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RANGE-ENERGY RELATIONS OF He^3 CALCULATED FOR SEVERAL ELEMENTS

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Andre C. Demildt

February 11, 1963

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ABSTRACT

The range-energy relations and the rate-of-energy losses for He^3 particles have been computed for different elements throughout the periodic table. The kinetic-energy range covered for the incident particles is from 2.5 MeV to 100 MeV.

The range-energy calculation results have also been included for a few compounds.

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RANGE-ENERGY RELATIONS OF He^3 CALCULATED FOR SEVERAL ELEMENTS*

Andre C. Demildt

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I. INTRODUCTION

Where nuclear reactions with He^3 particles are involved, especially when excitation curves or activation analysis methods are of interest, we need to know range-energy relations of these particles. To fill this need for extensive range-energy data for He^3 in a large number of elements, theoretical calculations are necessary, since experimental values are not available.

There were only a few published range-energy relations, when the activation analysis of oxygen in transuranium elements was started.[1] These are compiled by W. Whaling[2] and S. S. Markowitz and J. D. Mahony;[3] the latter authors calculated the range-energy relation for He^3 in aluminum from proton ranges, with the use of the empirical transformation formula $R_{He^3}(3E) = 3/4\ R_p(E)$.

It is possible to use the same formula for the calculation of reliable range-energy relations of He^3 in other elements when range-energy relations of sufficient accuracy for protons or α's are available. In the absence of such data, the calculations are done from interpolated values. The results are then uncertain by at least 10%, which is not satisfactory for accurate work.

Recently, new range-energy relations have been published by C. Williamson and J. P. Boujot.[4]

For elements with small atomic numbers our results are in good agreement with Williamson and Boujot's published values. For the heavier elements their results tend to have higher range values than those calculated here; this is especially true in the lower energy region. The reasons for this difference will be discussed in Sec. III.

In this study the theoretical calculations of the range-energy relations are carried out by use of the Bethe-Block formula, giving the theoretical kinetic energy loss per unit thickness expressed in cm or mg/cm^2. From these values, the range can be computed by numerical integration of the inverse kinetic-energy loss function.

The numerical work was done by the IBM 7090 of the Lawrence Radiation Laboratory. The program has been preserved for further use.

II. CALCULATIONS

A. Theoretical Aspects.

The formula of Bethe-Block given by R. M. Sternheimer[5] for the energy loss of protons is

$$-\frac{dT}{dx} = \frac{2\pi n e^4}{m v^2}\left[\ell n \frac{2 m v^2 W_{max}}{I(Z)^2(1-\beta^2)} - 2\beta^2 - \delta - U\right], \quad (1)$$

where

$-\frac{dT}{dx}$ = kinetic-energy loss per unit length expressed in erg/cm;

n = number of electrons per cm^3;

v = velocity of incident particles (cm/sec);

β = v/c, where c = velocity of light;

e = charge of the electron (esu);

m = mass of the electron (g);

$I(Z)$ = mean ionization potential (eV);

δ = correction for density effect, due to polarization;

U = shell correction term (This takes into account the fact that some atomic electrons do not contribute as much to $-\frac{dT}{dx}$ as is given by the first logarithmic term of the formula. This happens for electrons of the shell (primarily the K shell) as soon as the experimental condition $v < v_i$ exists, where v_i is the velocity of an atomic electron in the ith shell of the atom); and

W_{max} = maximum energy transfer from the incident particle to an atomic electron ("free" electron).

Following Steinheimer,[5] W_{max} is given by the relation

$$W_{max} = \frac{E^2 - \mu^2 e^4}{\mu c^2 \, (\mu/2m) + (m/2\,\mu) + (E/\mu c^2)}, \qquad (2)$$

where μ and E are the mass and total energy of the incident particle.

For $E \ll (\frac{\mu^2}{2\,m})\, c^2$ the formula for W_{max} can be reduced to

$$W_{max} = \frac{2\,m\,v^2}{(1 - \beta^2)} . \qquad (3)$$

B. Calculations of the Energy Loss.

For the case of He^3 having a kinetic energy between 3 and 100 MeV, the correction for density effect and even the shell corrections may be neglected. In this energy region the simplified relation (3) for W_{max} can be taken into account. The general formula for energy loss then becomes

$$-\frac{dT}{dx} = \frac{4\pi n e^4}{m v^2}\left[\ell n \frac{2 m v^2}{I(Z)(1-\beta^2)} - \beta^2\right]. \quad (4)$$

The coefficient of this formula can further be transformed by taking into account the fact that

$$n = \frac{L\rho}{A} Z, \quad (5)$$

where

L is Avogadro's number,

ρ is density expressed in mg/cm^3

Z is the atomic number of the irradiated material, and

A is the atomic mass number of the irradiated material.

In Eq. (6) the energy loss is expressed in $erg/mg\text{-}cm^{-2}$, and the factor v^2 which is dependent upon the kinetic energy, may be incorporated in the second factor. Finally, for particles of multiple charge z, one obtains the Bethe-Livingstone formula[6]

$$\frac{1}{\rho}\frac{dT}{dx} = \frac{4\pi e^4 z^2 L}{m}\left(\frac{Z}{A}\right)\left\{\frac{1}{v^2}\left[\ell n \frac{2 m v^2}{I(Z)(1-\beta^2)} - \beta^2\right]\right\} \quad (6)$$

or

$$-\frac{dT}{dx'} = \frac{MeV}{mg/cm^2} = (6.24208)\times 10^5 \left[\frac{4\pi e^4 z^2 L}{m}\left(\frac{Z}{A}\right)\right] \left\{\frac{1}{v^2}\left[\ell n \frac{2 m v^2}{I(Z)(1-\beta^2)} - \beta^2\right]\right\} \quad (7)$$

and

$$-\frac{dT}{dx'} = C\left(\frac{Z}{A}\right) D\left[E, I(z)\right], \quad (8)$$

where

$$C\left(\frac{Z}{A}\right) = (6.24208) \times 10^5 \frac{4\pi e^4 z^2 L}{m} \frac{Z}{A} = (1.10385) \times 10^{21} \frac{Z}{A}$$

and

$$D[E, I(Z)] = \frac{1}{v^2}\left[\ln \frac{2 m v^2}{I(Z)(1 - \beta^2)} - \beta^2\right].$$

For evaluation of $C(\frac{Z}{A})$, Z/A was calculated for the different elements for which the ranges have to be computed.

Table I gives the Z/A values and the coefficients $C(\frac{Z}{A})$ for the different elements. Ther term E x listed in the column of $C(\frac{Z}{A})$ means 10^x and will be used for further tabulation.

For computing the factor D[E, I(Z)] in the energy range between 3 and 100 MeV, we calculate the squares of the velocities, v^2 and β^2, for He^3 using the special relatistic formula

$$1-\beta^2 = \left[\frac{m_o c^2}{m_o c^2 + T}\right]^2 . \qquad (9)$$

The energy corresponding to the rest mass of He^3 is $m_o c^2$ = 2909.231 MeV; T is the kinetic energy in MeV.

There are considerable differences in the mean ionization potential I(Z) involved in the calculations according to the older or more recent literature, as shown in Table I. For those elements for which no I(Z) is found in the literature, a value is estimated by interpolation or extrapolations of the nearest values.

The energy loses per unit thickness are then found by computing the product $C(\frac{Z}{A}) \cdot D[E, I(Z)]$. (These values are tabulated in Tables III to XIX in units $MeV/mg\text{-}cm^{-2}$ as a function of kinetic energy.)

Table I. Values of Z/A, A(Z) and mean ionization potentials for different elements. Figures between brackets are interpolated ones.

Element	Z/A	$C(\frac{Z}{A})$	I(Z) in eV: Older values[a]	I(Z) in eV: More recent values[b]
$_1H$	0.9921	0.1095 E 22	15.6	[15.6]
$_4Be$	0.4438	0.4899 E 21	60.4	64
$_6C$	0.4995	0.5514 E 21	76.4	78
$_7N$	0.4997	0.5516 E 21	[87.5]	[93]
$_8O$	0.5000	0.5519 E 21	[97.6]	[105]
$_9F$	0.4737	0.5229 E 21	[108]	[115]
$_{13}Al$	0.4818	0.5319 E 21	150	166
$_{14}Si$	0.4984	0.5502 E 21	[157]	[170]
$_{29}Cu$	0.4564	0.5038 E 21	279	371
$_{42}Mo$	0.4377	0.4832 E 21	391	[520]
$_{47}Ag$	0.4357	0.4809 E 21	428	586
$_{57}La$	0.4103	0.4529 E 21	[530]	705
$_{74}W$	0.4025	0.4443 E 21	697	[935]
$_{78}Pt$	0.3998	0.4413 E 21	[725]	1020
$_{90}Th$	0.3879	0.4281 E 21	831	1070
$_{92}U$	0.3864	0.4266 E 21	881	1250
$_{95}Am$	0.3942	0.4351 E 21	894	[1350]

[a] See reference 7.

[b] See references 8 and 9.

C. Range-Energy Calculations Using the Computed Energy Losses.

To compute the range-energy values, we have to integrate the inverse of the energy loss function of Bethe-Livingstone [Eq. (7)]. Using this relation, the range is given by

$$R = \int_{T_1}^{T} \frac{dx'}{dT} \, dt + R_1, \qquad (10)$$

where T_1 is the lowest kinetic-energy value for which the Bethe-Livingstone formula is considered valid, and R_1 is the integration constant which is in fact the range of the particle having the kinetic energy T_1 (for lower values, a shell correction term has to be introduced), and T is the kinetic energy for which the range has to be computed.

In these calculations, where He^3 is involved, 3 MeV is chosen as the lower limit. The ranges are computed up to a kinetic-energy value of 100 MeV. To evaluate the integral of Eq. (10), we calculate the partial sums of the inversed -dT/dx values as

$$\int_{T_1}^{T} \frac{dx'}{dT} \, dT = \sum_{T=3}^{T=m} \left[\frac{dx'}{dT}(T)\right] = S \Big|_{2.5}^{m+0.5}, \qquad (11)$$

where m is an integer and is a value for the kinetic energy of He^3 expressed in MeV. In this case, the differences in $\frac{dT}{dx}$ for He^3 are computed for integral MeV values of the He energy. In summary, the resulting values are taken to be constant between each T-0.5 MeV and T+0.5 MeV. The resulting partial sum S of the inversed values comes from kinetic energies between 2.5 MeV and m + 0.5 MeV.

The integration constants of He^3 for the energy range 0 to 2.5 MeV are evaluated from the experimental values for protons given by Aron et al.[10]

Table II lists the integration constants for the different elements. Where experimental data are not available they have been estimated by interpolation and extrapolation. Values so derived are enclosed in brackets.

Table II. Integration constants involved in the calculations.

Elements:	H	Be	C	N	O	F	Al	Si	Cu	Mo	Ag
R_1 (mg/cm^2)	0.554	1.52	1.48	1.64	1.72	[2.46]	1.94	[1.96]	2.64	[1.36]	[1.36]

Elements:	La	W	Pt	Th	U	Am
R_1 (mg/cm^2)	[3.63]	[3.94]	[4.65]	[4.65]	[4.65]	[4.65]

The ranges computed from Eq. (11) are tabulated in Tables III-XIX.

D. Range-Energy Calculations of He^3 Computed From Theoretical and Experimental Proton Range-Energy Relations.

Mean values for the He^3 ranges are calculated using the theoretical computed values of proton ranges[5] and the experimental values found in the literature.[11] Those ranges are again computed up to 30 MeV in Be, C, Al, and Cu using the same empirical formula as mentioned before (page 1). Those values are also given as a supplement in Tables IV, V, IX, and XI.

III. RESULTS

For the lighter elements the range-energy calculations are but little affected by the choice of ionization potentials, since there are only small differences. The discrepancies are more pronounced for the heavier elements. The mean ionization potential figures for the actinides differ by about 50% between the older and newer values. This results in range differences up to 34% for Am in the low energy part.

The newer values are higher and result in higher range values. These newer values are considered to be the best approximation of the ranges. They are relatively close to certain ranges calculated from proton ranges (Tables IV, V, IX, and XI).

The range values are estimated to be uncertain by about 2%.

The ranges of He^3 for the different elements are plotted as functions of the energy (Figs. 1 to 17) and the different excitation potentials available. Curves (1) are computed with the older (smaller) values, curves (2) with the newer (higher). Some graphs show a third curve, computed from proton ranges (where available).

The possible reasons why our highest theoretical values for the ranges are still lower than the most recently published values[4] (essentially in the lower energy region) is that we neglected the shell correction factors. However, the mean ionization potentials used in this calculation are somewhat higher than those used in the most recent calculations; this tends to make our data higher. Further, our estimations in the lower region are done by addition of an integration constant which comes from the experiment, while Williamson et al.[4] did it by a refined smooth extrapolation to zero energy.

The ranges of He^3 in mixtures of elements and in chemical compounds can be calculated by use of Bragg's empirical formula by the addition of ranges (see reference 12):

$$\frac{1}{R_t} = \frac{w_1}{r_1} + \frac{w_2}{r_2} + \frac{w_3}{r_3} + \ldots \qquad (12)$$

Curves are established for quartz, teflon, CaF_2 and mylar using the larger range values. All these products are used in the activation analyses of oxygen either as calibrating standards or as material to measure the cross sections for some reactions involved. Their values are given in Table XX, and Figs. 18 and 19.

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* This work was done under the auspices of the U. S. Atomic Energy Commission.

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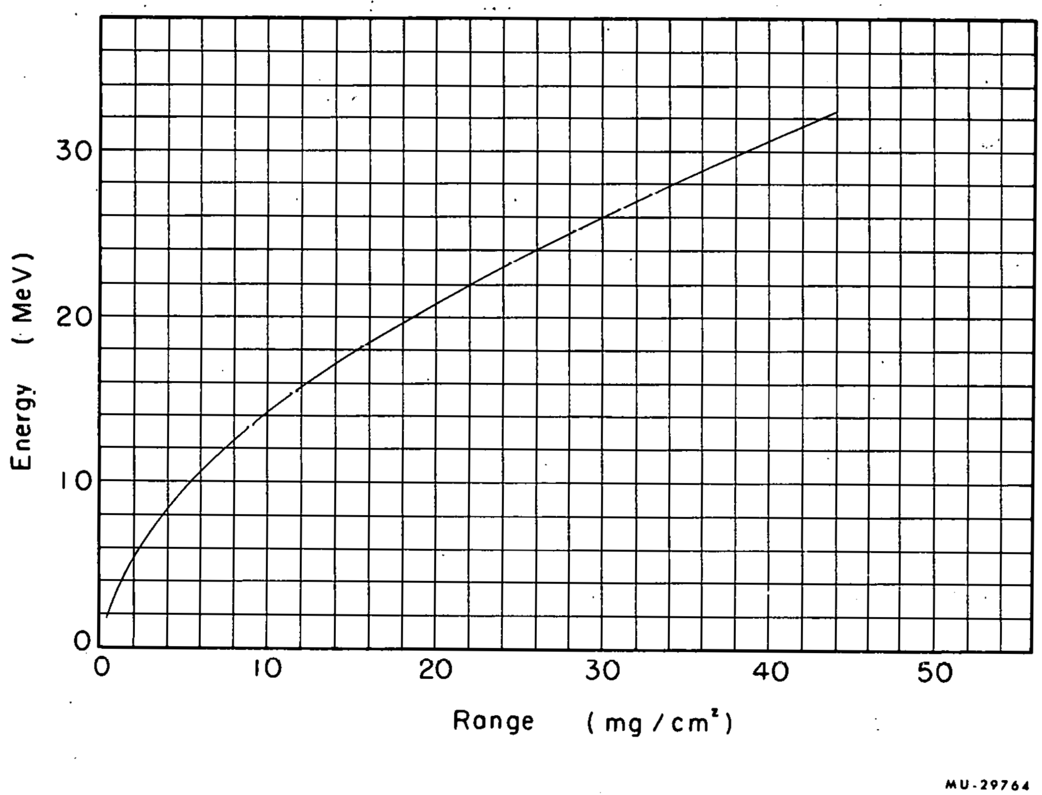


Fig. 1. Range-energy curve of H:
(1) I(Z) = 15.6 eV.

Table III. Range-energy relations of He^3 and energy losses calculated for $_1H$.

Element $_1H$	A(Z) = 0.1095.E 22	
	I(Z) = 15.6 eV	
Kinetic energy of He^3 (MeV)	- dE/dx ($MeV/mg\text{-}cm^{-2}$)	Range (mg/cm^2)
2.5	-	0.554
3	0.282.E 04	0.731
4	0.224	1.13
5	0.187	1.62
6	0.161	2.20
7	0.142	2.86
8	0.127	3.61
9	0.115	4.44
10	0.106	5.34
11	0.976.E 03	6.33
12	0.907	7.39
13	0.849	8.53
14	0.797	9.75
15	0.752	11.0
16	0.713	12.4
17	0.677	13.8
18	0.646	15.4
19	0.617	16.9
20	0.591	18.6
21	0.567	20.3
22	0.545	22.1
23	0.525	24.0
24	0.506	25.9
25	0.489	27.9
26	0.473	30.0
27	0.458	32.2
28	0.444	34.4
29	0.431	36.7
30	0.419	38.5
40	0.328	66.2
50	0.272	99.9
60	0.233	140
70	0.204	186
80	0.183	238
90	0.165	295
100	0.151	358

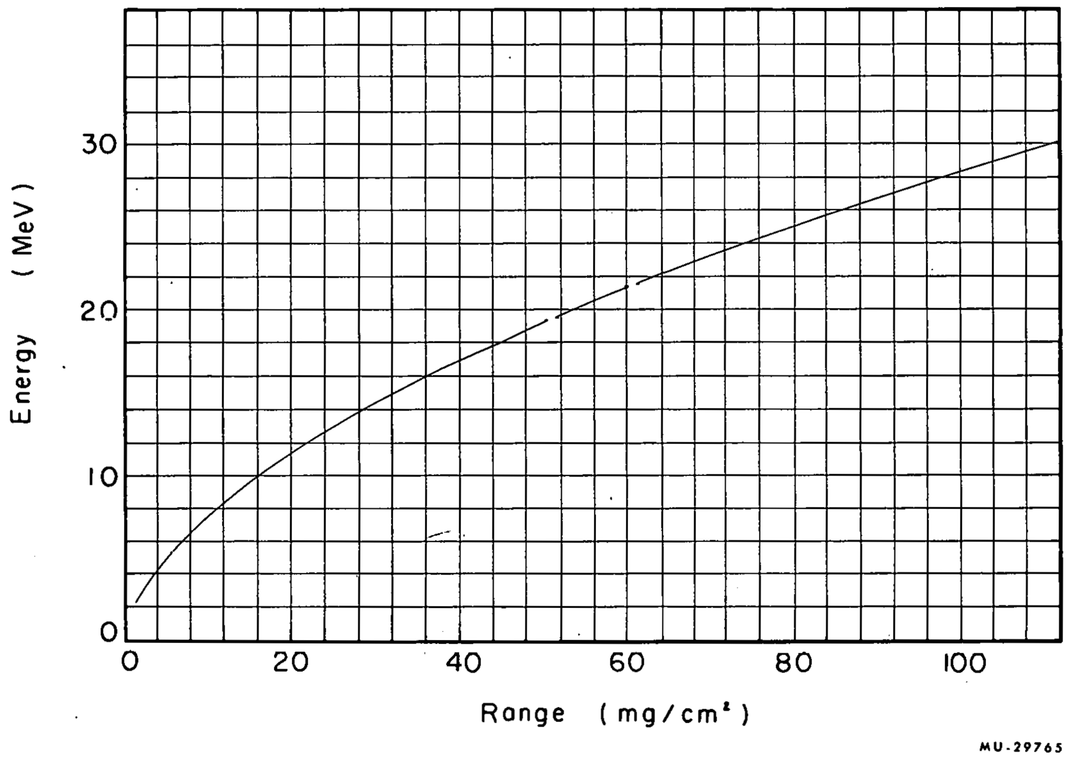


Fig. 2. Range-energy curves of Be:
(1) I(Z) = 60.4 eV
(2) I(Z) = 64.0 eV
(3) Calculated from proton ranges.

Differences are very small.

Table IV. Range-energy relations and energy losses of He^3 calculated for $_4Be$

Element $_4Be$			A(Z) = 0.4899.E 21		
Kinetic energy of He^3 (MeV)	I(Z) = 60.4 eV		I(Z) = 64.0 eV		Empirical calculated Range[a] (mg/cm^2)
	-dE/dx ($MeV/mg\text{-}cm^{-2}$)	Range (mg/cm^2)	-dE/dx ($MeV/mg\text{-}cm^{-2}$)	Range (mg/cm^2)	
2.5	-	1.52	-	1.52	
3	0.917.E 03	2.07	0.901.E 03	2.07	
4	0.743	3.28	0.732	3.31	
5	0.629	4.75	0.620	4.85	
6	0.548	6.46	0.540	6.53	6.83
7	0.486	8.41	0.480	8.50	
8	0.439	10.6	0.433	10.7	
9	0.400	13.0	0.395	13.1	13.5
10	0.368	15.6	0.364	15.8	
11	0.342	18.4	0.338	18.6	
12	0.319	21.4	0.315	21.7	22.2
13	0.299	24.6	0.296	24.8	
14	0.282	28.1	0.279	28.4	
15	0.267	31.4	0.264	32.1	32.7
16	0.254	35.6	0.251	36.0	
17	0.241	39.6	0.239	40.1	
18	0.231	43.9	0.228	44.4	45.0
19	0.221	48.7	0.218	48.9	
20	0.212	52.9	0.210	53.5	
21	0.204	57.7	0.201	58.4	59.2
22	0.196	62.7	0.194	63.5	
23	0.189	67.9	0.187	68.7	
24	0.183	73.3	0.181	74.1	74.9
25	0.177	78.9	0.175	79.8	
26	0.171	84.6	0.169	85.6	
27	0.166	90.6	0.164	91.6	92.4
28	0.161	96.7	0.159	97.8	
29	0.157	103	0.155	104	
30	0.152	109	0.151	111	111
40	0.120	184	0.119	186	
50	0.100	275	0.993.E 02	278	
60	0.863.E 02	383	0.855	386	
70	0.761	507	0.754	511	
80	0.682	646	0.676	652	
90	0.619	700	0.614	808	
100	0.568	969	0.564	978	

[a] See reference 5.

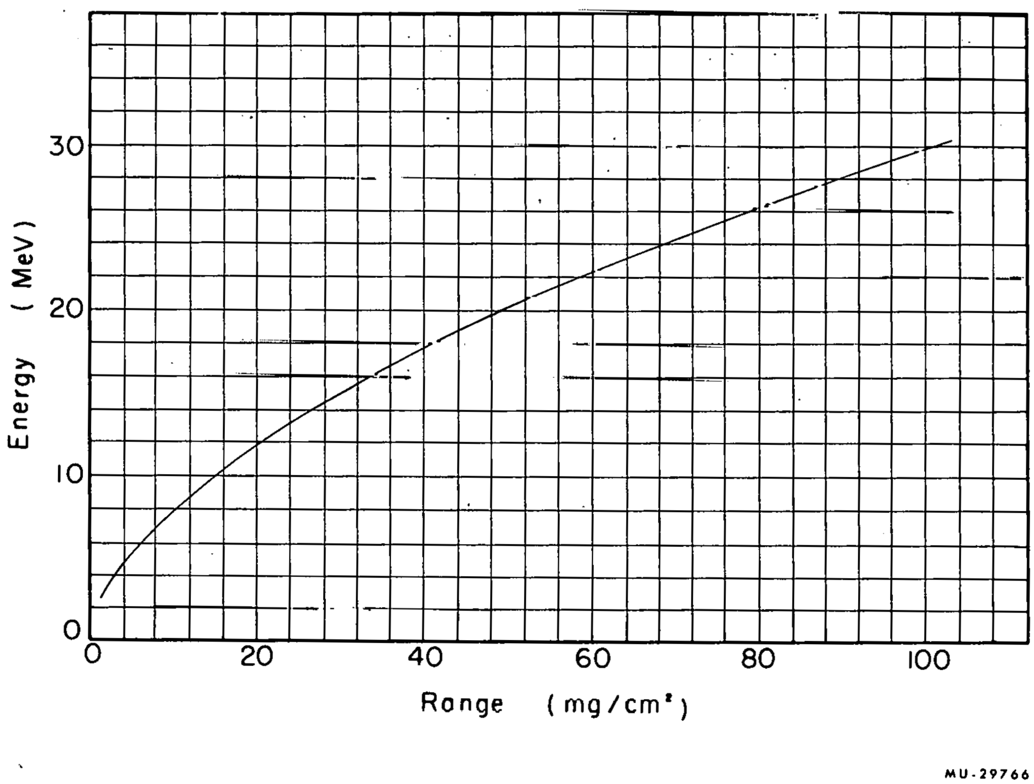


Fig. 3. Range-energy curve of C:
(1) I(Z) = 76.4 eV
(2) I(Z) = 78.0 eV
(3) Calculated from proton ranges

} Differeces are very small.

Table V. Range-energy relations and energy losses of He^3 calculated for $_6C$.

Element $_6C$		A(Z) = 0.5514.E 21			
Kinetic energy of He^3 (MeV)	I(Z) = 76.4 eV		I(Z) = 78.0 eV		Empirical calculated Range (mg/cm^2)
	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	
2.5	-	1.48	-	1.48	
3	0.964.E 03	2.00	0.958.E 03	2.00	
4	0.786	3.15	0.781	3.21	
5	0.667	4.54	0.664	4.55	
6	0.582	6.15	0.579	6.17	6.30
7	0.519	7.97	0.516	8.00	
8	0.468	10.0	0.466	10.0	
9	0.428	12.2	0.426	12.3	12.6
10	0.394	14.7	0.393	14.9	
11	0.366	17.3	0.364	17.4	
12	0.342	20.1	0.340	20.2	20.6
13	0.321	23.1	0.320	23.3	
14	0.303	26.4	0.302	26.5	
15	0.287	29.8	0.286	29.9	30.5
16	0.273	33.3	0.271	33.5	
17	0.260	37.1	0.259	37.3	
18	0.248	41.0	0.247	41.2	41.85
19	0.238	45.1	0.237	45.3	
20	0.228	49.4	0.227	49.7	
21	0.219	53.9	0.219	54.1	54.9
22	0.211	58.6	0.211	58.8	
23	0.204	63.3	0.203	63.6	
24	0.197	68.4	0.196	68.7	69.5
25	0.191	73.5	0.190	74.0	
26	0.185	78.8	0.184	79.2	
27	0.179	84.3	0.179	84.7	85.6
28	0.174	90.0	0.173	90.4	
29	0.169	95.8	0.169	96.2	
30	0.164	102	0.164	102	103.2
40	0.130	171	0.130	171	
50	0.109	255	0.108	256	
60	0.937.E 02	354	0.934.E 02	356	
70	0.826	468	0.823	470	
80	0.741	596	0.739	599	
90	0.673	738	0.671	740	
100	0.618	893	0.616	896	

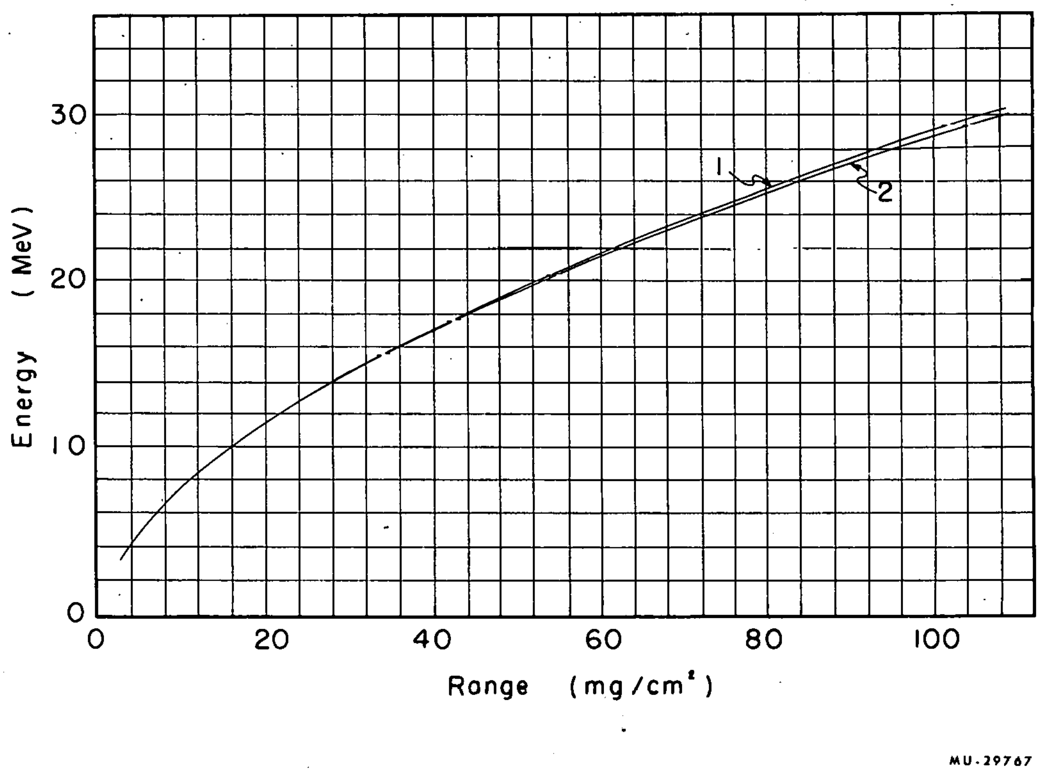


Fig. 4. Range-energy curve of N:
(1) I(Z) = 87.5 eV } Maximum difference is 2%
(2) I(Z) = 93.0 eV

Table VI. Range-energy relations and energy losses of He^3 calculated for $_7N$.

Element $_7N$			A(Z) = 0.5516.E 21	
	I(Z) = 87.5 eV		I(Z) = 93.0 eV	
Kinetic energy of He^3 (MeV)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	1.64	-	1.64
3	0.925.E 03	2.18	0.908.E 03	2.19
4	0.756	3.38	0.743	3.41
5	0.644	4.82	0.633	4.88
6	0.563	6.48	0.554	6.57
7	0.502	8.37	0.494	8.48
8	0.454	10.5	0.447	10.6
9	0.415	12.8	0.409	12.9
10	0.383	15.3	0.377	15.5
11	0.356	18.0	0.351	18.2
12	0.332	20.9	0.328	21.2
13	0.312	24.0	0.308	24.4
14	0.295	27.3	0.291	27.7
15	0.279	30.8	0.276	31.2
16	0.265	34.5	0.262	34.9
17	0.253	38.3	0.250	38.9
18	0.242	42.4	0.239	42.9
19	0.232	46.6	0.229	47.2
20	0.222	51.0	0.220	51.7
21	0.214	55.6	0.211	56.3
22	0.206	60.4	0.204	61.1
23	0.199	65.3	0.197	66.1
24	0.192	70.4	0.190	71.3
25	0.186	75.7	0.184	76.7
26	0.180	81.2	0.178	82.2
27	0.175	86.8	0.173	87.9
28	0.170	92.6	0.168	93.7
29	0.165	98.6	0.163	99.8
30	0.161	105	0.159	106
40	0.127	175	0.126	177
50	0.106	261	0.105	264
60	0.917.E 02	363	0.908.E 02	367
70	0.809	479	0.801	485
80	0.726	610	0.719	617
90	0.660	755	0.654	763
100	0.606	913	0.600	922

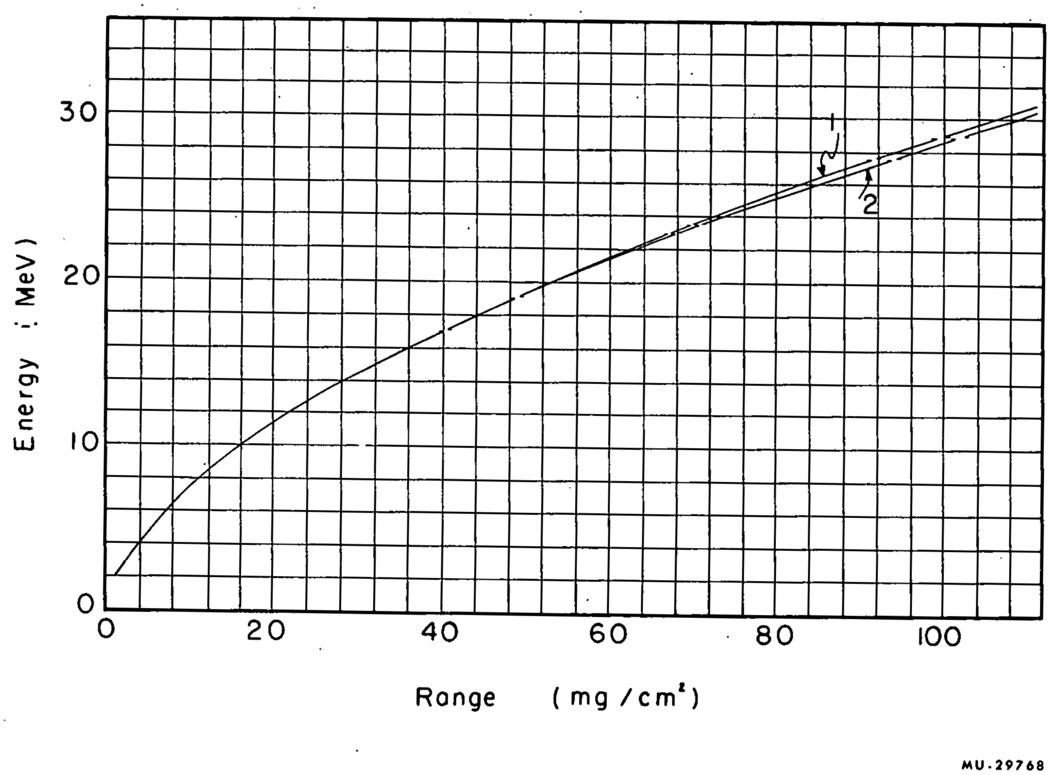


Fig. 5. Range-energy curve of O:
(1) I(Z) = 97.6 eV
(2) I(Z) = 105 eV
} Maximum difference is 2%.

Table VII. Range-energy relations and energy losses of He^3 calculated for $_8O$.

Element $_8O$			A(Z) = 0.5519.E 21	
Kinetic energy of He^3 (MeV)	I(Z) = 97.6 eV - dE/dx (MeV/mg-cm^{-2})	I(Z) = 97.6 eV Range (mg/cm^2)	I(Z) = 105 eV - dE/dx (MeV/mg-cm^{-2})	I(Z) = 105 eV Range (mg/cm^2)
2.5	-	1.72	-	1.72
3	0.894.E 03	2.28	0.873.E 03	2.29
4	0.733	3.52	0.717	3.56
5	0.625	5.00	0.613	5.07
6	0.548	6.71	0.537	6.82
7	0.489	8.65	0.480	8.79
8	0.442	10.8	0.434	11.0
9	0.405	13.2	0.398	13.4
10	0.373	15.7	0.367	16.0
11	0.347	18.5	0.341	18.8
12	0.325	21.5	0.319	21.9
13	0.305	24.7	0.300	25.0
14	0.288	28.0	0.284	28.5
15	0.273	31.6	0.269	32.2
16	0.260	35.4	0.256	36.0
17	0.247	39.3	0.244	40.0
18	0.237	43.5	0.233	44.2
19	0.227	47.8	0.223	48.6
20	0.218	52.3	0.214	53.1
21	0.209	57.0	0.206	57.9
22	0.202	61.8	0.199	62.8
23	0.195	66.9	0.192	67.9
24	0.188	72.1	0.186	73.2
25	0.182	77.5	0.180	78.7
26	0.177	83.0	0.174	84.4
27	0.171	88.8	0.169	90.2
28	0.167	94.7	0.164	96.2
29	0.162	101	0.160	102
30	0.158	107	0.155	109
40	0.125	179	0.123	181
50	0.104	267	0.103	270
60	0.901.E 02	370	0.890.E 02	375
70	0.795	489	0.786	495
80	0.714	621	0.706	629
90	0.649	769	0.642	778
100	0.597	929	0.590	941

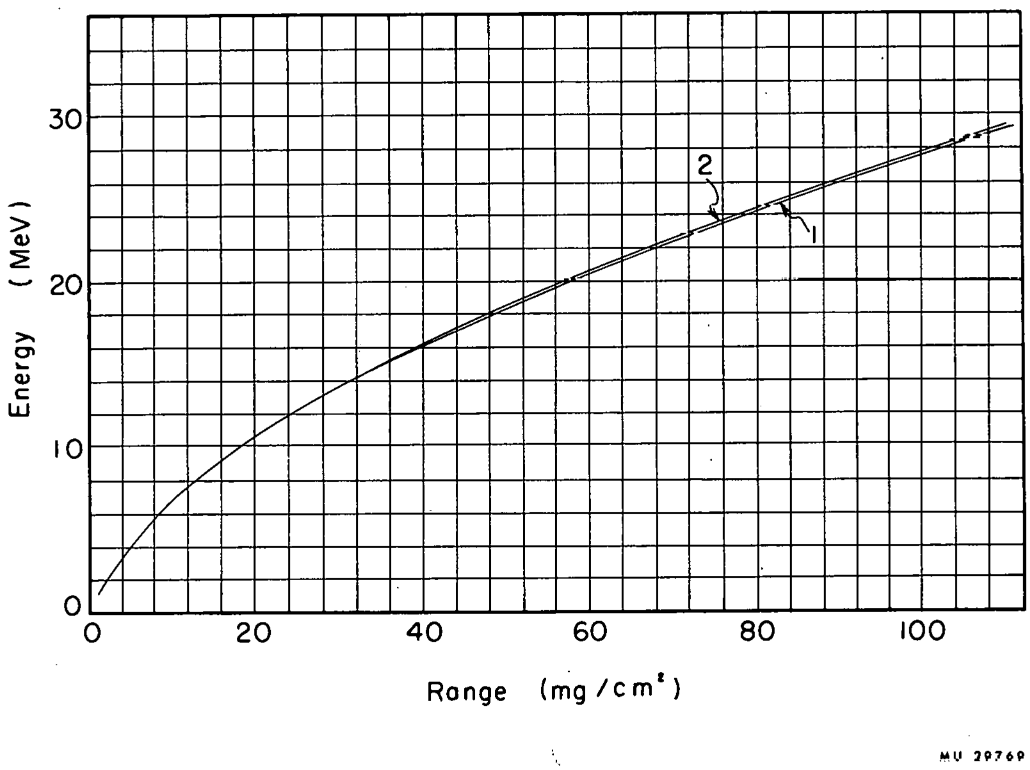


Fig. 6. Range-energy curve of F:
(1) I(Z) = 108 eV
(2) I(Z) = 115 eV
} Maximum difference is 3%.

Table VIII. Range-energy relations and energy losses of He^3 calculated for $_9F$.

Element $_9F$			A(Z) = 0.5229.E 21	
Kinetic energy of He^3 (MeV)	I(Z) = 108 eV		I(Z) = 115 eV	
	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	2.46	-	2.46
3	0.820.E 03	3.07	0.803.E 03	3.08
4	0.674	4.42	0.661	4.46
5	0.576	6.03	0.566	6.00
6	0.505	7.89	0.496	7.99
7	0.451	9.99	0.444	10.1
8	0.409	12.3	0.402	12.5
9	0.374	14.9	0.368	14.5
10	0.345	17.7	0.340	17.9
11	0.321	20.7	0.317	20.9
12	0.301	23.9	0.296	23.7
13	0.283	27.3	0.279	27.7
14	0.267	31.0	0.263	31.1
15	0.253	34.8	0.250	35.3
16	0.241	38.9	0.237	39.4
17	0.230	43.1	0.226	43.7
18	0.219	47.6	0.217	48.3
19	0.210	52.2	0.208	53.0
20	0.202	57.1	0.199	57.9
21	0.194	62.2	0.192	63.0
22	0.187	67.4	0.185	68.3
23	0.181	72.8	0.179	73.8
24	0.175	78.4	0.173	79.5
25	0.169	84.2	0.167	85.4
26	0.164	90.2	0.162	91.4
27	0.159	96.4	0.157	97.7
28	0.155	103	0.153	104
29	0.150	109	0.149	111
30	0.147	116	0.145	118
40	0.116	193	0.115	196
50	0.972.E 02	288	0.962.E 02	291
60	0.839	399	0.831	403
70	0.741	526	0.734	532
80	0.667	668	0.659	676
90	0.606	826	0.600	835
100	0.557	998	0.551	1009

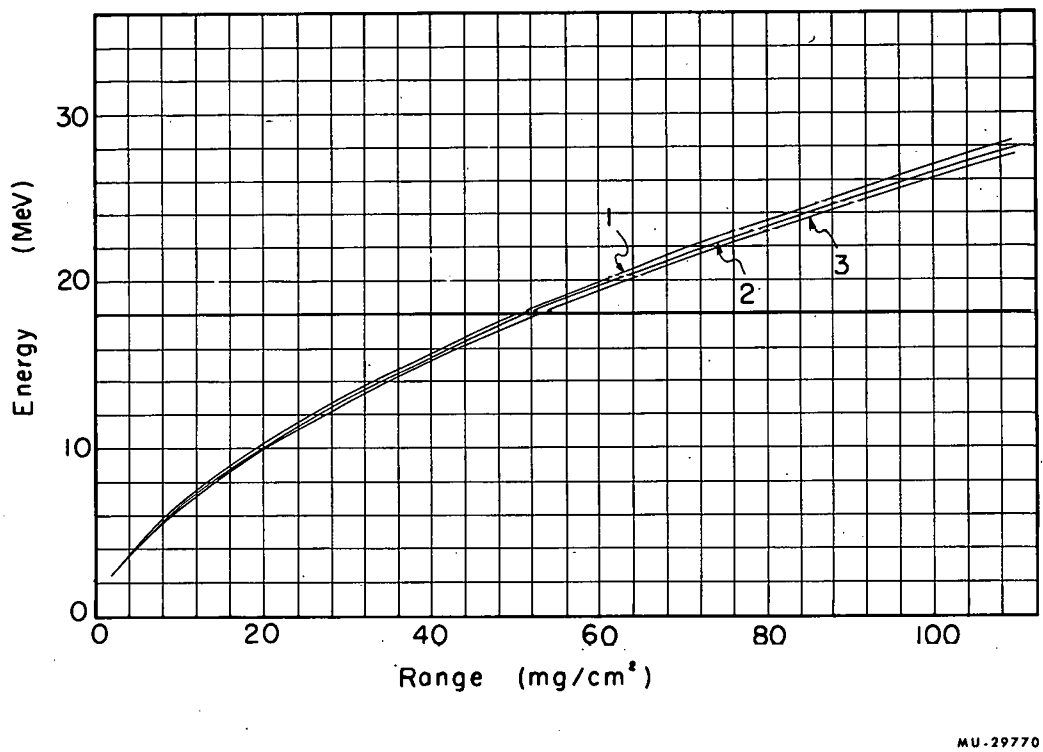


Fig. 7. Range-energy curves of Al:
(1) I(Z) = 150 eV,
(2) I(Z) = 166 eV,
(3) Calculated from proton ranges.

Table IX. Range-energy relations and energy losses of He^3 calculated for $_{13}Al$.

Element $_{13}Al$	A(Z) = 0.5319.E 21				
Kinetic energy of He^3 (MeV)	I(Z) = 150 eV		I(Z) = 166 eV		Empirical calculated Range (mg/cm^2)
	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	
2.5	-	1.94	-	1.94	
3	0.743.E 03	2.61	0.715.E 03	2.64	
4	0.617	4.09	0.596	4.18	
5	0.531	5.85	0.514	5.99	
6	0.468	7.86	0.454	8.06	8.63
7	0.420	10.1	0.408	10.4	
8	0.381	12.6	0.371	13.0	
9	0.350	15.4	0.341	15.8	16.6
10	0.324	18.3	0.315	18.6	
11	0.302	21.5	0.294	22.1	
12	0.283	25.0	0.276	25.6	26.6
13	0.266	28.6	0.260	29.4	
14	0.252	32.5	0.246	33.3	
15	0.239	36.5	0.233	37.5	38.8
16	0.228	40.8	0.222	41.9	
17	0.217	45.3	0.212	46.5	
18	0.208	50.0	0.203	51.3	52.8
19	0.199	54.9	0.195	56.3	
20	0.192	60.1	0.187	61.6	
21	0.185	65.4	0.181	67.0	68.8
22	0.178	70.9	0.174	72.7	
23	0.172	76.6	0.168	78.5	
24	0.166	82.5	0.162	84.5	86.6
25	0.161	88.6	0.158	90.8	
26	0.156	94.9	0.153	97.2	
27	0.152	101	0.149	104	106.7
28	0.148	108	0.144	111	
29	0.144	115	0.141	118	
30	0.140	122	0.137	125	127.5
40	0.111	203	0.109	207	
50	0.933.E 02	301	0.916.E 02	308	
60	0.807	417	0.792	425	
70	0.714	549	0.701	560	
80	0.642	697	0.631	710	
90	0.584	861	0.574	876	
100	0.537	1039	0.528	1059	

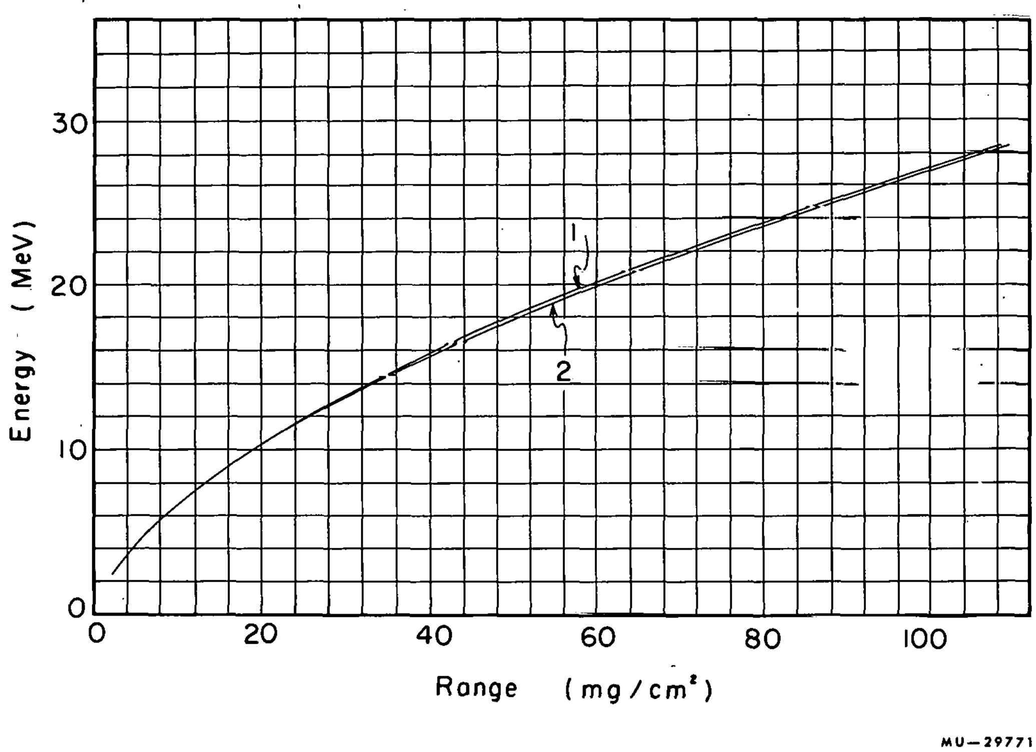


Fig. 8. Range-energy curves of Si:
(1) I(Z) = 157 eV
(2) I(Z) = 170 eV.

Table X. Range-energy relations and energy losses of He^3 calculated for $_{14}Si$.

Element $_{14}Si$			A(Z) = 0.5502.E 21	
Kinetic energy of He^3 (MeV)	I(Z) = 157 eV		I(Z) = 170 eV	
	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	1.96	-	1.96
3	0.755.E 03	2.62	0.732.E 03	2.69
4	0.629	4.08	0.611	4.15
5	0.541	5.80	0.528	5.91
6	0.478	7.77	0.466	7.93
7	0.429	9.98	0.419	10.1
8	0.390	12.4	0.381	12.7
9	0.358	15.1	0.350	15.4
10	0.331	18.0	0.324	18.4
11	0.309	21.1	0.302	21.6
12	0.289	24.5	0.284	25.0
13	0.272	28.1	0.267	28.7
14	0.258	31.8	0.253	32.5
15	0.245	35.8	0.240	36.6
16	0.233	40.0	0.229	40.8
17	0.222	44.4	0.218	45.3
18	0.213	49.0	0.209	50.0
19	0.204	53.8	0.201	55.4
20	0.196	58.8	0.193	60.0
21	0.189	64.0	0.186	65.2
22	0.182	69.4	0.179	70.7
23	0.176	74.6	0.173	76.4
24	0.171	80.7	0.168	82.3
25	0.165	86.7	0.162	87.8
26	0.160	92.8	0.158	94.6
27	0.155	99.1	0.153	101
28	0.151	106	0.149	107
29	0.147	112	0.145	114
30	0.143	119	0.141	122
40	0.114	198	0.112	201
50	0.957.E 02	294	0.943.E 02	299
60	0.828	407	0.816	413
70	0.732	536	0.711	544
80	0.659	680	0.648	690
90	0.600	839	0.587	852
100	0.552	1013	0.538	1028

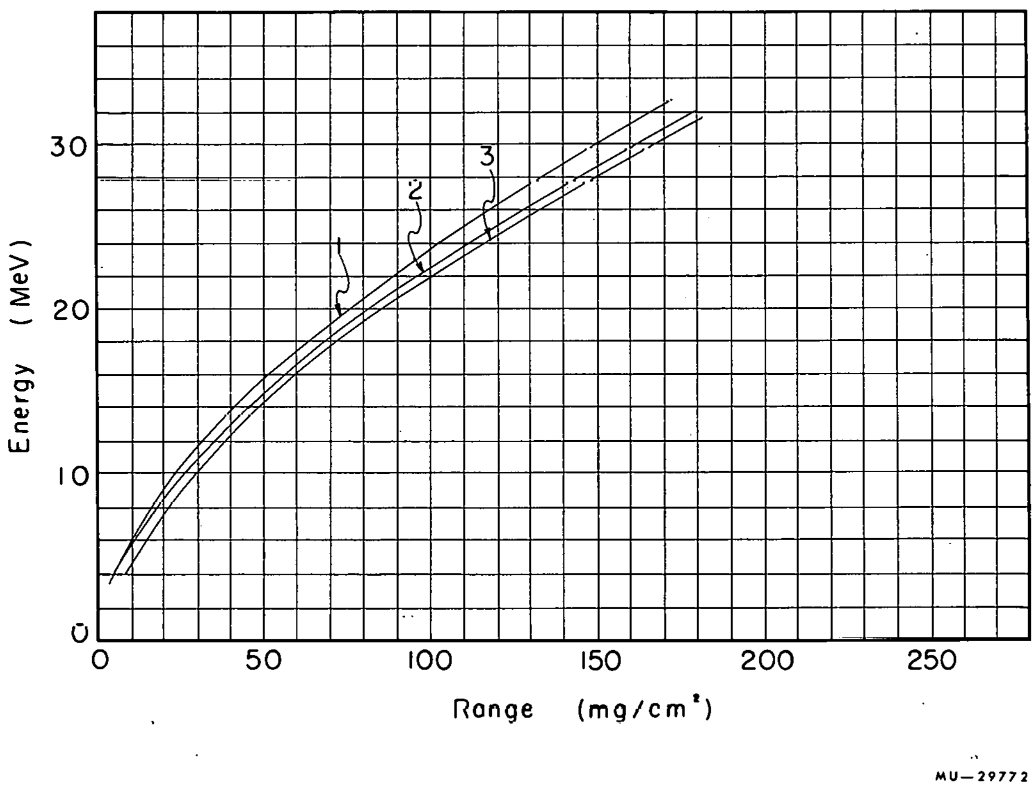


Fig. 9. Range-energy curves of Cu:
(1) I(Z) = 279 eV,
(2) I(Z) = 371 eV,
(3) calculated from proton ranges.

Table XI. Range-energy relations and energy losses of He^3 calculated for $_{29}Cu$.

Element $_{29}Cu$	A(Z) = 0.5037.E 21				
Kinetic energy of He^3 (MeV)	I(Z) = 279 eV - dE/dx (MeV/mg-cm^{-2})	I(Z) = 279 eV Range (mg/cm^2)	I(Z) = 371 eV - dE/dx (MeV/mg-cm^{-2})	I(Z) = 371 eV Range (mg/cm^2)	Empirical calculated Range (mg/cm^2)
2.5	-	2.64	-	2.64	
3	0.540.E 03	3.57	0.465.E 03	3.71	
4	0.462	5.57	0.406	6.02	
5	0.405	7.89	0.360	8.64	
6	0.362	10.5	0.324	11.6	14.3
7	0.327	13.4	0.295	14.8	
8	0.300	16.6	0.272	18.3	
9	0.277	20.1	0.252	22.2	25.1
10	0.258	23.9	0.235	26.3	
11	0.241	27.8	0.221	30.7	
12	0.227	32.1	0.208	35.3	38.5
13	0.214	36.7	0.197	40.3	
14	0.203	41.4	0.187	45.5	
15	0.194	46.5	0.178	51.0	54.3
16	0.185	51.8	0.171	56.8	
17	0.177	57.3	0.163	62.7	
18	0.170	63.1	0.157	68.9	72.5
19	0.163	69.1	0.151	75.4	
20	0.157	75.4	0.146	82.2	
21	0.151	81.8	0.141	89.2	93.0
22	0.146	88.6	0.136	96.4	
23	0.141	95.5	0.132	104	
24	0.137	103	0.128	112	116
25	0.133	110	0.124	120	
26	0.129	118	0.120	128	
27	0.125	126	0.117	136	141
28	0.122	134	0.114	145	
29	0.119	142	0.111	154	
30	0.116	151	0.108	163	168
40	0.930.E 02	248	0.872.E 02	266	
50	0.783	365	0.737	392	
60	0.680	503	0.642	537	
70	0.603	659	0.570	703	
80	0.544	834	0.515	888	
90	0.496	1027	0.470	1092	
100	0.457	1237	0.434	1313	

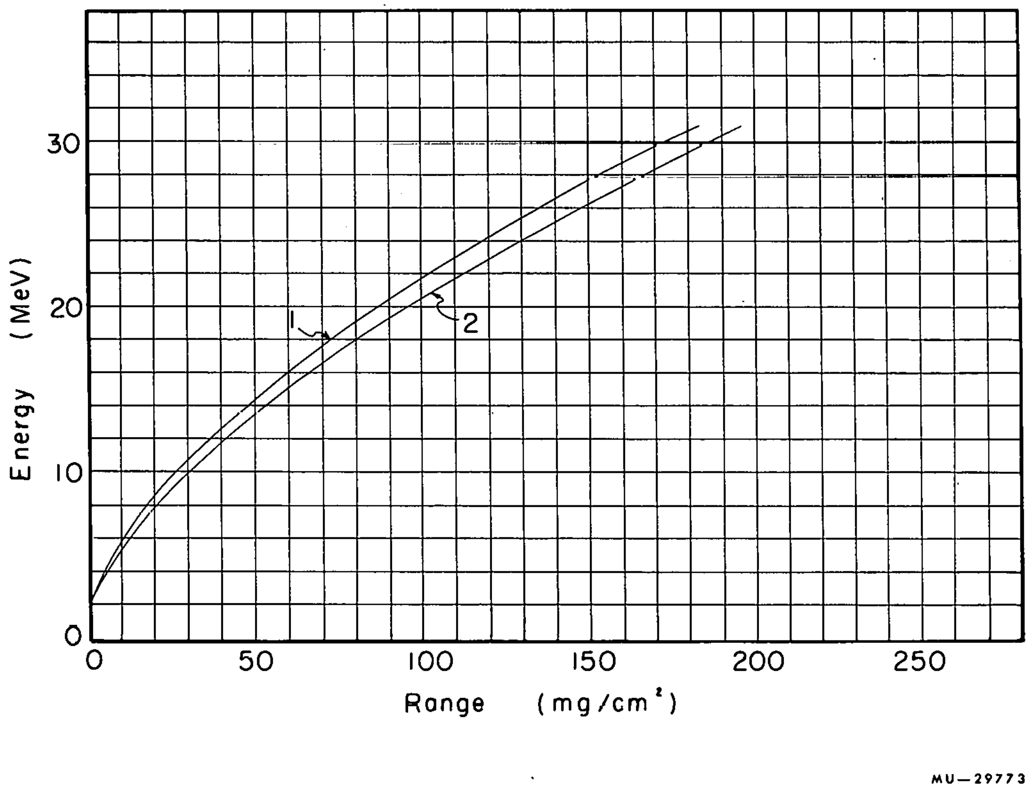


Fig. 10. Range-energy curves of Mo:
(1) I(Z) = 391 eV,
(2) I(Z) = 520 eV.

Table XII. Range-energy relations and energy losses of He^3 calculated for $_{42}Mo$.

Element $_{42}Mo$			A(Z) = 0.4832.E 21	
Kinetic energy of He^3 (MeV)	I(Z) = 391 eV - dE/dx (MeV/mg/cm^{-2})	Range (mg/cm^2)	I(Z) = 520 eV - dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	1.36	-	1.36
3	0.433.E 03	2.52	0.361.E 03	2.74
4	0.379	4.99	0.325	6.66
5	0.337	7.79	0.294	8.90
6	0.304	10.9	0.268	12.5
7	0.278	14.4	0.247	16.4
8	0.255	18.1	0.229	20.5
9	0.237	22.2	0.213	25.1
10	0.222	26.6	0.200	30.0
11	0.208	31.2	0.188	35.1
12	0.196	36.2	0.178	40.6
13	0.186	41.4	0.169	46.3
14	0.177	46.9	0.161	52.4
15	0.169	52.7	0.154	58.7
16	0.161	58.8	0.148	65.4
17	0.154	65.1	0.142	71.8
18	0.148	71.7	0.136	79.5
19	0.143	78.6	0.131	87.0
20	0.138	85.7	0.127	94.7
21	0.133	93.1	0.123	103
22	0.129	101	0.119	111
23	0.124	109	0.115	120
24	0.121	117	0.112	128
25	0.117	125	0.108	138
26	0.114	134	0.105	147
27	0.111	143	0.103	156
28	0.108	152	0.100	166
29	0.105	161	0.975.E 02	176
30	0.102	171	0.952	187
40	0.827.E 02	280	0.772	304
50	0.699	413	0.655	445
60	0.609	566	0.571	609
70	0.541	741	0.509	795
80	0.489	936	0.460	1002
90	0.446	1150	0.421	1229
100	0.412	1383	0.389	1476

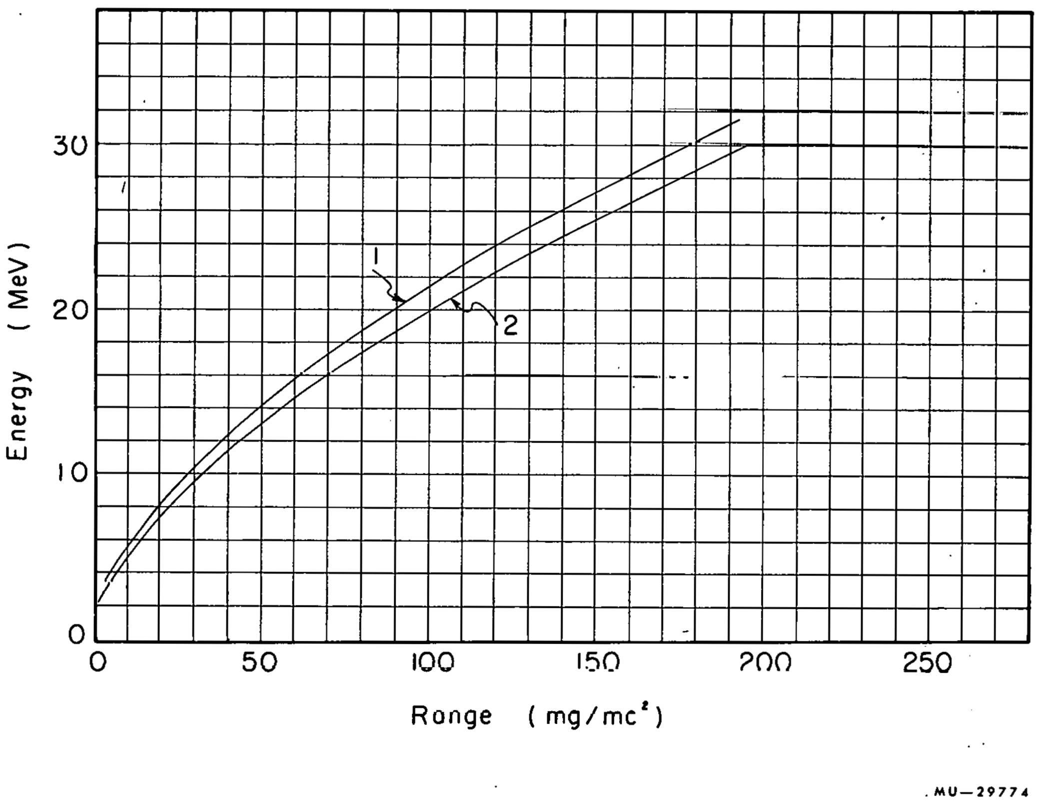


Fig. 11. Range energy curves of Ag:
(1) I(Z) = 428 eV,
(2) I(Z) = 586 eV.

Table XIII. Range-energy relations and energy losses of He^3 calculated for $_{47}Ag$.

Element $_{47}Ag$			A(Z) = 0.4809.E 21	
Kinetic energy of He^3 (MeV)	I(Z) = 428 eV - dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	I(Z) = - dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	1.36	-	1.36
3	0.408.E 03	2.58	0.330.E 03	2.87
4	0.361	5.20	0.301	6.05
5	0.322	8.13	0.275	9.53
6	0.291	11.4	0.252	13.3
7	0.266	15.0	0.233	17.5
8	0.246	18.9	0.216	21.9
9	0.228	23.1	0.202	26.7
10	0.214	27.7	0.190	31.8
11	0.201	32.5	0.179	37.2
12	0.190	37.6	0.170	43.0
13	0.180	43.0	0.162	49.0
14	0.171	43.7	0.154	55.4
15	0.163	54.7	0.147	62.0
16	0.156	61.0	0.141	68.9
17	0.150	67.5	0.136	76.2
18	0.144	74.4	0.131	83.8
19	0.138	81.4	0.126	91.5
20	0.134	88.8	0.122	100
21	0.129	96.4	0.118	108
22	0.125	104	0.114	117
23	0.121	112	0.110	125
24	0.117	121	0.107	135
25	0.114	129	0.104	144
26	0.111	138	0.102	154
27	0.108	148	0.988.E 02	164
28	0.105	157	0.963	175
29	0.102	167	0.939	185
30	0.997.E 02	177	0.917	195
40	0.806	289	0.746	317
50	0.682	424	0.633	463
60	0.594	582	0.553	633
70	0.528	761	0.493	824
80	0.477	960	0.447	1038
90	0.436	1179	0.409	1272
100	0.403	1418	0.378	1527

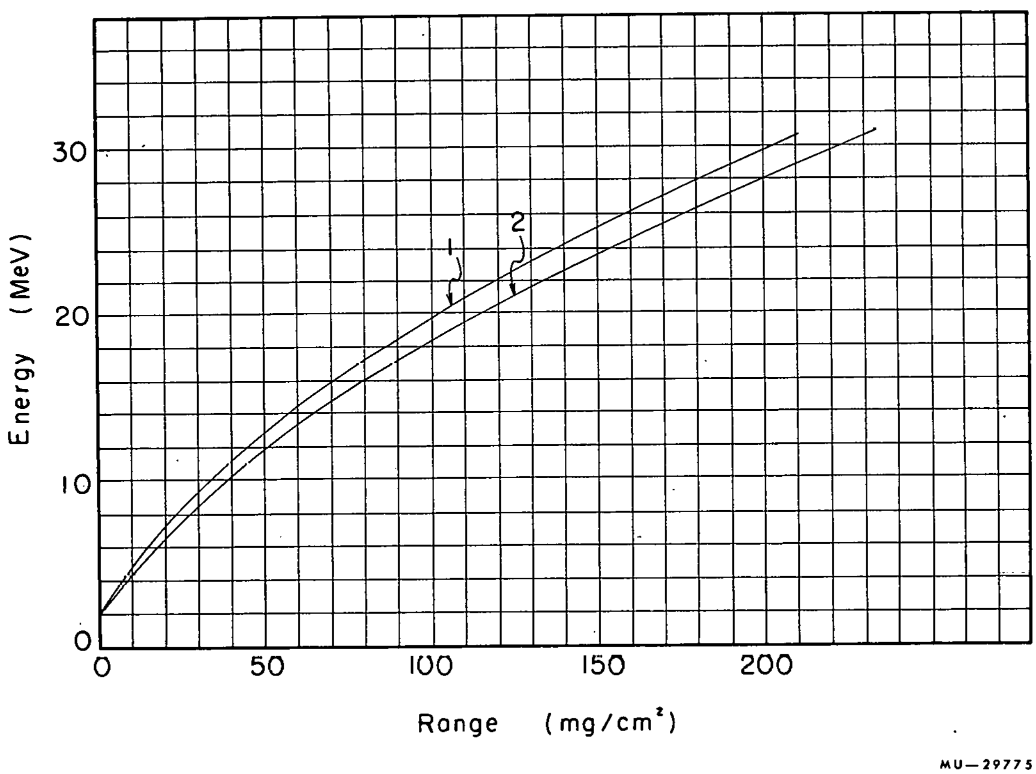


Fig. 12. Range-energy curves of La:
(1) I(Z) = 530 eV,
(2) I(Z) = 705 eV.

Table XIV. Range-energy relations and energy losses of He^3 calculated for $_{57}La$.

Element $_{57}La$			A(Z) = 0.4529.E 21	
Kinetic energy of He^3 (MeV)	I(Z) = 530 eV $-dE/dx$ (MeV/mg-cm^{-2})	I(Z) = 530 eV Range (mg/cm^2)	I(Z) = 705 eV $-dE/dx$ (MeV/mg-cm^{-2})	I(Z) = 705 eV Range (mg/cm^2)
2.5	-	2.63	-	2.63
3	0.334.E 03	4.13	0.267.E 03	4.50
4	0.302	7.28	0.251	8.37
5	0.273	10.8	0.233	12.5
6	0.249	14.6	0.215	17.0
7	0.229	18.8	0.200	21.8
8	0.213	23.3	0.187	27.0
9	0.193	28.2	0.176	32.8
10	0.186	33.4	0.166	38.3
11	0.175	38.9	0.157	44.5
12	0.165	44.8	0.149	51.1
13	0.158	51.0	0.142	58.0
14	0.150	57.5	0.136	65.2
15	0.144	64.3	0.130	72.7
16	0.137	71.4	0.125	80.6
17	0.132	78.9	0.120	88.2
18	0.127	86.6	0.116	97.2
19	0.122	94.6	0.112	106
20	0.118	103	0.108	115
21	0.114	112	0.104	125
22	0.110	120	0.101	134
23	0.107	130	0.983.E 02	144
24	0.104	139	0.955	155
25	0.101	149	0.929	165
26	0.983.E 02	159	0.904	176
27	0.957	169	0.881	187
28	0.933	180	0.859	199
29	0.909	191	0.839	210
30	0.888	202	0.819	223
40	0.720	328	0.668	354
50	0.611	479	0.570	521
60	0.533	655	0.499	709
70	0.475	854	0.445	922
80	0.430	1075	0.404	1158
90	0.393	1319	0.370	1417
100	0.363	1583	0.342	1699

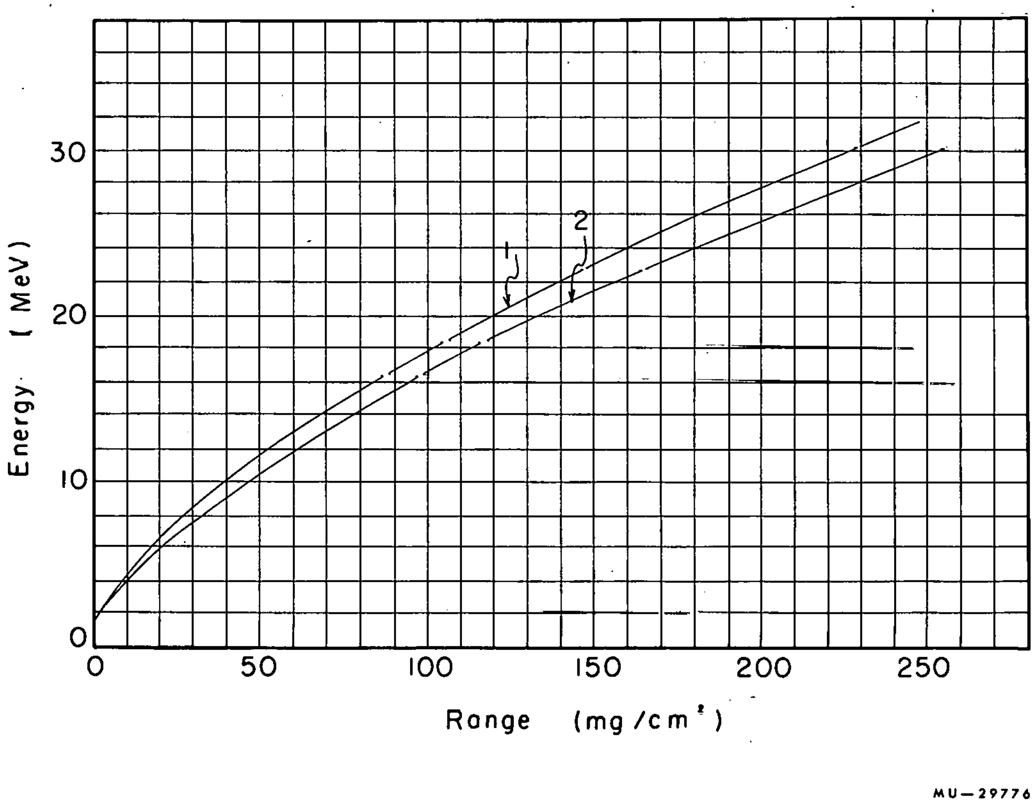


Fig. 13. Range-energy curves of W:
(1) I(Z) = 697 eV,
(2) I(Z) = 935 eV.

Table XV. Range-energy relations and energy losses for He^3 calculated for $_{74}W$.

Element $_{74}W$			A(Z) = 0.4443.E 21	
	I(Z) = 697 eV		I(Z) = 935 eV	
Kinetic energy for He^3 (MeV)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	3.94	-	3.94
3	0.264.E 03	5.83	0.196.E 03	6.49
4	0.248	9.73	0.197	11.6
5	0.230	13.9	0.189	16.8
6	0.213	18.5	0.178	22.2
7	0.198	23.3	0.168	28.9
8	0.185	28.6	0.159	34.1
9	0.173	34.2	0.150	40.6
10	0.163	40.1	0.143	47.4
11	0.155	46.4	0.136	54.6
12	0.147	53.0	0.130	62.1
13	0.140	60.0	0.124	70.0
14	0.134	67.4	0.119	78.2
15	0.128	75.0	0.114	86.8
16	0.123	83.0	0.110	95.7
17	0.118	91.3	0.106	105
18	0.114	100	0.102	115
19	0.110	109	0.991.E 02	125
20	0.106	118	0.959	135
21	0.103	123	0.930	145
22	0.997.E 02	138	0.903	155
23	0.968	148	0.878	167
24	0.940	158	0.854	179
25	0.914	169	0.831	191
26	0.890	180	0.811	203
27	0.867	191	0.791	216
28	0.846	203	0.772	228
29	0.825	215	0.754	241
30	0.806	227	0.737	255
40	0.658	366	0.606	405
50	0.560	531	0.518	584
60	0.491	722	0.455	791
70	0.438	938	0.408	1023
80	0.397	1179	0.370	1281
90	0.364	1442	0.340	1563
100	0.336	1728	0.315	1869

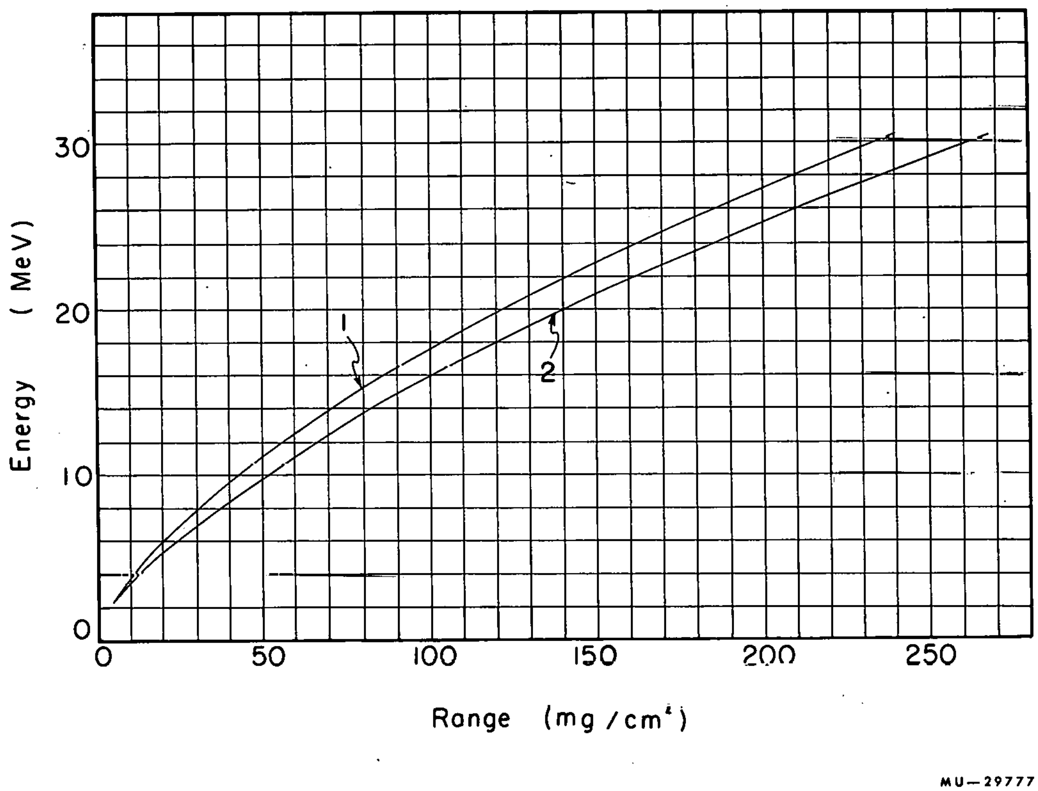


Fig. 14. Range-energy curves of Pt:
(1) I(Z) = 725 eV,
(2) I(Z) = 1020 eV.

Table XVI. Range-energy relations and energy losses for He^3 calculated for $_{78}Pt$.

Element $_{78}Pt$			A(Z) = 0.4413.E 21	
Kinetic energy of He^3 (MeV)	I(Z) = 725 eV		I(Z) = 1020 eV	
	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	4.65	-	4.65
3	0.253.E 03	6.63	0.185	7.51
4	0.240	10.7	0.181	13.1
5	0.223	15.0	0.175	18.8
6	0.207	19.7	0.167	24.6
7	0.192	24.7	0.159	30.7
8	0.180	30.0	0.150	37.2
9	0.169	35.8	0.143	44.0
10	0.160	41.9	0.136	51.2
11	0.151	48.3	0.130	58.8
12	0.144	55.2	0.124	66.7
13	0.137	62.3	0.119	74.9
14	0.131	69.8	0.114	83.5
15	0.125	77.6	0.109	92.5
16	0.120	85.7	0.105	102
17	0.116	94.2	0.102	111
18	0.112	103	0.984.E 02	121
19	0.108	112	0.952	132
20	0.104	122	0.923	142
21	0.101	131	0.895	153
22	0.978.E 02	141	0.870	165
23	0.949	152	0.846	177
24	0.922	162	0.823	188
25	0.897	173	0.801	201
26	0.874	185	0.782	213
27	0.851	196	0.763	226
28	0.830	208	0.745	240
29	0.810	220	0.728	253
30	0.792	233	0.712	267
40	0.647	374	0.587	423
50	0.551	542	0.503	608
60	0.483	736	0.442	820
70	0.431	956	0.396	1060
80	0.391	1200	0.360	1325
90	0.358	1467	0.331	1615
100	0.331	1758	0.306	1930

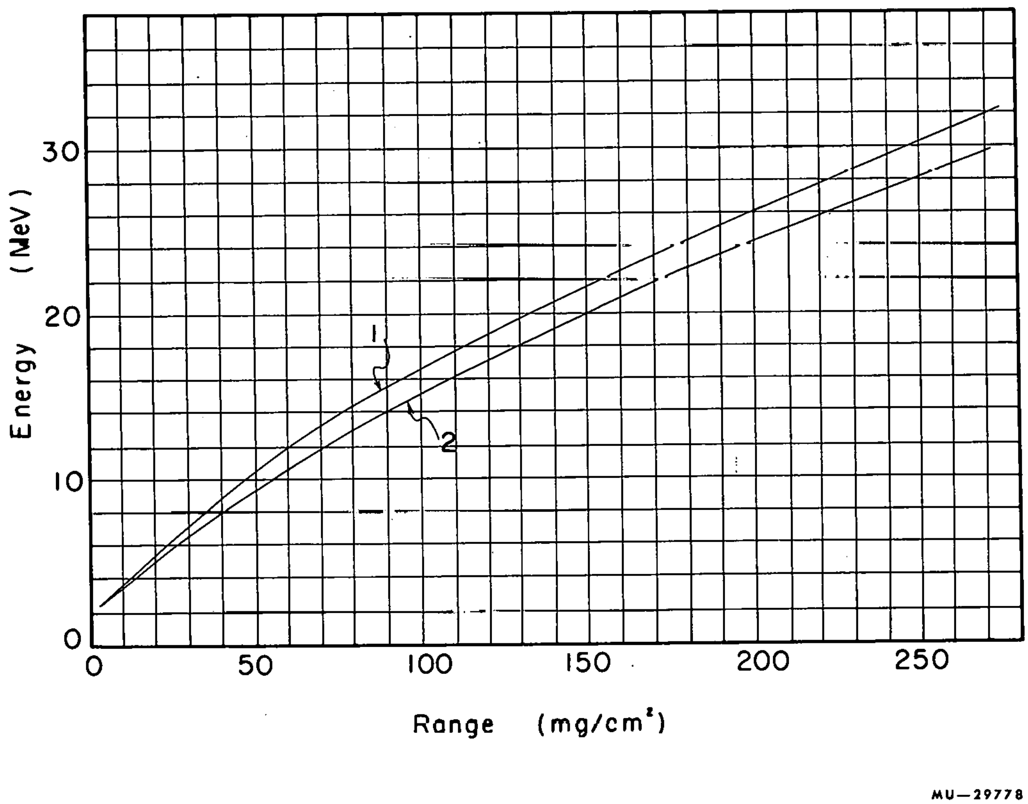


Fig. 15. Range-energy curves of Th:
(1) I(Z) = 837 eV,
(2) I(Z) = 1070 eV.

Table XVII. Range-energy relations and energy losses of He^3 calculated for $_{90}Th$.

Element $_{90}Th$			A(Z) = 0.4281.E 21	
	I(Z) = 837 eV		I(Z) = 1070 eV	
Kinetic energy of He^3 (MeV)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	4.65	-	4.65
3	0.214.E 03	6.99	0.159.E 03	7.80
4	0.209	11.7	0.167	13.9
5	0.197	16.7	0.164	20.0
6	0.184	21.9	0.157	26.2
7	0.173	27.5	0.149	32.8
8	0.163	33.5	0.142	39.6
9	0.153	39.8	0.135	46.9
10	0.145	46.5	0.129	54.4
11	0.138	53.6	0.123	62.4
12	0.131	61.0	0.117	70.7
13	0.125	68.9	0.113	79.4
14	0.120	77.0	0.108	88.6
15	0.115	85.5	0.104	97.9
16	0.111	94.4	0.100	108
17	0.107	104	0.968.E 02	118
18	0.103	113	0.936	128
19	0.994.E 02	123	0.907	139
20	0.962	133	0.879	150
21	0.932	144	0.853	162
22	0.904	155	0.829	174
23	0.879	166	0.806	186
24	0.854	177	0.785	199
25	0.831	189	0.765	212
26	0.810	201	0.746	225
27	0.790	214	0.728	238
28	0.770	227	0.711	252
29	0.753	240	0.695	266
30	0.735	253	0.680	281
40	0.603	405	0.561	444
50	0.515	585	0.481	637
60	0.452	793	0.423	859
70	0.404	1027	0.380	1109
80	0.365	1287	0.345	1386
90	0.336	1573	0.317	1689
100	0.311	1882	0.294	2016

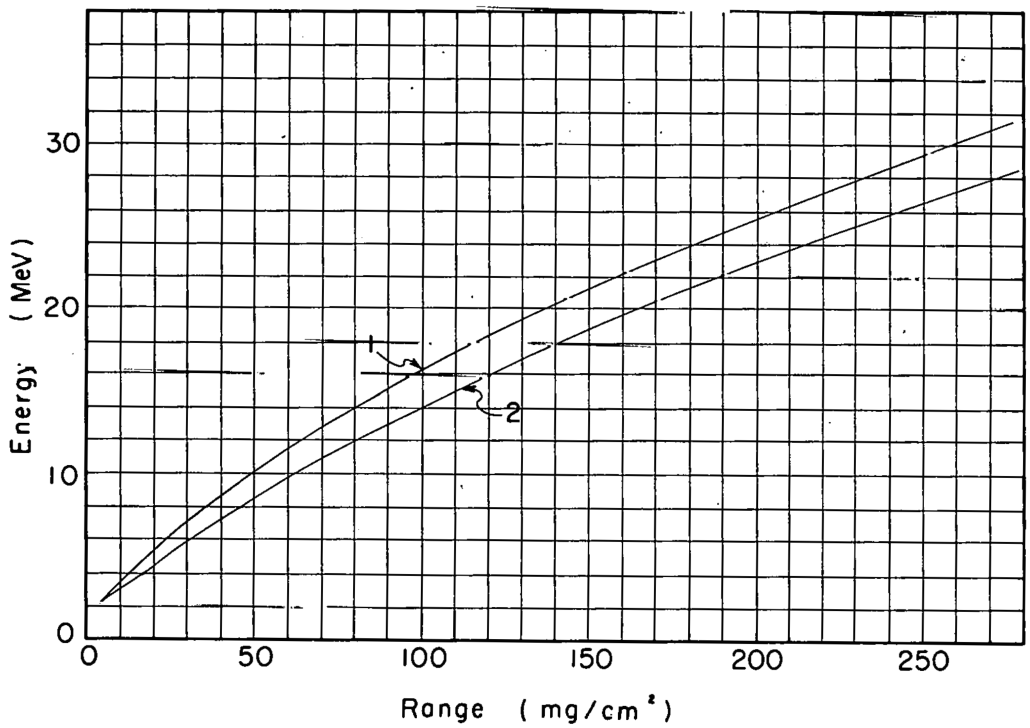


Fig. 16. Range-energy curves of U:
(1) I(Z) = 881 eV,
(2) I(Z) = 1250 eV.

Table XVIII. Range-energy relations and energy losses of He^3 calculated for $_{92}U$

Element $_{92}U$			A(Z) = 0.4266.E 21	
Kinetic energy for He^3 (MeV)	I(Z) = 881 eV		I(Z) = 1250 eV	
	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)	- dE/dx (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	4.65	-	4.65
3	0.202.E 03	7.13	0.124.E 03	8.69
4	0.199	12.1	0.141	16.3
5	0.189	17.3	0.142	23.4
6	0.178	22.7	0.139	30.5
7	0.167	28.5	0.134	37.8
8	0.158	34.7	0.128	45.4
9	0.149	41.2	0.123	53.4
10	0.141	48.1	0.118	61.7
11	0.134	55.4	0.113	70.4
12	0.128	63.0	0.108	79.4
13	0.122	71.0	0.104	88.8
14	0.117	79.4	0.100	98.6
15	0.112	88.1	0.976.E 02	109
16	0.108	97.2	0.934	119
17	0.104	107	0.903	130
18	0.100	116	0.875	141
19	0.972.E 02	127	0.848	153
20	0.941	137	0.823	165
21	0.912	148	0.800	177
22	0.885	159	0.778	190
23	0.860	170	0.758	203
24	0.837	182	0.738	216
25	0.814	194	0.720	230
26	0.794	207	0.703	244
27	0.774	219	0.686	259
28	0.755	232	0.671	273
29	0.738	246	0.656	288
30	0.721	260	0.642	304
40	0.592	414	0.532	476
50	0.506	597	0.458	679
60	0.444	808	0.404	912
70	0.397	1047	0.363	1174
80	0.361	1311	0.330	1463
90	0.331	1601	0.304	1779
100	0.307	1915	0.282	2121

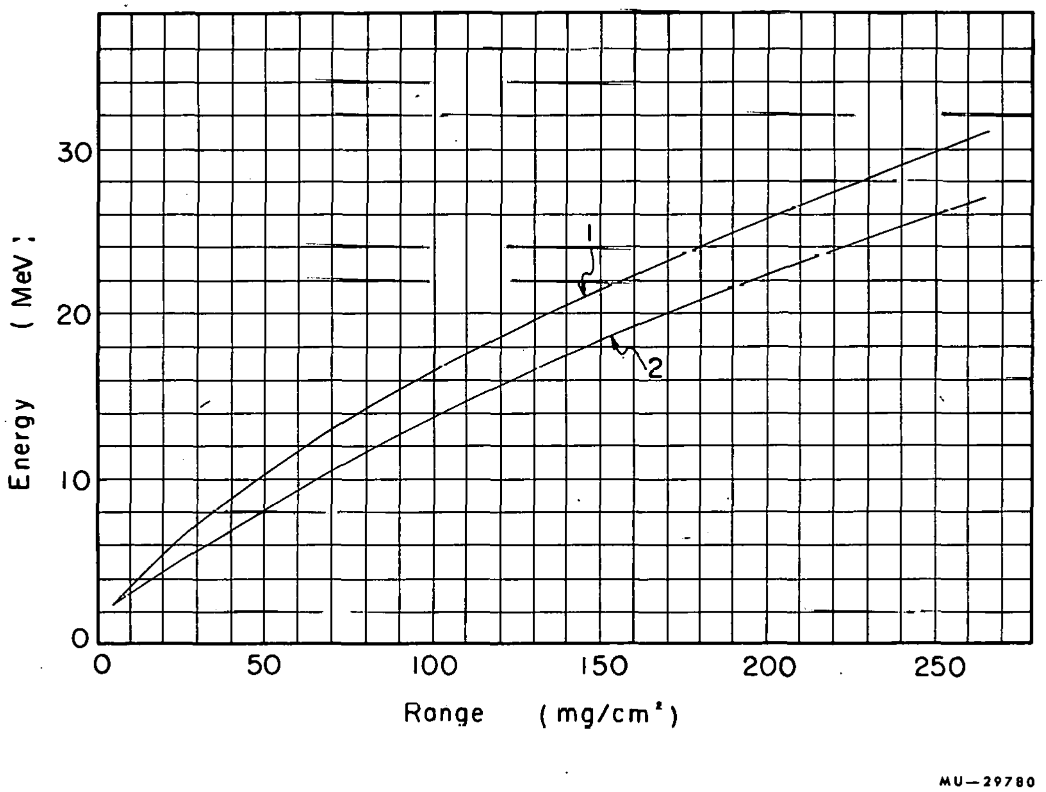
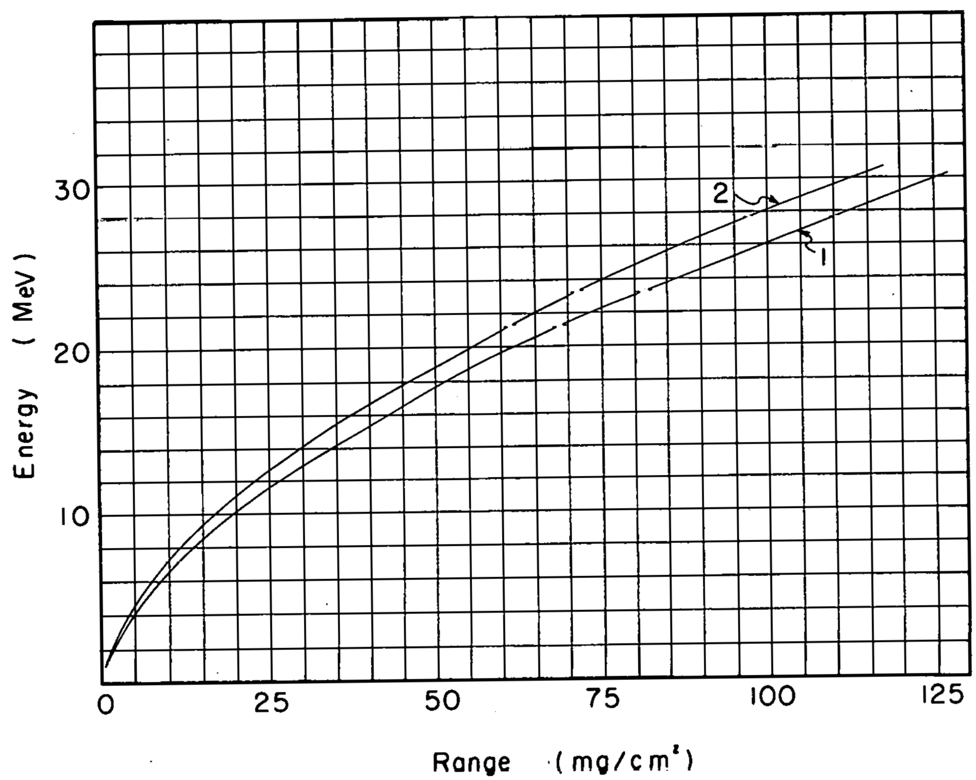


Fig. 17. Range-energy curves of Am:
(1) I(Z) = 893 eV,
(2) I(Z) = 1350 eV.

Table XIX. Range-energy relations and energy losses for He^3 calculated for $_{95}Am$.

Element $_{95}Am$			A(Z) = 0.4351.E 21	
Kinetic energy for He^3 (MeV)	I(Z) = 893 eV		I(Z) = 1350 eV	
	$-dE/dx$ (MeV/mg-cm^{-2})	Range (mg/cm^2)	$-dE/dx$ (MeV/mg-cm^{-2})	Range (mg/cm^2)
2.5	-	4.65	-	4.65
3	0.203.E 03	7.12	0.109.E 03	9.25
4	0.201	12.1	0.130	17.7
5	0.191	17.2	0.135	25.2
6	0.180	22.6	0.133	33.2
7	0.169	28.3	0.129	40.3
8	0.160	34.4	0.124	48.2
9	0.151	40.8	0.120	56.5
10	0.143	47.6	0.115	64.9
11	0.136	54.8	0.110	73.8
12	0.130	62.3	0.106	83.1
13	0.124	70.2	0.102	93.2
14	0.119	78.5	0.985.E 02	103
15	0.114	87.1	0.951	113
16	0.110	96.0	0.920	124
17	0.106	105	0.891	135
18	0.102	115	0.863	146
19	0.987.E 02	125	0.837	158
20	0.956	135	0.813	170
21	0.926	146	0.791	182
22	0.899	157	0.770	195
23	0.874	168	0.750	208
24	0.850	180	0.731	222
25	0.827	192	0.713	236
26	0.806	204	0.696	250
27	0.786	216	0.681	265
28	0.767	229	0.665	279
29	0.749	242	0.651	295
30	0.733	256	0.637	310
40	0.601	408	0.530	483
50	0.514	588	0.456	688
60	0.451	796	0.403	921
70	0.404	1031	0.362	1183
80	0.367	1291	0.330	1473
90	0.337	1576	0.304	1789
100	0.312	1885	0.282	2130



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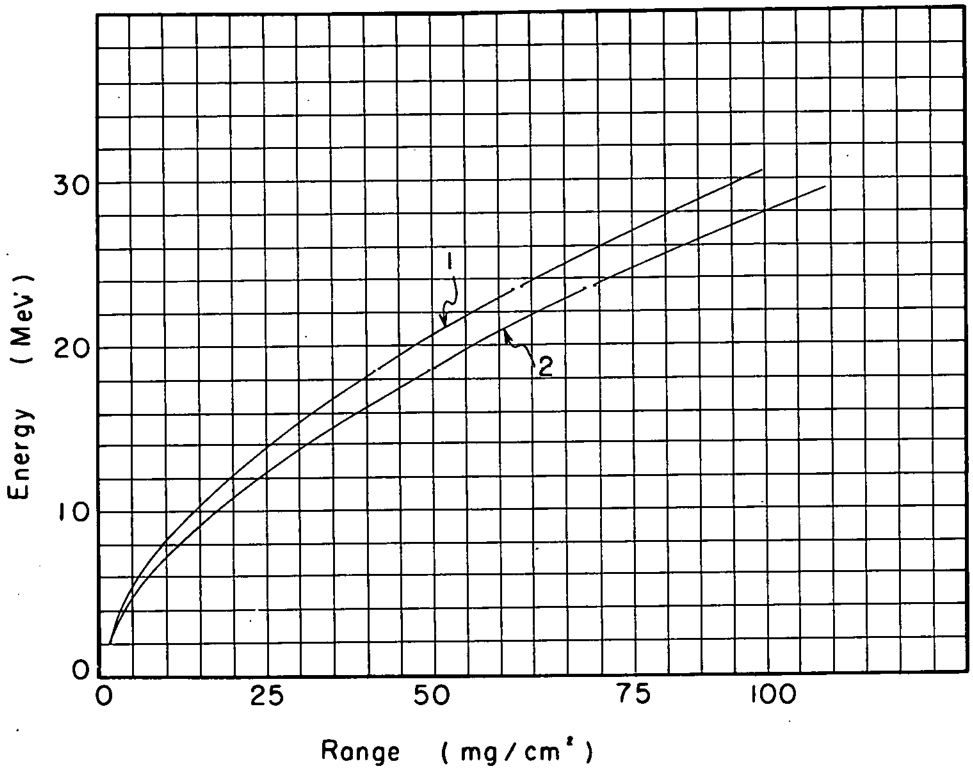

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Fig. 19. Range-energy curves of (3) S_1O_2 and (4) Mylar.

Table XX. Range-energy values of different compounds.

Kinetic energy of He^3 (MeV)	Range in CaF_2	Range in Teflon	Range in Quartz	Range in Mylar
2.5	2.48	2.12	1.82	1.45
3	3.14	2.72	2.46	1.94
4	4.70	4.05	3.81	3.07
5	6.49	5.59	5.43	4.37
6	8.55	7.42	7.30	5.91
7	10.98	9.43	9.55	7.65
8	13.6	11.6	11.7	9.58
9	16.5	14.2	14.3	11.75
10	19.7	16.9	17.0	14.17
11	23.1	20.8	20.0	16.6
12	26.7	22.9	23.2	19.3
13	30.4	26.2	26.6	22.2
14	34.5	29.8	30.2	25.3
15	38.6	33.4	34.1	28.5
16	43.0	37.4	38.1	32.0
17	47.6	41.5	42.3	35.6
18	52.5	45.8	46.7	39.3
19	57.5	50.3	51.5	43.2
20	62.8	55.2	56.1	47.4
21	68.4	60.0	61.1	51.6
22	74.0	65.2	66.3	56.1
23	80.0	70.5	71.6	60.7
24	86.1	75.7	77.2	65.5
25	92.5	81.4	82.7	70.5
26	99.0	87.2	88.9	75.5
27	106	93.3	95.0	80.8
28	112	99.7	100.9	86.3
29	119	105.6	107	91.7
30	127	112.4	115	97.5