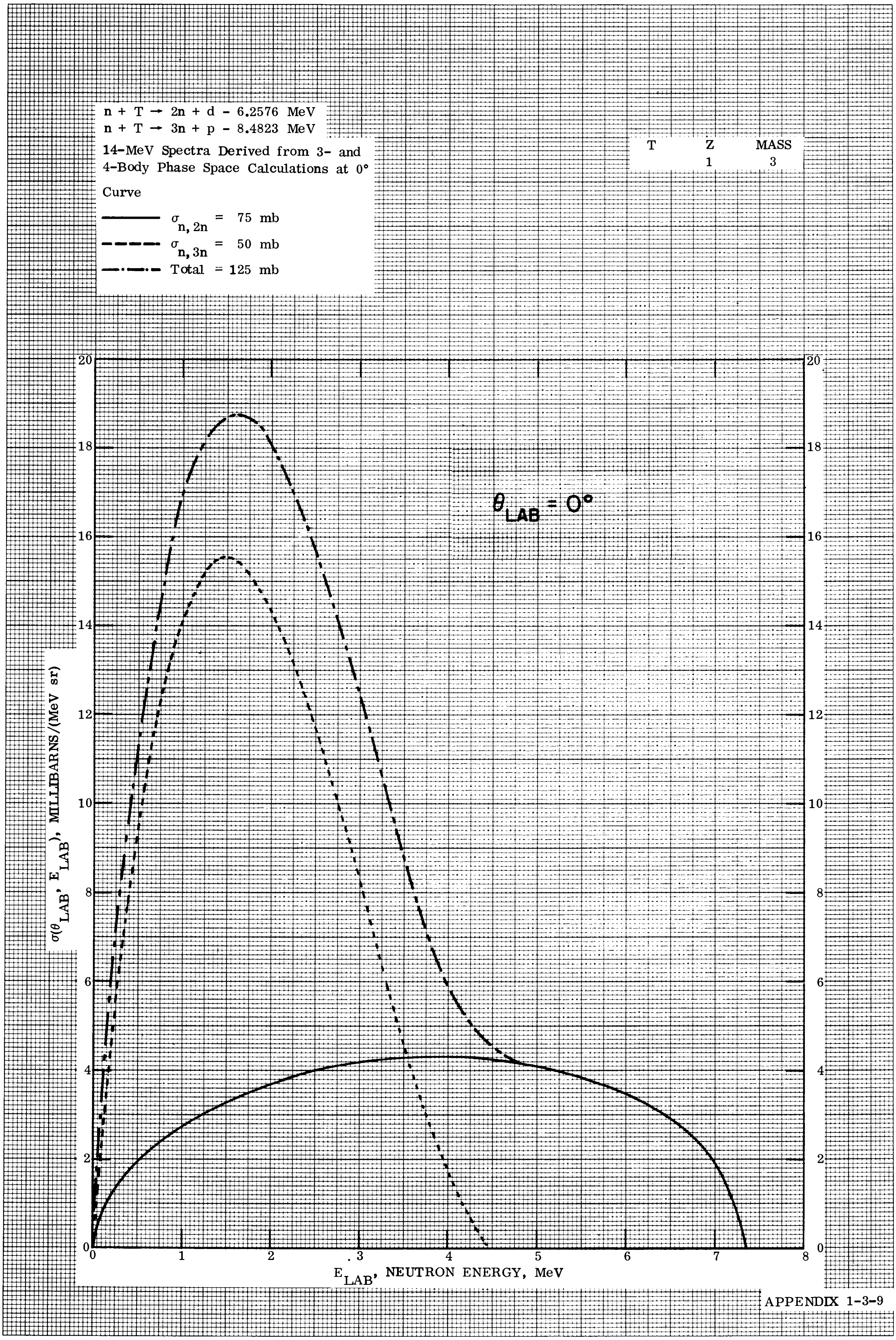
10 X 10 PER HALF INCH

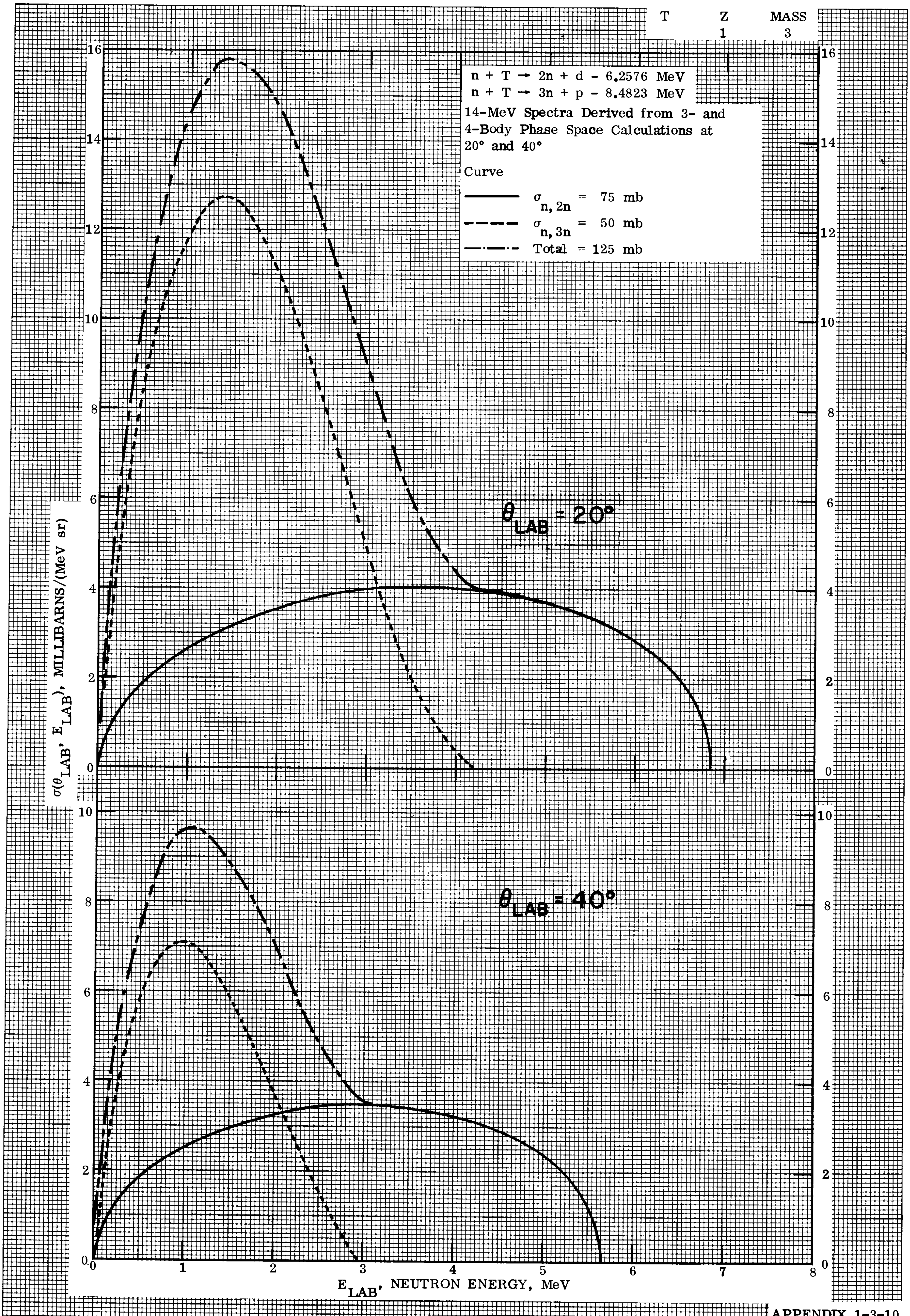
T Z MASS
1 3



APPENDIX 1-3-8

FEB. 1965


n + T → 2n + d - 6.2576 MeV
n + T → 3n + p - 8.4823 MeV
14-MeV Spectra Derived from 3- and 4-Body Phase Space Calculations at 0°
Curve
$\sigma_{n,2n}$ = 75 mb
$\sigma_{n,3n}$ = 50 mb
Total = 125 mb
T Z MASS
1 3
$\theta_{LAB} = 0°$
$\sigma(\theta_{LAB}, E_{LAB})$, MILLIBARNS/(MeV sr)
E_{LAB}, NEUTRON ENERGY, MeV
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20



APPENDIX 1-3-10

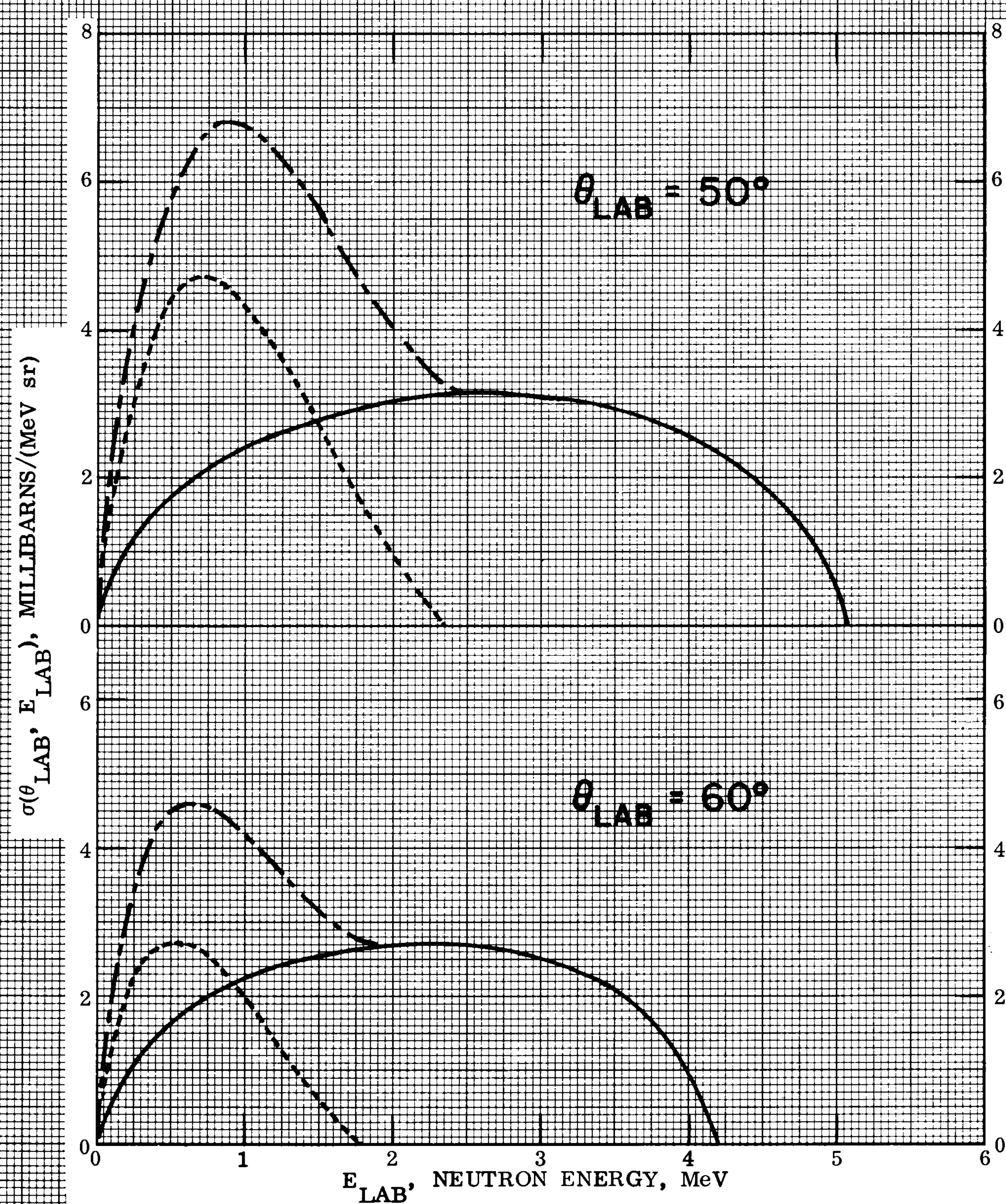
n + T → 2n + d − 6.2576 MeV
n + T → 3n + p − 8.4823 MeV

14-MeV Energy Spectra Derived from a Combination 3- and 4-Body Phase Space Calculations at 50° and 60°

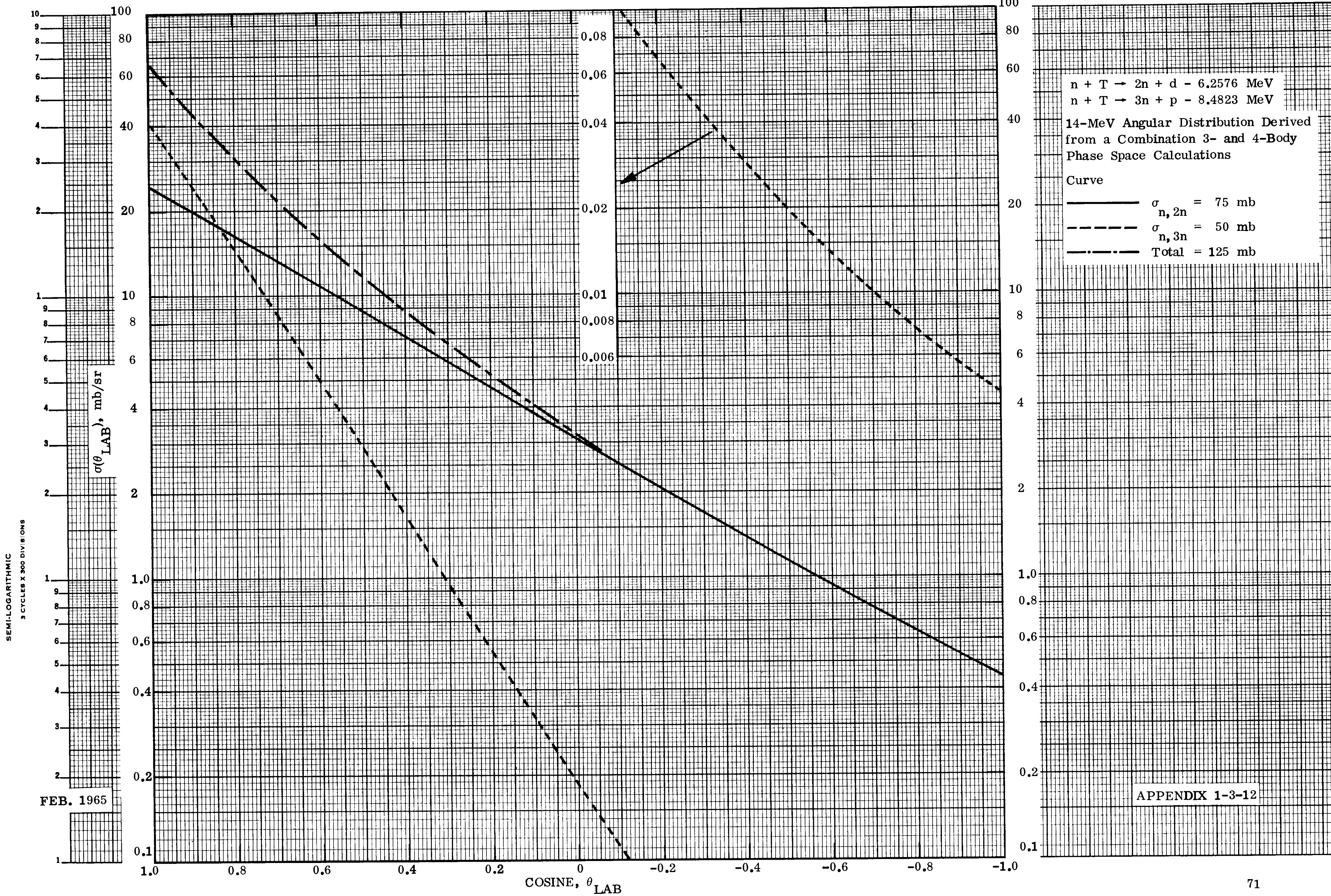
Curve

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

T	Z	MASS
	1	3



APPENDIX 1-3-11



FEB. 1965

APPENDIX 1-3-12

T	Z	MASS
	1	3

n + T → 2n + d − 6.2576 MeV
n + T → 3n + p − 8.4823 MeV
14-MeV Energy Spectra Derived from 3- and 4-Body Phase Space Calculations