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Authors

Bichsel, Hans

Tschalaer, Christoph

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A RANGE ENERGY TABLE FOR HEAVY PARTICLES IN SILICON*

Hans Bichsel[†] and Christoph Tschalaer[‡]Lawrence Radiation Laboratory
University of California
Berkeley, California

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Abstract

Stopping-power S and range R tables for protons, deuterons, tritons, He^3 , He^4 and Li^7 ions of energies between 1- and 200-MeV penetrating silicon absorbers are presented. Auxiliary data include tables for the coefficients C and α needed for the approximate expression $S = C \cdot E^\alpha$ and figures giving the energy dependence for the coefficients of $R = C_R \cdot E^\beta$. A short review is given of principles to be considered in detector applications.

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[†]On leave of absence from the University of Southern California, Los Angeles.

[‡]Now at Rutherford High Energy Laboratory, Didcot, England.

1. Introduction

Since silicon detectors have found wide spread applications, energy-loss tables for heavy particles are a necessity. Recent accurate measurements for protons^{11,33)} permit the presentation of calculated tables with a better basis than previous calculations. In particular it was found that the difference of the I-values of Al and Si is only about 7 eV rather than 12.5 eV as would be expected from a statistical model²⁾. There still are unresolved differences between experimental data²¹⁾ and some changes may have to be made in these tables as further results become available. A number of auxiliary tables and figures useful for the design and evaluation of particle-identifier systems are presented.

2. General Basis for Stopping-Power and Range-Energy Tables

2.1. Theory

The mean energy loss S of energetic charged particles in matter has been derived by Bethe¹), and is extensively discussed by Fano²). For the present application to silicon, the following expression will be used^{3,4}):

$$S = (0.30706 z^2/A \cdot \beta^2) \{ Z[f(\beta) - \ln I] - C_K - C_L \} \quad (1)$$

where

ze = charge of incident particle

A = 28.086 = chemical atomic weight of silicon

β = v/c = velocity of particle/velocity of light

Z = 14 = atomic number of silicon

$f(\beta) = \ln[2 mc^2 \beta^2 / (1 - \beta^2)] - \beta^2$

I = 173.5 eV = mean ionization potential of Si (ref. 11)

C_K = Walske's K-shell correction⁵)

C_L = Walske's L-shell correction⁶), modified to fit experimental data^{7,8})

$\beta^2 = \zeta(\zeta+2)/(\zeta+1)^2$ where $\zeta = E/Mc^2$

E = kinetic energy of particle of restmass M .

For a discussion of the effective charge at low velocities, see ref. 3 or 4.

The ranges R in the continuous slowing down approximation²) (csda) are calculated from S :

$$R = \int_{1 \text{ MeV}}^E (1/S) dE + R(1 \text{ MeV}). \quad (2)$$

2.2. Applications to experiments

A number of relatively small corrections should be considered for the use in experiments of S and R as defined above.

The distribution functions in energy E observed after a beam of particles has traversed a foil ("straggling distributions") are asymmetric, especially for small energy losses^{9,10}), but even for a final energy of $E_1 \sim 0.2 E$, a straggling asymmetry is still found^{11,34}). In addition, an asymmetry is caused by multiple scattering^{7,11}). It gets larger with thicker absorbers. A detailed discussion is given in Ref. 12. The multiple scattering correction for total ranges can be obtained from fig. 1.

At particle energies in excess of a few MeV, nuclear reactions will cause a perceptible attenuation of the beam intensity^{3,13,14}). A rough estimate can be obtained with the following equation

$$I/I_0 = e^{-\Delta/L} \quad (3)$$

where I/I_0 is the fraction of the beam transmitted through an absorber of thickness Δ and the mean free path length is given for protons by

$$L \sim 31 \cdot A^{1/3} \text{ g cm}^{-2} . \quad (4)$$

For particle identification applications, these effects are usually small and can be partially avoided by the use of more sophisticated instrumentation (systems with three or more counters, anticoincidence arrangements etc).

The Lewis correction¹⁵⁾, the difference between the actual path-length and the csda range, is usually less than 0.1% for protons and heavier particles.

2.3. Stopping-power and range tables

While accurate energy-loss measurements¹¹⁾ in silicon are available for protons with energies between 3 and 30 MeV, the determination of the parameters at low energies leans heavily on the data for aluminum^{7,8)}. It has been assumed that eq. (1) applies equally well to Al and Si, in particular that the L-shell correction can be scaled using Walske's η_L .

For the starting ranges R (1 MeV), measured values are available for protons⁷⁾, tritons¹⁶⁾ and α particles^{17,18)} in aluminum. The following procedure was used to get starting ranges for the other particles: ranges were calculated for particles from 0.25 to 1 MeV. The ratio of measured to calculated range was then used for the other particles. Errors of at least $\pm 0.2 \text{ mg cm}^{-2}$ should be assigned to the starting ranges. The starting ranges for Si were assumed to be 0.981 of the Al values. The accurate energy-loss measurements for heavy ions in Al of ref. (19) are not suitable to give starting values for the ranges. Further measurements would be highly desirable.

The charge-state corrections are not well-known for Li^7 ions, and therefore the tables will be accurate only to a few percent below about 5 MeV.

The stopping power S for p, d, t, He^3 , He^4 and Li^7 ions in silicon is given in Table 1. The csda ranges R for the same ions are given in Table 2. For both tables, linear interpolation will give an

accuracy of 0.1%. Since the tables are a direct printout of computer output, it was not practical to change the number of digits presented, and this number is not to be considered indicative of the accuracy of the tables. An I-value of 173.5 eV was used for the calculation¹¹).

2.4. Comparison with experimental data

The silicon range curve for protons deviates by less than 0.2% from the experimental data of ref. (11) for the energy range from 3 to 30 MeV. An older measurement²⁰) gives an absorber thickness of 0.985 mg cm^{-2} of Si to be equivalent to 1.00 mg cm^{-2} of Al for 8-MeV deuterons. Nothing is said about the composition of the samples or the assumed density. From Table 2, the corresponding number is about 0.979, depending on what lower energy is used. See Ref. 33 for stopping power measurements.

To get a fair estimate of the overall accuracy, the following data should be considered, based on a calculation of Al ranges and stopping power with $I = 166 \text{ eV}$ (from ref. (11)).

It was found²¹) that there exists a difference of up to 1% between the proton energy-loss measurements of ref. (11) and the stopping-power measurements of ref. (8). No explanation for this difference has been forwarded so far.

For the α -particle ranges there is a systematic deviation of between 3 and 7% from the experimental data of ref. (17), and about 3% from ref. (18). Since $I = 166 \text{ eV}$ was used for Al, these deviations are not unexpected. The triton ranges of ref. (16) agree to about 1% with Table 2.

Burkig and MacKenzie's range measurement²²) at 18.00 MeV agrees to 0.05 mg cm^{-2} with the Al range table. The Princeton range data⁷) agree with the table to 0.3% above 3.5 MeV.

It should be pointed out that the shell corrections used here do not appear to decrease fast enough for Al data (see fig. 4 of ref. (23)). A shift of the peak of the K-shell correction to lower energies might improve the situation somewhat.

2.5. Practical use of the tables

A list comparing thickness of silicon in different units is given in Table 3.

Monoenergetic particles of initial kinetic energy E will emerge from an absorber of thickness Δ with a mean energy $\langle E_1 \rangle$ given by

$$\Delta = \int_{\langle E_1 \rangle}^E (1/S) dE . \quad (5)$$

For most practical purposes, a csda-range table giving R as a function of E can be used to determine $\langle E_1 \rangle$: first, the mean residual range $R(\langle E_1 \rangle)$ is determined from

$$R(\langle E_1 \rangle) = R(E) - \Delta$$

and $\langle E_1 \rangle$ is obtained by interpolation from the table.

In applications using computers this method requires table look up. This is simple if the argument (here the energy E) shows a regular spacing, permitting selection of necessary locations with integer algebra. See Table 4 for an example.

If the energy difference $E - \langle E_1 \rangle$ is small enough, the mean value theorem can be used and

$$E - \langle E_1 \rangle = \underline{\Delta} \cdot S(E') \quad (6)$$

where $S(E')$ is the stopping power at an energy $E' \sim (E + \langle E_1 \rangle)/2$. This method requires successive approximations and thus is not very suitable for practical applications.

A third method is useful if an approximation formula is given for the stopping power and the range (see Table 5):

$$S = C \cdot E^{\underline{\alpha}} \quad (7)$$

$$\underline{\Delta} R = C_R (E^{\underline{\beta}} - E_1^{\underline{\beta}}) \quad (8)$$

where $\underline{\beta} = 1 - \underline{\alpha}$ and $C_R = 1/(C \cdot \underline{\beta})$. The mean residual energy then is obtained analytically:

$$\langle E_1 \rangle = (E^{\underline{\beta}} - \underline{\Delta}/C_R)^{1/\underline{\beta}} \quad (9)$$

If a digital computer is used to analyze pulses from an identifier system giving pulseheights in discrete channels proportional to the particle energy, it will be useful to generate range tables for energies corresponding to the value of the energy for the center of each channel. The residual range RX for a particle having a total energy producing a pulse in channel J then is simply $RX(J)$.

3. Useful Data for Particle-Identifier Applications

Many articles describing analog-particle identifiers based on the use of eqs. (7) and (8) have appeared (e.g. refs. (25 and 26)). In order to achieve a better understanding of the approximations involved, the following functions derived from Tables 1 and 2 are given here:

a) The quantity $q = R/E^{1.76}$ is plotted in fig. 2.

b) The quantity $\gamma = \frac{\ln[R(E)/0.763 \cdot R(1 \text{ MeV})]}{\ln E}$ is plotted in fig. 3.

c) The values C , α and $C_R = CRL$ evaluated from eq. (7) are given in Table 5 for energy intervals from $E_1 = \text{LOWER } E$ to $E_2 = \text{UPPER } E$ such that the maximum deviation from Table 1 does not exceed about 0.1, 0.3, 0.6 or 1%. The actual deviation at the center point of the tabular entries is given in % under MAX.DEV.

d) Since the resolution of an identifier systems depends on the ratio of the straggling width σ to the mean energy loss, the quantity $\zeta = \sigma/(E - \langle E_1 \rangle)$ is plotted versus E_1/E for protons of initial energies $E = 10, 30$ and 100 MeV in fig. 4.

e) For the particle pairs (d,p), (t,d), (He^3 ,t) and (He^4 , He^3) the ratio r of their energy losses $r = (E - \langle E_1 \rangle)_x / (E - \langle E_1 \rangle)_y$ is plotted as a function of E for detectors of thicknesses $\Delta = 20 \text{ mg cm}^{-2}$, $\Delta = 50 \text{ mg cm}^{-2}$, in fig. 5 and for $\Delta = 100 \text{ mg cm}^{-2}$ and $\Delta = 500 \text{ mg cm}^{-2}$ in fig. 6

f) The "particle characteristic" $E^{1.76} - \langle E_1 \rangle^{1.76}$ (fig. 2a of ref. (26)) is given by a suitable average of q of fig. 2 over the range $\langle E_1 \rangle$ to E .

g) The relative stopping power of Al (based on $I = 166 \text{ eV}$) and Si is given in fig. 7.

4. Some Comments about Energy Measurements in Silicon Detectors

A number of details have to be considered if an energy determination in silicon detectors is desired to an accuracy of better than 1%.

Obviously, corrections have to be applied for the energy loss in the entrance window. A practical way to determine its thickness is to measure the change in pulseheight of natural α particles as a function of the angle of incidence of the particles.

The energy ϵ for the formation of an electron hole pair increases for particles of low velocities. For more energetic particles this effect can be lumped together into an ionization defect. This means that particles will seem to deposit less energy than they actually possess. An estimate of the effect²⁷⁾ indicates that the observed energy will have to be increased by about $6 \cdot M$ keV where M is the particle mass in amu. The effect is not easy to determine because it is obscured by losses due to incomplete charge collection and other effects²⁸⁾. Contradictory results are obtained by Siffert et al²⁹⁾ and by Ewing³⁰⁾.

For protons of energies from 3 to 18 MeV, pulseheight and energy in a 2-mm Li-drift-silicon detector were observed to be proportional to better than ± 5 keV after correction for entrance window and ionization defect¹¹⁾. At 20 MeV in a 3-mm detector, the pulseheight was reduced by about 1% due to pulse rise time problems.

A definite dependence of ϵ on temperature and also a difference in ϵ for electrons and α particles has been found³¹⁾. A difference in ϵ for protons and α particles has been observed at the University of

Southern California by the authors, but further experimentation will be necessary to test all possible sources of systematic error.

An extensive discussion of counter resolution and associated problems is given in ref. (32).

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List of Tables

1. Stopping power S of p , d , t , He^3 , α and Li^7 ions in silicon.
2. Ranges R in silicon.
3. Conversion table for different units of thickness for single crystal silicon.
4. Example of Table lookup in FORTRAN IV.
5. The coefficients C , α , and C_R for approximate calculation of stopping power and ranges (see p. 8).

Figure Captions

1. Multiple scattering correction for mean ranges of protons in Si. An observed protected median range (corrected for nuclear absorption) has to be increased by ΔR to give mean range.
2. The quotient $q = R/E^{1.76}$ for six particles. Note the strong dependence of q on the value of γ for protons: for $\gamma = 1.76$, q changes by $\pm 1\%$ from 6.5 to 65 MeV, while for $\gamma = 1.72$, the same change occurs between 3.2 and 18 MeV.
3. The exponent γ in the approximate expression $R(E) = C_R \cdot E^\gamma$ where C_R is a constant chosen to be $R(1 \text{ MeV}) \cdot 0.763$. This produces $\gamma = 1.76$ at about 40 MeV for protons and gives approximately the smallest change in γ for protons from about 7 to 200 MeV.
4. The straggling parameter σ as a function of the mean energy loss $\Delta E = E - \langle E_1 \rangle$. Plotted is the fraction $\sigma/\Delta E$ versus the residual energy $\langle E_1 \rangle$ expressed as a fraction of the initial energy for $E = 10 \text{ MeV}$ and $E = 100 \text{ MeV}$.

Figure Captions (cont'd)

5 + 6. The ratio r of the energy loss of two particles x, y in different

thicknesses of silicon absorbers: $r = (E - \langle E_1 \rangle)_x / (E - \langle E_1 \rangle)_y$.

7. Relative stopping power of Si and Al. Plotted is

$S_r = (S_{Si}/S_{Al}) - 1$ in percent for 5 particles.

Table 1.

STOPPING POWER IN MEV.SQCM/GM FOR SILICON							Z= 14 A= 28.086 I= 173.5						
E(MEV)	P	D	T	HE 3	HE 4	LI 7	E(MEV)	P	D	T	HE 3	HE 4	LI 7
1.00	174.902	256.298	302.610	1183.209	1224.494	1870.058	7.00	45.385	75.662	100.662	402.595	488.091	1409.919
1.10	165.072	244.187	291.546	1156.467	1211.196	1893.188	7.20	44.431	74.142	98.715	394.809	478.985	1393.568
1.20	156.418	233.336	281.238	1118.590	1200.907	1913.675	7.40	43.521	72.689	96.853	387.360	470.250	1377.744
1.30	148.741	223.585	271.825	1083.332	1186.984	1942.589	7.60	42.652	71.299	95.068	380.223	461.878	1362.466
1.40	141.866	214.715	265.028	1052.493	1174.378	1964.550	7.80	41.821	69.968	93.357	373.379	453.832	1347.721
1.50	135.680	206.654	256.091	1023.798	1144.776	1963.405	8.00	41.026	68.692	91.714	366.806	446.100	1333.419
1.60	130.074	199.255	247.847	991.295	1116.573	1956.030	8.20	40.264	67.468	90.135	360.491	438.660	1319.588
1.70	124.969	192.440	240.231	960.909	1089.794	1946.316	8.40	39.533	66.292	88.616	354.418	431.494	1306.250
1.80	120.298	186.134	233.137	932.455	1065.739	1934.883	8.60	38.831	65.162	87.155	348.573	424.601	1293.289
1.90	116.006	180.289	226.535	906.050	1043.222	1933.278	8.80	38.156	64.075	85.747	342.942	417.949	1280.725
2.00	112.048	174.850	220.344	881.286	1021.891	1930.895	9.00	37.508	63.029	84.390	337.513	411.532	1265.955
2.10	108.382	169.776	214.526	858.015	996.904	1927.222	9.20	36.883	62.020	83.080	332.276	405.332	1250.702
2.20	104.982	165.021	209.077	836.219	973.550	1922.547	9.40	36.281	61.047	81.817	327.222	399.343	1235.909
2.30	101.816	160.560	203.934	815.648	951.332	1902.113	9.60	35.701	60.113	80.596	322.340	393.554	1221.570
2.40	98.859	156.369	199.073	796.207	930.182	1880.232	9.80	35.142	59.205	79.416	317.620	387.951	1207.624
2.50	96.091	152.420	194.472	777.803	910.254	1862.314	10.00	34.602	58.328	78.274	313.053	382.529	1194.099
2.60	93.494	148.694	190.108	760.350	891.262	1844.916	10.20	34.080	57.480	77.168	308.632	377.272	1180.970
2.70	91.051	145.164	185.959	743.755	873.132	1827.693	10.40	33.575	56.659	76.098	304.351	372.179	1168.184
2.80	88.748	141.821	182.015	727.977	855.850	1810.699	10.60	33.087	55.864	75.061	300.203	367.239	1155.745
2.90	86.573	138.650	178.263	712.971	839.407	1793.971	10.80	32.615	55.093	74.056	296.184	362.445	1143.552
3.00	84.515	135.636	174.682	698.650	823.665	1777.537	11.00	32.157	54.346	73.081	292.285	357.792	1131.528
3.10	82.566	132.768	171.265	684.984	808.583	1762.768	11.20	31.714	53.622	72.136	288.503	353.272	1119.816
3.20	80.717	130.031	167.992	671.889	794.126	1749.186	11.40	31.284	52.920	71.217	284.828	348.880	1108.417
3.30	78.959	127.422	164.859	659.362	780.251	1739.309	11.60	30.866	52.238	70.324	281.257	344.608	1097.302
3.40	77.285	124.928	161.858	647.356	766.923	1729.595	11.80	30.461	51.575	69.456	277.786	340.455	1086.464
3.50	75.690	122.543	158.974	635.822	754.098	1720.013	12.00	30.068	50.932	68.613	274.413	336.414	1075.902
3.60	74.168	120.258	156.214	624.781	741.752	1710.571	12.20	29.687	50.307	67.791	271.128	332.480	1065.587
3.70	72.715	118.068	153.557	614.156	729.866	1701.809	12.40	29.316	49.699	66.992	267.932	328.651	1055.515
3.80	71.325	115.967	151.002	603.936	718.429	1693.280	12.60	28.955	49.106	66.214	264.821	324.919	1045.689
3.90	69.993	113.949	148.543	594.103	707.383	1684.886	12.80	28.604	48.530	65.457	261.792	321.284	1036.002
4.00	68.717	112.010	146.170	584.608	696.726	1676.634	13.00	28.262	47.969	64.719	258.841	317.739	1026.226
4.20	66.316	108.346	141.675	566.631	676.473	1660.556	13.20	27.930	47.421	64.000	255.964	314.282	1016.685
4.40	64.098	104.946	137.487	549.883	657.508	1643.923	13.40	27.606	46.888	63.299	253.160	310.908	1007.356
4.60	62.042	101.781	133.568	534.208	639.704	1624.916	13.60	27.290	46.368	62.615	250.424	307.615	998.231
4.80	60.135	98.825	129.895	519.514	622.996	1606.689	13.80	26.982	45.862	61.947	247.753	304.401	989.313
5.00	58.349	96.058	126.444	505.712	607.239	1589.405	14.00	26.683	45.368	61.295	245.147	301.262	980.583
5.20	56.680	93.462	123.196	492.722	592.373	1572.889	14.20	26.390	44.885	60.664	242.624	298.198	972.037
5.40	55.114	91.019	120.130	480.458	578.295	1557.033	14.40	26.105	44.414	60.042	240.135	295.204	963.678
5.60	53.642	88.717	117.231	468.866	564.959	1541.818	14.60	25.826	43.954	59.434	237.704	292.279	955.489
5.80	52.257	86.542	114.489	457.897	552.320	1522.427	14.80	25.554	43.504	58.840	235.326	289.418	947.471
6.00	50.951	84.486	111.888	447.495	540.297	1501.768	15.00	25.289	43.065	58.259	233.003	286.620	939.630
6.20	49.717	82.537	109.417	437.612	528.862	1481.907	15.50	24.651	42.009	56.862	227.416	279.884	920.698
6.40	48.548	80.688	107.067	428.213	517.948	1462.831	16.00	24.048	41.010	55.538	222.122	273.497	902.680
6.60	47.439	78.931	104.831	419.270	507.543	1444.522	16.50	23.477	40.063	54.282	217.097	267.430	885.512
6.80	46.386	77.257	102.698	410.740	497.601	1426.896	17.00	22.936	39.163	53.089	212.324	261.663	869.140
7.00	45.385	75.662	100.662	402.595	488.091	1409.919	17.50	22.423	38.308	51.953	207.783	256.172	853.297

STOPPING POWER IN MEV.SQCM/GM FOR SILICON

Z= 14 A= 28.086 I= 173.5

E(MEV)	P	D	T	HE 3	HE 4	LI 7	E(MEV)	P	D	T	HE 3	HE 4	LI 7
17.50	22.423	38.308	51.953	207.783	256.172	853.297	40.00	11.723	20.189	27.668	110.654	137.680	473.728
18.00	21.934	37.493	50.872	203.458	250.937	837.499	40.50	11.610	19.993	27.402	109.592	136.373	469.358
18.50	21.469	36.717	49.840	199.331	245.938	822.376	41.00	11.499	19.802	27.142	108.553	135.094	465.076
19.00	21.025	35.975	48.854	195.388	241.179	807.887	41.50	11.391	19.614	26.888	107.537	133.841	460.887
19.50	20.601	35.267	47.911	191.617	236.600	793.990	42.00	11.285	19.431	26.639	106.541	132.613	456.784
20.00	20.197	34.589	47.008	188.004	232.214	780.647	42.50	11.181	19.251	26.395	105.566	131.412	452.761
20.50	19.809	33.939	46.142	184.544	228.008	767.822	43.00	11.079	19.075	26.156	104.611	130.235	448.815
21.00	19.438	33.316	45.313	181.226	223.970	755.487	43.50	10.980	18.903	25.922	103.674	129.081	444.947
21.50	19.083	32.719	44.516	178.038	220.089	743.615	44.00	10.883	18.734	25.693	102.757	127.949	441.152
22.00	18.741	32.145	43.750	174.975	216.356	732.180	44.50	10.787	18.568	25.468	101.857	126.840	437.431
22.50	18.413	31.593	43.013	172.028	212.766	721.156	45.00	10.694	18.406	25.247	100.975	125.751	433.779
23.00	18.098	31.062	42.304	169.190	209.308	710.190	45.50	10.602	18.247	25.031	100.109	124.684	430.195
23.50	17.795	30.550	41.620	166.455	205.973	699.313	46.00	10.513	18.091	24.819	99.260	123.636	426.676
24.00	17.503	30.057	40.960	163.818	202.761	688.809	46.50	10.425	17.938	24.610	98.427	122.608	423.220
24.50	17.222	29.582	40.324	161.274	199.658	678.657	47.00	10.338	17.788	24.406	97.610	121.598	419.826
25.00	16.950	29.123	39.710	158.816	196.660	668.846	47.50	10.254	17.641	24.205	96.807	120.608	416.498
25.50	16.689	28.680	39.116	156.440	193.762	659.355	48.00	10.171	17.496	24.008	96.019	119.636	413.231
26.00	16.436	28.251	38.541	154.143	190.958	650.165	48.50	10.089	17.354	23.815	95.246	118.682	410.020
26.50	16.192	27.837	37.986	151.921	188.242	641.257	49.00	10.009	17.215	23.625	94.487	117.744	406.864
27.00	15.956	27.436	37.448	149.769	185.613	632.621	49.50	9.931	17.078	23.439	93.742	116.823	403.761
27.50	15.727	27.048	36.926	147.684	183.068	624.246	50.00	9.854	16.944	23.256	93.009	115.918	400.711
28.00	15.506	26.672	36.421	145.663	180.600	616.118	51.00	9.704	16.682	22.899	91.582	114.154	394.764
28.50	15.292	26.308	35.931	143.702	178.205	608.225	52.00	9.560	16.430	22.554	90.203	112.448	389.016
29.00	15.085	25.955	35.456	141.802	175.880	600.558	53.00	9.420	16.186	22.221	88.869	110.799	383.451
29.50	14.883	25.612	34.994	139.958	173.625	593.108	54.00	9.285	15.950	21.898	87.579	109.203	378.060
30.00	14.688	25.279	34.546	138.165	171.432	585.867	55.00	9.155	15.721	21.586	86.331	107.658	372.836
30.50	14.499	24.955	34.111	136.424	169.301	578.825	56.00	9.028	15.500	21.283	85.121	106.162	367.776
31.00	14.315	24.641	33.687	134.730	167.227	571.974	57.00	8.906	15.286	20.990	83.949	104.712	362.867
31.50	14.136	24.336	33.275	133.082	165.210	565.302	58.00	8.788	15.079	20.706	82.813	103.305	358.102
32.00	13.962	24.038	32.875	131.480	163.249	558.804	59.00	8.673	14.878	20.431	81.711	101.940	353.473
32.50	13.793	23.749	32.485	129.921	161.338	552.474	60.00	8.562	14.682	20.163	80.641	100.614	348.976
33.00	13.629	23.468	32.105	128.403	159.477	546.352	61.00	8.454	14.493	19.904	79.603	99.327	344.609
33.50	13.469	23.194	31.735	126.923	157.663	540.330	62.00	8.350	14.309	19.651	78.594	98.076	340.363
34.00	13.314	22.927	31.375	125.481	155.894	534.455	63.00	8.248	14.130	19.406	77.614	96.859	336.231
34.50	13.162	22.667	31.023	124.075	154.170	528.720	64.00	8.150	13.957	19.168	76.660	95.676	332.209
35.00	13.014	22.414	30.680	122.704	152.488	523.128	65.00	8.054	13.788	18.936	75.733	94.526	328.293
35.50	12.871	22.167	30.346	121.366	150.847	517.667	66.00	7.961	13.624	18.710	74.831	93.407	324.479
36.00	12.730	21.925	30.020	120.061	149.245	512.333	67.00	7.870	13.464	18.491	73.952	92.316	320.766
36.50	12.594	21.690	29.701	118.788	147.680	507.119	68.00	7.782	13.308	18.277	73.097	91.254	317.148
37.00	12.460	21.460	29.391	117.545	146.152	502.026	69.00	7.696	13.157	18.068	72.263	90.219	313.620
37.50	12.330	21.236	29.087	116.331	144.658	497.045	70.00	7.613	13.009	17.865	71.451	89.210	310.177
38.00	12.203	21.017	28.790	115.144	143.199	492.174	71.00	7.532	12.866	17.667	70.659	88.226	306.818
38.50	12.079	20.803	28.500	113.984	141.773	487.408	72.00	7.452	12.725	17.474	69.886	87.265	303.539
39.00	11.957	20.593	28.216	112.849	140.379	482.748	73.00	7.375	12.589	17.286	69.133	86.328	300.337
39.50	11.839	20.389	27.939	111.740	139.015	478.191	74.00	7.300	12.455	17.102	68.398	85.414	297.211
40.00	11.723	20.189	27.668	110.654	137.680	473.728	75.00	7.226	12.325	16.923	67.680	84.520	294.158

STOPPING POWER IN MEV.SQCM/GM FOR SILICON

Z= 14 A= 28.086 I= 173.5

E(MEV)	P	D	T	HE 3	HE 4	LI 7	E(MEV)	P	D	T	HE 3	HE 4	LI 7
75.00	7.226	12.325	16.923	67.680	84.520	294.158	120.00	5.120	8.559	11.704	46.808	58.436	204.250
76.00	7.155	12.198	16.747	66.980	83.648	291.174	122.00	5.061	8.451	11.554	46.208	57.683	201.628
77.00	7.085	12.074	16.576	66.295	82.795	288.257	124.00	5.003	8.347	11.408	45.625	56.951	199.081
78.00	7.016	11.953	16.409	65.627	81.962	285.405	126.00	4.947	8.245	11.266	45.058	56.240	196.604
79.00	6.950	11.834	16.246	64.973	81.148	282.614	128.00	4.893	8.147	11.129	44.508	55.548	194.196
80.00	6.885	11.718	16.086	64.334	80.352	279.884	130.00	4.840	8.051	10.995	43.974	54.877	191.853
81.00	6.821	11.605	15.930	63.709	79.573	277.212	132.00	4.789	7.958	10.865	43.454	54.223	189.572
82.00	6.759	11.495	15.777	63.098	78.811	274.596	134.00	4.739	7.867	10.738	42.948	53.587	187.351
83.00	6.698	11.386	15.627	62.500	78.065	272.034	136.00	4.690	7.779	10.615	42.455	52.968	185.189
84.00	6.638	11.280	15.481	61.914	77.335	269.529	138.00	4.643	7.694	10.496	41.976	52.366	183.082
85.00	6.580	11.177	15.338	61.341	76.620	267.076	140.00	4.597	7.610	10.379	41.509	51.778	181.029
86.00	6.523	11.075	15.197	60.780	75.920	264.671	142.00	4.552	7.529	10.265	41.054	51.206	179.027
87.00	6.467	10.976	15.060	60.230	75.234	262.315	144.00	4.509	7.450	10.154	40.611	50.648	177.073
88.00	6.413	10.879	14.925	59.692	74.561	260.004	146.00	4.467	7.372	10.046	40.178	50.104	175.167
89.00	6.359	10.783	14.793	59.164	73.903	257.739	148.00	4.425	7.297	9.941	39.757	49.573	173.307
90.00	6.307	10.690	14.664	58.647	73.257	255.517	150.00	4.385	7.224	9.838	39.345	49.055	171.491
91.00	6.256	10.598	14.537	58.141	72.624	253.337	152.00	4.346	7.152	9.738	38.946	48.549	169.717
92.00	6.206	10.509	14.413	57.644	72.003	251.199	154.00	4.308	7.082	9.640	38.554	48.055	167.984
93.00	6.157	10.421	14.291	57.156	71.394	249.101	156.00	4.270	7.014	9.544	38.171	47.573	166.290
94.00	6.108	10.334	14.172	56.678	70.796	247.041	158.00	4.234	6.947	9.451	37.797	47.101	164.634
95.00	6.061	10.250	14.054	56.209	70.210	245.019	160.00	4.198	6.882	9.359	37.432	46.641	163.016
96.00	6.015	10.167	13.939	55.749	69.635	243.035	162.00	4.164	6.818	9.270	37.075	46.190	161.432
97.00	5.969	10.085	13.826	55.297	69.070	241.088	164.00	4.130	6.756	9.183	36.726	45.750	159.883
98.00	5.925	10.005	13.715	54.854	68.516	239.175	166.00	4.097	6.695	9.097	36.384	45.319	158.368
99.00	5.881	9.927	13.607	54.419	67.971	237.296	168.00	4.064	6.636	9.014	36.050	44.897	156.884
100.00	5.838	9.850	13.500	53.991	67.437	235.449	170.00	4.033	6.578	8.932	35.723	44.485	155.432
101.00	5.796	9.774	13.395	53.572	66.912	233.634	172.00	4.002	6.521	8.852	35.403	44.081	154.010
102.00	5.754	9.701	13.292	53.159	66.396	231.851	174.00	3.971	6.465	8.774	35.090	43.686	152.618
103.00	5.714	9.628	13.190	52.754	65.889	230.097	176.00	3.942	6.411	8.697	34.783	43.299	151.254
104.00	5.674	9.556	13.091	52.356	65.390	228.373	178.00	3.913	6.357	8.622	34.483	42.919	149.917
105.00	5.635	9.486	12.993	51.965	64.901	226.677	180.00	3.884	6.305	8.548	34.189	42.548	148.607
106.00	5.596	9.416	12.897	51.580	64.419	225.010	182.00	3.857	6.254	8.476	33.901	42.183	147.322
107.00	5.558	9.348	12.802	51.202	63.945	223.369	184.00	3.829	6.203	8.406	33.618	41.826	146.062
108.00	5.521	9.282	12.709	50.830	63.480	221.755	186.00	3.803	6.154	8.337	33.341	41.476	144.827
109.00	5.485	9.216	12.618	50.465	63.022	220.167	188.00	3.777	6.106	8.269	33.070	41.133	143.615
110.00	5.449	9.151	12.528	50.105	62.571	218.604	190.00	3.751	6.059	8.202	32.804	40.797	142.425
111.00	5.413	9.087	12.440	49.751	62.128	217.066	192.00	3.726	6.012	8.137	32.542	40.466	141.258
112.00	5.379	9.025	12.353	49.403	61.691	215.553	194.00	3.701	5.967	8.073	32.286	40.142	140.113
113.00	5.344	8.963	12.267	49.061	61.262	214.064	196.00	3.677	5.922	8.010	32.035	39.824	138.988
114.00	5.311	8.903	12.183	48.724	60.839	212.597	198.00	3.654	5.879	7.948	31.788	39.512	137.884
115.00	5.278	8.843	12.100	48.392	60.423	211.153	200.00	3.631	5.836	7.888	31.546	39.206	136.799
116.00	5.245	8.785	12.018	48.065	60.014	209.731							
117.00	5.213	8.727	11.938	47.744	59.610	208.330							
118.00	5.182	8.670	11.858	47.427	59.213	206.950							
119.00	5.151	8.614	11.781	47.115	58.822	205.590							
120.00	5.120	8.559	11.704	46.808	58.436	204.250							

Table 2.

RANGES IN GM/SQCM FOR SILICON							Z= 14 A= 28.086 I= 173.5						
E(MEV)	P	D	T	HE 3	HE 4	LI 7	E(MEV)	P	D	T	HE 3	HE 4	LI 7
1.00	.003800	.002860	.002550	.001030	.000960	.000750	7.00	.089838	.055734	.043135	.011181	.009508	.004331
1.10	.004389	.003260	.002887	.001115	.001042	.000803	7.20	.094292	.058405	.045141	.011682	.009922	.004474
1.20	.005011	.003679	.003236	.001203	.001125	.000856	7.40	.098841	.061129	.047187	.012194	.010343	.004618
1.30	.005667	.004117	.003598	.001294	.001209	.000908	7.60	.103483	.063908	.049271	.012715	.010773	.004764
1.40	.006356	.004573	.003969	.001388	.001294	.000959	7.80	.108219	.066739	.051394	.013246	.011209	.004912
1.50	.007077	.005048	.004353	.001484	.001380	.001010	8.00	.113047	.069624	.053556	.013786	.011654	.005061
1.60	.007830	.005541	.004750	.001583	.001468	.001061	8.20	.117969	.072562	.055756	.014336	.012106	.005212
1.70	.008614	.006052	.005160	.001686	.001559	.001112	8.40	.122982	.075553	.057993	.014896	.012566	.005364
1.80	.009430	.006580	.005582	.001791	.001652	.001163	8.60	.128087	.078596	.060269	.015465	.013033	.005518
1.90	.010277	.007126	.006018	.001900	.001747	.001215	8.80	.133283	.081692	.062583	.016043	.013508	.005673
2.00	.011154	.007690	.006465	.002012	.001843	.001267	9.00	.138570	.084839	.064934	.016631	.013990	.005830
2.10	.012062	.008270	.006925	.002127	.001943	.001319	9.20	.143947	.088038	.067323	.017228	.014480	.005989
2.20	.012999	.008868	.007398	.002245	.002044	.001371	9.40	.149415	.091288	.069749	.017835	.014977	.006150
2.30	.013967	.009482	.007882	.002366	.002148	.001423	9.60	.154972	.094590	.072212	.018451	.015481	.006313
2.40	.014964	.010113	.008378	.002490	.002254	.001476	9.80	.160619	.097942	.074712	.019076	.015993	.006478
2.50	.015990	.010761	.008887	.002618	.002363	.001529	10.00	.166354	.101346	.077248	.019710	.016513	.006644
2.60	.017045	.011425	.009407	.002748	.002474	.001583	10.20	.172179	.104800	.079822	.020354	.017039	.006813
2.70	.018129	.012106	.009939	.002881	.002587	.001638	10.40	.178091	.108305	.082432	.021006	.017573	.006983
2.80	.019241	.012803	.010482	.003016	.002703	.001693	10.60	.184092	.111860	.085078	.021668	.018114	.007155
2.90	.020382	.013516	.011037	.003155	.002821	.001748	10.80	.190180	.115465	.087761	.022339	.018662	.007329
3.00	.021551	.014246	.011604	.003297	.002941	.001804	11.00	.196356	.119120	.090480	.023018	.019217	.007505
3.10	.022749	.014991	.012182	.003442	.003064	.001861	11.20	.202619	.122825	.093234	.023707	.019780	.007683
3.20	.023974	.015752	.012772	.003589	.003189	.001918	11.40	.208969	.126580	.096025	.024405	.020350	.007862
3.30	.025226	.016529	.013373	.003739	.003316	.001975	11.60	.215405	.130384	.098851	.025112	.020926	.008043
3.40	.026507	.017321	.013985	.003892	.003445	.002033	11.80	.221928	.134237	.101713	.025827	.021510	.008227
3.50	.027814	.018130	.014608	.004048	.003577	.002091	12.00	.228537	.138139	.104610	.026551	.022101	.008412
3.60	.029149	.018954	.015243	.004207	.003710	.002149	12.20	.235231	.142091	.107542	.027285	.022699	.008598
3.70	.030511	.019793	.015889	.004368	.003846	.002207	12.40	.242011	.146090	.110510	.028027	.023304	.008787
3.80	.031899	.020647	.016545	.004532	.003984	.002266	12.60	.248875	.150139	.113513	.028778	.023916	.008977
3.90	.033315	.021517	.017213	.004699	.004125	.002326	12.80	.255825	.154236	.116551	.029537	.024535	.009169
4.00	.034757	.022403	.017892	.004869	.004267	.002385	13.00	.262859	.158381	.119624	.030306	.025161	.009363
4.20	.037720	.024218	.019282	.005217	.004558	.002505	13.20	.269978	.162575	.122732	.031083	.025794	.009559
4.40	.040788	.026094	.020715	.005575	.004858	.002626	13.40	.277181	.166816	.125874	.031868	.026434	.009757
4.60	.043960	.028030	.022191	.005944	.005167	.002748	13.60	.284468	.171106	.129051	.032663	.027081	.009956
4.80	.047235	.030024	.023710	.006324	.005484	.002872	13.80	.291838	.175443	.132262	.033466	.027735	.010158
5.00	.050612	.032077	.025270	.006714	.005809	.002997	14.00	.299292	.179827	.135508	.034277	.028395	.010361
5.20	.054090	.034188	.026873	.007115	.006142	.003124	14.20	.306829	.184260	.138788	.035097	.029062	.010566
5.40	.057669	.036357	.028517	.007526	.006484	.003252	14.40	.314449	.188739	.142102	.035926	.029736	.010772
5.60	.061347	.038583	.030203	.007947	.006834	.003381	14.60	.322152	.193266	.145450	.036763	.030417	.010981
5.80	.065125	.040865	.031929	.008379	.007192	.003511	14.80	.329937	.197839	.148832	.037609	.031105	.011191
6.00	.069002	.043205	.033696	.008821	.007558	.003643	15.00	.337805	.202460	.152248	.038463	.031799	.011403
6.20	.072976	.045600	.035504	.009273	.007932	.003777	15.50	.357833	.214216	.160936	.040635	.033565	.011940
6.40	.077047	.048051	.037352	.009735	.008314	.003913	16.00	.378371	.226264	.169834	.042860	.035372	.012489
6.60	.081215	.050557	.039240	.010207	.008705	.004051	16.50	.399416	.238600	.178941	.045137	.037221	.013048
6.80	.085479	.053118	.041168	.010689	.009103	.004190	17.00	.420964	.251224	.188256	.047466	.039111	.013618
7.00	.089838	.055734	.043135	.011181	.009508	.004331	17.50	.443014	.264134	.197777	.049847	.041043	.014199

RANGES IN GM/SQCM FOR SILICON

Z= 14. A= 28.086 I= 173.5

E(MEV)	P	D	T	HE 3	HE 4	LI 7	E(MEV)	P	D	T	HE 3	HE 4	LI 7
17.50	.443014	.264134	.197777	.049847	.041043	.014199	40.00	1.917865	1.121874	.825803	.206876	.167653	.051318
18.00	.465561	.277328	.207504	.052279	.043015	.014790	40.50	1.960725	1.146761	.841962	.211416	.171302	.052378
18.50	.488604	.290805	.217434	.054762	.045028	.015393	41.00	2.004000	1.171891	.862296	.216000	.174986	.053449
19.00	.512140	.304563	.227568	.057295	.047081	.016006	41.50	2.047689	1.197262	.880805	.220628	.178705	.054529
19.50	.536166	.318601	.237903	.059879	.049174	.016630	42.00	2.091790	1.222875	.899488	.225299	.182458	.055618
20.00	.560680	.332918	.248439	.062514	.051307	.017266	42.50	2.136304	1.248727	.918344	.230014	.186245	.056718
20.50	.585679	.347512	.259176	.065198	.053480	.017911	43.00	2.181227	1.274820	.937373	.234772	.190067	.057827
21.00	.611161	.362382	.270111	.067933	.055693	.018568	43.50	2.226560	1.301151	.956575	.239573	.193924	.058946
21.50	.637123	.377527	.281244	.070716	.057945	.019235	44.00	2.272301	1.327722	.975949	.244418	.197814	.060074
22.00	.663564	.392945	.292575	.073549	.060236	.019913	44.50	2.318448	1.354530	.995496	.249305	.201739	.061213
22.50	.690480	.408635	.304101	.076431	.062567	.020601	45.00	2.365001	1.381576	1.015214	.254235	.205698	.062360
23.00	.717871	.424597	.315823	.079362	.064936	.021299	45.50	2.411959	1.408859	1.035104	.259209	.209691	.063518
23.50	.745734	.440829	.327740	.082342	.067345	.022009	46.00	2.459319	1.436379	1.055165	.264225	.213719	.064685
24.00	.774066	.457330	.339850	.085370	.069791	.022729	46.50	2.507082	1.464135	1.075396	.269283	.217780	.065862
24.50	.802866	.474099	.352153	.088446	.072276	.023461	47.00	2.555245	1.492126	1.095798	.274384	.221875	.067048
25.00	.832132	.491135	.364649	.091570	.074800	.024203	47.50	2.603808	1.520352	1.116370	.279528	.226003	.068244
25.50	.861861	.508436	.377336	.094743	.077361	.024956	48.00	2.652770	1.548813	1.137111	.284714	.230166	.069449
26.00	.892052	.526002	.390214	.097963	.079961	.025719	48.50	2.702130	1.577508	1.158022	.289942	.234362	.070664
26.50	.922702	.543832	.403262	.101230	.082598	.026494	49.00	2.751886	1.606436	1.179101	.295213	.238592	.071888
27.00	.953810	.561925	.416539	.104545	.085273	.027279	49.50	2.802037	1.635597	1.200349	.300526	.242855	.073121
27.50	.985374	.580280	.429985	.107907	.087986	.028075	50.00	2.852582	1.664990	1.221765	.305881	.247152	.074364
28.00	1.017393	.598896	.443620	.111316	.090735	.028881	51.00	2.954850	1.724471	1.265100	.316716	.255845	.076879
28.50	1.049863	.617772	.457442	.114772	.093523	.029698	52.00	3.058676	1.784876	1.309105	.327719	.264672	.079431
29.00	1.082785	.636907	.471451	.118275	.096347	.030525	53.00	3.164058	1.846200	1.353776	.338888	.273631	.082020
29.50	1.116155	.656300	.485646	.121824	.099208	.031363	54.00	3.270987	1.908441	1.399111	.350224	.282722	.084646
30.00	1.149973	.675951	.500027	.125420	.102106	.032211	55.00	3.379455	1.971594	1.445107	.361725	.291945	.087310
30.50	1.184237	.695859	.514592	.129062	.105041	.033070	56.00	3.489454	2.035655	1.491763	.373390	.301299	.090011
31.00	1.218944	.716022	.529343	.132750	.108013	.033939	57.00	3.600976	2.100622	1.539076	.385220	.310784	.092748
31.50	1.254094	.736441	.544277	.136484	.111021	.034818	58.00	3.714014	2.166491	1.587044	.397214	.320399	.095522
32.00	1.289685	.757114	.559395	.140264	.114066	.035708	59.00	3.828558	2.233258	1.635665	.409371	.330144	.098333
32.50	1.325715	.778041	.574695	.144090	.117147	.036607	60.00	3.944603	2.300920	1.684935	.421690	.340019	.101180
33.00	1.362183	.799220	.590178	.147961	.120264	.037518	61.00	4.062140	2.369474	1.734854	.434172	.350022	.104064
33.50	1.399087	.820652	.605843	.151878	.123417	.038438	62.00	4.181162	2.438916	1.785419	.446815	.360154	.106984
34.00	1.436426	.842334	.621688	.155840	.126607	.039368	63.00	4.301661	2.509244	1.836627	.459619	.370414	.109940
34.50	1.474198	.864267	.637715	.159847	.129832	.040309	64.00	4.423630	2.580453	1.888477	.472583	.380803	.112932
35.00	1.512401	.886450	.653922	.163899	.133093	.041260	65.00	4.547063	2.652542	1.940967	.485708	.391318	.115960
35.50	1.551035	.908882	.670309	.167997	.136390	.042220	66.00	4.671952	2.725506	1.994095	.498992	.401961	.119024
36.00	1.590097	.931563	.686875	.172139	.139722	.043191	67.00	4.798289	2.799343	2.047859	.512435	.412730	.122124
36.50	1.629587	.954491	.703621	.176326	.143090	.044172	68.00	4.926069	2.874049	2.102257	.526036	.423625	.125259
37.00	1.669502	.977666	.720544	.180557	.146493	.045163	69.00	5.055284	2.949622	2.157287	.539796	.434646	.128430
37.50	1.709843	1.001088	.737645	.184833	.149932	.046164	70.00	5.185928	3.026059	2.212947	.553713	.445793	.131637
38.00	1.750606	1.024756	.754923	.189153	.153406	.047175	71.00	5.317994	3.103356	2.269235	.567787	.457065	.134878
38.50	1.791791	1.048669	.772379	.193518	.156916	.048196	72.00	5.451475	3.181511	2.326150	.582018	.468462	.138155
39.00	1.833397	1.072827	.790011	.197926	.160460	.049227	73.00	5.586365	3.260521	2.383689	.596405	.479984	.141467
39.50	1.875422	1.097229	.807819	.202379	.164039	.050267	74.00	5.722657	3.340383	2.441851	.610947	.491630	.144814
40.00	1.917865	1.121874	.825803	.206876	.167653	.051318	75.00	5.860344	3.421095	2.500634	.625645	.503399	.148196

RANGES IN GM/SQCM FOR SILICON

Z= 14 A= 28.086 I= 173.5

E(MEV)	P	D	T	HE 3	HE 4	LI 7	E(MEV)	P	D	T	HE 3	HE 4	LI 7
75.00	5.860344	3.421095	2.500634	.625645	.503399	.148196	120.00	13.407743	7.892332	5.763194	1.441406	1.156578	.335347
76.00	5.999422	3.502654	2.560036	.640498	.515292	.151613	122.00	13.800639	8.127495	5.935191	1.484411	1.191027	.345203
77.00	6.139882	3.585056	2.620055	.655505	.527309	.155065	124.00	14.198116	8.365629	6.109404	1.527971	1.225923	.355186
78.00	6.281720	3.668300	2.680690	.670666	.539448	.158551	126.00	14.600138	8.606718	6.285824	1.572083	1.261263	.365295
79.00	6.424928	3.752383	2.741938	.685980	.551710	.162073	128.00	15.006671	8.850750	6.464443	1.616744	1.297047	.375531
80.00	6.569502	3.837302	2.803799	.701448	.564094	.165628	130.00	15.417682	9.097709	6.645252	1.661953	1.333272	.385893
81.00	6.715434	3.923054	2.866270	.717068	.576601	.169218	132.00	15.833138	9.347580	6.828242	1.707707	1.369937	.396380
82.00	6.862719	4.009637	2.929351	.732840	.589229	.172843	134.00	16.253004	9.600351	7.013404	1.754004	1.407040	.406993
83.00	7.011351	4.097049	2.993038	.748765	.601978	.176502	136.00	16.677249	9.856008	7.200731	1.800843	1.444581	.417730
84.00	7.161323	4.185287	3.057332	.764840	.614848	.180195	138.00	17.105841	10.114535	7.390213	1.848220	1.482557	.428592
85.00	7.312631	4.274348	3.122230	.781067	.627839	.183922	140.00	17.538747	10.375921	7.581843	1.895135	1.520967	.439578
86.00	7.465268	4.364230	3.187730	.797445	.640951	.187683	142.00	17.975936	10.640152	7.775612	1.944584	1.559809	.450688
87.00	7.619229	4.454931	3.253832	.813973	.654183	.191479	144.00	18.414737	10.907214	7.971513	1.993566	1.599082	.461921
88.00	7.774508	4.546448	3.320534	.830650	.667535	.195308	146.00	18.863040	11.177095	8.169537	2.043080	1.638785	.473278
89.00	7.931100	4.638778	3.387833	.847478	.681006	.199171	148.00	19.312893	11.449781	8.369676	2.093122	1.678916	.484757
90.00	8.088998	4.731920	3.455730	.864454	.694597	.203067	150.00	19.766907	11.725259	8.571924	2.143691	1.719474	.496338
91.00	8.248198	4.825871	3.524221	.881580	.708307	.206998	152.00	20.225052	12.003518	8.776269	2.194785	1.760457	.508081
92.00	8.408693	4.920629	3.593306	.898854	.722136	.210962	154.00	20.687298	12.284544	8.982694	2.246399	1.801865	.519926
93.00	8.570479	5.016191	3.662984	.916276	.736084	.214960	156.00	21.153617	12.568325	9.191205	2.298534	1.843695	.531893
94.00	8.733550	5.112555	3.733252	.933845	.750150	.218991	158.00	21.623980	12.854849	9.401792	2.351189	1.885946	.543981
95.00	8.897901	5.209719	3.804110	.951563	.764334	.223056	160.00	22.098357	13.144103	9.614450	2.404361	1.928618	.556189
96.00	9.063526	5.307680	3.875556	.969427	.778636	.227154	162.00	22.576722	13.436075	9.829170	2.458048	1.971708	.568518
97.00	9.230420	5.406437	3.947589	.987438	.793055	.231285	164.00	23.059045	13.730754	10.045945	2.512250	2.015216	.580967
98.00	9.398578	5.505987	4.020207	1.005595	.807592	.235449	166.00	23.545300	14.028128	10.264767	2.566964	2.059140	.593536
99.00	9.567995	5.606328	4.093409	1.023898	.822246	.239647	168.00	24.035460	14.328184	10.485631	2.622188	2.103479	.606225
100.00	9.738665	5.707458	4.167193	1.042347	.837016	.243878	170.00	24.529496	14.630912	10.708528	2.677920	2.148231	.619033
101.00	9.910584	5.809374	4.241559	1.060941	.851903	.248141	172.00	25.027383	14.936299	10.933452	2.734159	2.193397	.631959
102.00	10.083746	5.912069	4.316504	1.079680	.866906	.252438	174.00	25.529093	15.244334	11.160396	2.790903	2.238973	.645005
103.00	10.258147	6.015545	4.392027	1.098564	.882025	.256767	176.00	26.034601	15.555007	11.389353	2.848151	2.284959	.658169
104.00	10.433781	6.119801	4.468128	1.117591	.897260	.261130	178.00	26.543881	15.868305	11.620316	2.905900	2.331354	.671450
105.00	10.610644	6.224835	4.544804	1.136763	.912611	.265525	180.00	27.056906	16.184217	11.853278	2.964149	2.378157	.684850
106.00	10.788730	6.330646	4.622055	1.156079	.928076	.269953	182.00	27.573652	16.502733	12.081233	3.022896	2.425366	.698367
107.00	10.968035	6.437230	4.699879	1.175538	.943657	.274414	184.00	28.094094	16.823842	12.325174	3.082140	2.472981	.712001
108.00	11.148554	6.544586	4.778275	1.195140	.959353	.278907	186.00	28.618205	17.147532	12.564094	3.141878	2.520999	.725753
109.00	11.330282	6.652711	4.857242	1.214884	.975163	.283432	188.00	29.145962	17.473792	12.804987	3.202110	2.569420	.739620
110.00	11.513214	6.761605	4.936778	1.234771	.991088	.287991	190.00	29.677340	17.802613	13.047847	3.262834	2.618244	.753605
111.00	11.697346	6.871264	5.016883	1.254800	1.007127	.292581	192.00	30.212315	18.133984	13.292666	3.324048	2.667468	.767705
112.00	11.882672	6.981687	5.097554	1.274971	1.023280	.297204	194.00	30.750862	18.467894	13.539439	3.385750	2.717091	.781922
113.00	12.069189	7.092872	5.178792	1.295284	1.039546	.301860	196.00	31.292959	18.804332	13.788160	3.447939	2.767113	.796254
114.00	12.256891	7.204817	5.260593	1.315737	1.055926	.306547	198.00	31.838580	19.143288	14.038822	3.510613	2.817532	.810701
115.00	12.445774	7.317519	5.342959	1.336331	1.072420	.311267	200.00	32.387704	19.484753	14.291418	3.573772	2.868347	.825263
116.00	12.635833	7.430977	5.425886	1.357066	1.089026	.316019							
117.00	12.827064	7.545190	5.509375	1.377942	1.105745	.320803							
118.00	13.019463	7.660154	5.593423	1.398957	1.122577	.325619							
119.00	13.213024	7.775869	5.678030	1.420112	1.139522	.330467							
120.00	13.407743	7.892332	5.763194	1.441406	1.156578	.335347							

Table 3

Conversion table for thickness of monocrystalline silicon absorbers. Density used $\rho = 2.3290 \text{ g cm}^{-3}$ (Ref. 24)

mg cm^{-2}	mm	μ	mils = 0.001"
1	0.0043	4.294	0.169
2	0.0086	8.587	0.338
3	0.0129	12.881	0.507
4	0.0172	17.175	0.676
5	0.0215	21.468	0.845
6	0.0258	25.76	1.014
7	0.0301	30.06	1.183
8	0.0344	34.35	1.352
9	0.0386	38.64	1.521
10	0.0429	42.94	1.690
20	0.0859	85.87	3.338
40	0.1718	171.75	6.762
70	0.3006	300.6	11.83
100	0.4294	429.4	16.90
200	0.8587	858.7	33.38
400	1.7175	1717.5	67.62
700	3.006	3006.	118.3
1000	4.294	4294	169.0
2000	8.587	8587	333.8
4000	17.175	17175	676.2
7000	30.056	30056	1183
10000	42.9369	42937	1690.431

Table 4

Table lookup in a FORTRAN program.

Example: Find the range RX for a particle of energy E1 = 2.12. The following FORTRAN statements are necessary:

```
DIMENSION R(11)
```

```
XA = E1*5.0
```

```
JX = XA - 3.99999
```

```
RX = R(JX) + (R(JX+1) - R(JX))*(XA - FLOAT(JX+4))
```

J	E	R(J)
1	1.0	3.80
2	1.2	5.01
3	1.4	6.36
4	1.6	7.83
5	1.8	9.43
6	2.0	11.15
7	2.2	13.00
8	2.4	14.96
9	2.6	17.04
10	2.8	19.24
11	3.0	21.55

Note that it is not necessary to store E in the memory.

Table 5.

POLYNOMIAL APPROXIMATION FOR SILICON

PARTICLE P	LOWER E	UPPER E	ALPHA	C	MAX. DEV	CRL
ERROR= .1 0/0						
1.000	1.300		-.617530	174.902	-.1056	3.53470E-03
1.300	1.800		-.652180	176.499	-.1428	3.42925E-03
1.800	2.500		-.683931	179.824	-.1110	3.30238E-03
2.500	3.600		-.710193	184.204	-.1102	3.17435E-03
3.600	5.400		-.732328	189.502	-.1024	3.04619E-03
5.400	8.600		-.752515	196.064	-.1058	2.91032E-03
8.600	14.600		-.770541	203.818	-.1041	2.77109E-03
14.600	52.000		-.782407	210.407	.1108	2.66645E-03
52.000	77.000		-.763266	195.080	.1079	2.90716E-03
77.000	105.000		-.738363	175.079	.1056	3.28568E-03
105.000	138.000		-.708246	152.182	.1061	3.84669E-03
138.000	174.000		-.674162	128.655	.1015	4.64277E-03
174.000	200.000		-.643992	110.111	.0427	5.52422E-03
ERROR= .3 0/0						
1.000	1.600		-.630049	174.902	-.3279	3.50755E-03
1.600	2.800		-.683155	179.323	-.3237	3.31315E-03
2.800	5.600		-.726342	187.476	-.3255	3.08978E-03
5.600	12.800		-.760621	198.881	-.3015	2.85588E-03
12.800	67.000		-.779611	208.747	.3147	2.69187E-03
67.000	114.000		-.740052	176.759	.3004	3.25129E-03
114.000	174.000		-.687374	137.730	.3116	4.30289E-03
174.000	200.000		-.643992	110.111	.0427	5.52422E-03
ERROR= .6 0/0						
1.000	2.000		-.642434	174.902	-.6535	3.48110E-03
2.000	4.800		-.710855	183.397	-.6105	3.18709E-03
4.800	16.500		-.761745	198.637	-.6279	2.85757E-03
16.500	78.000		-.777539	207.630	.6003	2.70951E-03
78.000	152.000		-.717962	160.164	.6016	3.63432E-03
152.000	200.000		-.655272	116.892	.1570	5.16829E-03
ERROR= 1.0 0/0						
1.000	2.500		-.653642	174.902	-1.0302	3.45751E-03
2.500	9.000		-.734429	188.341	-1.0160	3.06126E-03
9.000	100.000		-.772518	204.781	1.0102	2.75499E-03
100.000	200.000		-.685216	136.989	.8409	4.33169E-03

STOPPING POWER $S=C \cdot E^{**} \text{ALPHA}$, RANGE $R=CRL \cdot E^{**}(1-\text{ALPHA})$.

PARTICLE D	LOWER E	UPPER E	ALPHA	C	MAX. DEV	CRL
ERROR= .1 0/0						
1.000	1.300		-.520459	256.298	-.1304	2.56614E-03
1.300	1.700		-.559184	258.916	-.1271	2.47710E-03
1.700	2.200		-.596165	264.047	-.1101	2.37269E-03
2.200	2.900		-.630300	271.249	-.1145	2.26133E-03
2.900	3.900		-.662246	280.634	-.1123	2.14370E-03
3.900	5.400		-.690440	291.612	-.1046	2.02859E-03
5.400	7.800		-.715280	304.087	-.1039	1.91720E-03
7.800	11.600		-.736314	317.513	-.1059	1.81388E-03
11.600	18.500		-.755371	332.696	-.1036	1.71231E-03
18.500	32.000		-.773005	350.262	-.1040	1.61027E-03
32.000	105.000		-.782572	362.071	.1040	1.54939E-03
105.000	156.000		-.762592	329.920	.1052	1.71965E-03
156.000	200.000		-.740027	294.389	.0664	1.95219E-03
ERROR= .3 0/0						
1.000	1.600		-.535653	256.298	-.3978	2.54075E-03
1.600	2.500		-.600379	264.215	-.3276	2.36494E-03
2.500	4.200		-.657904	278.515	-.3511	2.16566E-03
4.200	7.800		-.706393	298.586	-.3203	1.96269E-03
7.800	16.500		-.744207	322.703	-.3107	1.77664E-03
16.500	47.500		-.775741	352.530	-.3024	1.59744E-03
47.500	132.000		-.778857	356.796	.3157	1.57557E-03
132.000	200.000		-.746440	304.563	.1683	1.88005E-03
ERROR= .6 0/0						
1.000	1.800		-.544203	256.298	-.6060	2.52668E-03
1.800	3.500		-.628601	269.333	-.6419	2.27979E-03
3.500	8.000		-.700179	294.600	-.6140	1.99651E-03
8.000	24.000		-.752361	328.366	-.6181	1.73787E-03
24.000	164.000		-.776683	354.755	.6037	1.58658E-03
164.000	200.000		-.737936	291.146	.0436	1.97631E-03
ERROR= 1.0 0/0						
1.000	2.200		-.558391	256.298	-1.0630	2.50367E-03
2.200	5.400		-.662635	278.254	-1.0051	2.16153E-03
5.400	20.500		-.739485	316.757	-1.0267	1.81490E-03
20.500	198.000		-.773088	350.593	1.0250	1.60867E-03
198.000	200.000		-.729303	278.128	.0001	2.07914E-03

POLYNOMIAL APPROXIMATION FOR SILICON

PARTICLE T		ALPHA	C	MAX. DEV	CRL
LOWER E	UPPER E				
ERROR= .1 0/0					
1.000	1.200	-.401724	302.610	-.1043	2.35751E-03
1.200	1.400	-.385125	301.695	.3223	2.39300E-03
1.400	1.800	-.510147	314.657	-.1099	2.10447E-03
1.800	2.300	-.545983	321.356	-.1061	2.01284E-03
2.300	3.000	-.582705	331.337	-.1226	1.90691E-03
3.000	3.900	-.617808	344.364	-.1053	1.79496E-03
3.900	5.200	-.650374	359.970	-.1126	1.68326E-03
5.200	7.200	-.680768	378.468	-.1130	1.57204E-03
7.200	10.200	-.706990	398.575	-.1052	1.46980E-03
10.200	15.500	-.729743	420.202	-.1105	1.37581E-03
15.500	24.500	-.750656	444.992	-.1019	1.28365E-03
24.500	40.500	-.768623	471.315	-.1013	1.19965E-03
40.500	168.000	-.781536	494.388	.1047	1.13537E-03
168.000	200.000	-.765477	455.335	.0202	1.24396E-03
ERROR= .3 0/0					
1.000	1.600	-.424745	302.610	-.4142	2.31942E-03
1.600	2.500	-.543431	319.970	-.3545	2.02490E-03
2.500	3.900	-.605842	338.802	-.3180	1.83803E-03
3.900	6.400	-.661029	365.228	-.3122	1.64838E-03
6.400	11.800	-.707354	398.025	-.3100	1.47152E-03
11.800	25.000	-.744697	436.453	-.3124	1.31324E-03
25.000	67.000	-.775320	481.667	-.3022	1.16944E-03
67.000	198.000	-.779207	489.604	.3078	1.14797E-03
198.000	200.000	-.760933	444.505	.0001	1.27756E-03
ERROR= .6 0/0					
1.000	1.700	-.434884	302.610	-1.5424	2.30303E-03
1.700	3.100	-.563387	323.964	-.6248	1.97441E-03
3.100	6.000	-.644674	355.171	-.6008	1.71192E-03
6.000	14.800	-.711824	400.581	-.6041	1.45831E-03
14.800	52.000	-.763084	459.916	-.6142	1.23324E-03
52.000	200.000	-.779926	491.562	.3468	1.14293E-03
ERROR= 1.0 0/0					
1.000	1.700	-.434884	302.610	-1.5424	2.30303E-03
1.700	3.700	-.575552	326.062	-1.0058	1.94656E-03
3.700	10.000	-.677757	372.712	-1.0314	1.59918E-03
10.000	41.000	-.750625	440.799	-1.0111	1.29588E-03
41.000	200.000	-.779807	491.253	.2941	1.14373E-03

STOPPING POWER $S=C \cdot E^{**} \text{ALPHA}$, RANGE $R=CRL \cdot E^{**}(1-\text{ALPHA})$.

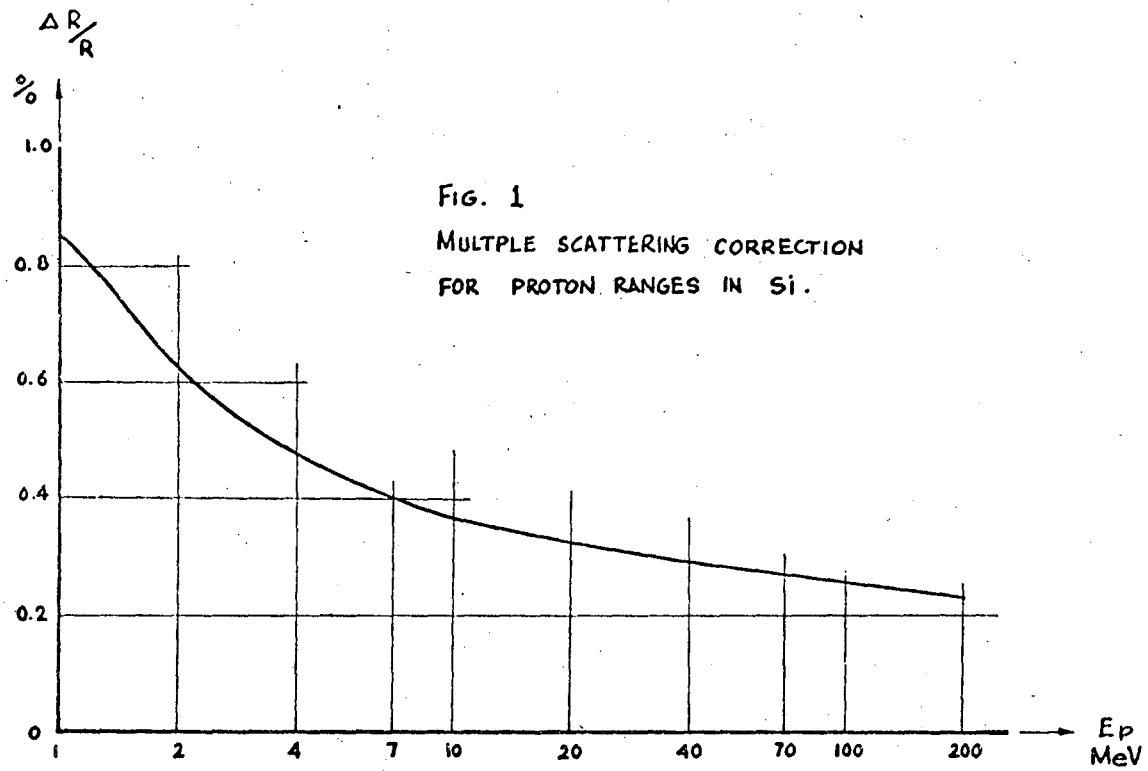
PARTICLE HE 3		ALPHA	C	MAX. DEV	CRL
LOWER E	UPPER E				
ERROR= .1 0/0					
1.000	1.100	-.239861	1183.209	-.4695	6.81656E-04
1.100	1.600	-.411304	1202.702	-.4314	5.89144E-04
1.600	2.100	-.530978	1272.290	-.1386	5.13387E-04
2.100	2.700	-.568649	1308.352	-.1169	4.87248E-04
2.700	3.500	-.604184	1355.355	-.1151	4.59931E-04
3.500	4.600	-.637166	1412.529	-.1083	4.32424E-04
4.600	6.200	-.668201	1481.037	-.1096	4.04749E-04
6.200	8.600	-.695216	1555.867	-.1027	3.79142E-04
8.600	12.600	-.719475	1639.238	-.1045	3.54783E-04
12.600	19.000	-.740286	1727.994	-.1030	3.32535E-04
19.000	30.500	-.758999	1825.876	-.1068	3.11360E-04
30.500	54.000	-.775868	1934.240	-.1009	2.91125E-04
54.000	150.000	-.783212	1991.737	.1023	2.81556E-04
150.000	200.000	-.767962	1845.220	.0475	3.06534E-04
ERROR= .3 0/0					
1.000	1.100	-.239861	1183.209	-.4695	6.81656E-04
1.100	1.600	-.411304	1202.702	-.4314	5.89144E-04
1.600	2.500	-.543460	1279.776	-.3544	5.06257E-04
2.500	3.900	-.605867	1355.090	-.3180	4.59539E-04
3.900	6.400	-.661048	1460.776	-.3122	4.12130E-04
6.400	11.800	-.707367	1591.933	-.3100	3.67916E-04
11.800	25.000	-.744705	1745.610	-.3124	3.28345E-04
25.000	67.000	-.775325	1926.423	-.3022	2.92395E-04
67.000	198.000	-.779203	1958.090	.3080	2.87040E-04
198.000	200.000	-.760922	1777.660	.0001	3.19456E-04
ERROR= .6 0/0					
1.000	1.200	-.308034	1183.209	-.6477	6.46129E-04
1.200	1.700	-.436239	1211.192	-.7652	5.74858E-04
1.700	3.100	-.563414	1295.747	-.6247	4.93635E-04
3.100	6.000	-.644696	1420.558	-.6007	4.28012E-04
6.000	14.800	-.711837	1602.156	-.6040	3.64614E-04
14.800	52.000	-.763090	1839.439	-.6141	3.08347E-04
52.000	200.000	-.779923	1965.937	.3470	2.85778E-04
ERROR= 1.0 0/0					
1.000	1.600	-.376537	1183.209	-1.0545	6.13975E-04
1.600	3.500	-.567343	1294.222	-1.0409	4.92977E-04
3.500	9.000	-.670556	1472.868	-1.0123	4.06420E-04
9.000	34.500	-.744729	1733.574	-1.0088	3.30620E-04
34.500	200.000	-.779261	1959.052	.2116	2.86889E-04

POLYNOMIAL APPROXIMATION FOR SILICON

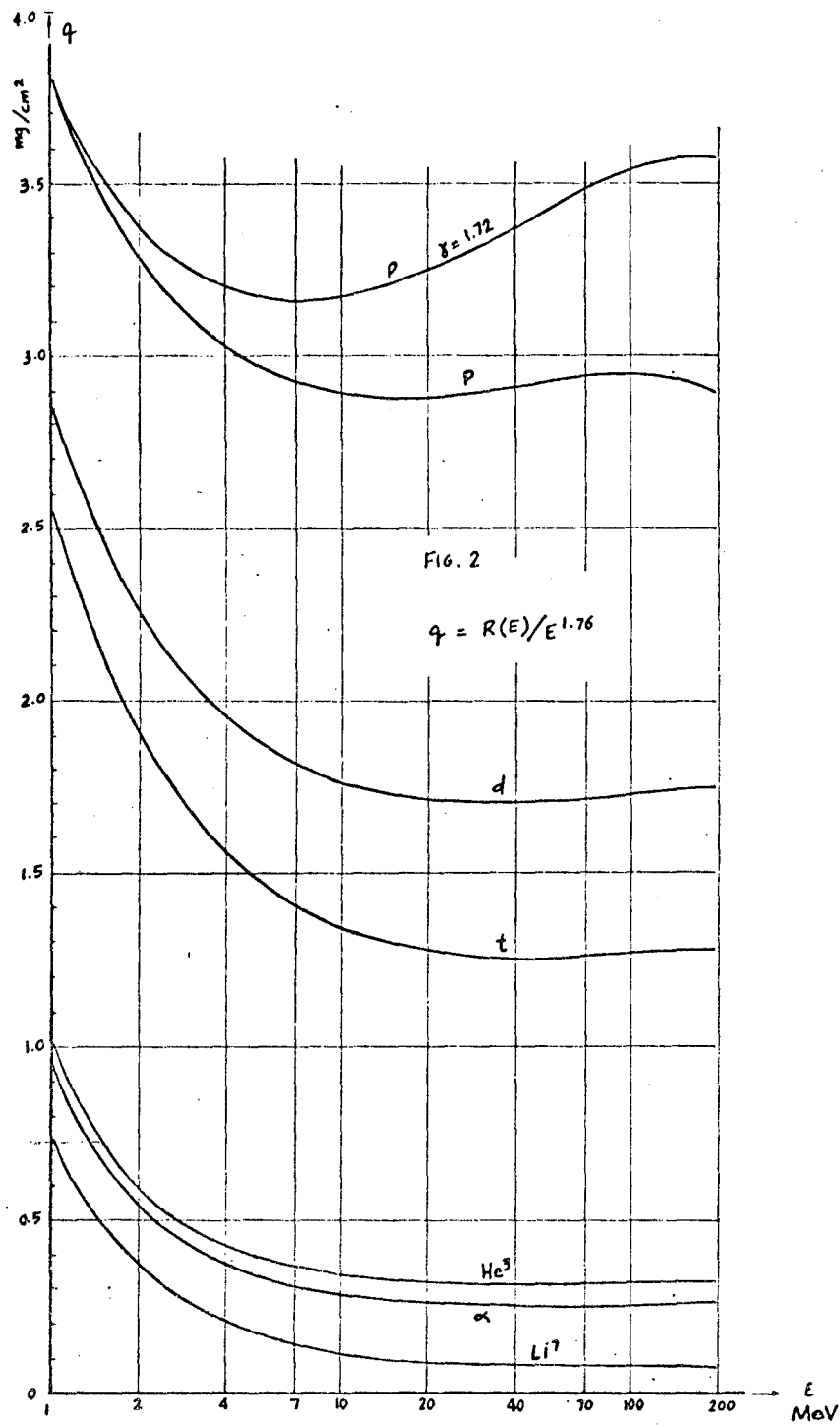
PARTICLE HE 4		ALPHA	C	MAX. DEV	CRL
LOWER E	UPPER E				
ERROR= .1 0/0					
1.000	1.100	-.114566	1224.494	.1434	7.32719E-04
1.100	1.300	-.120875	1225.231	-.1984	7.28157E-04
1.300	1.500	-.253018	1268.454	-.8041	6.29170E-04
1.500	2.100	-.411056	1352.396	-.3399	5.24025E-04
2.100	2.700	-.527499	1474.429	-.1162	4.44013E-04
2.700	3.500	-.564770	1530.034	-.1218	4.17684E-04
3.500	4.600	-.601978	1603.043	-.1191	3.89402E-04
4.600	6.000	-.635621	1687.494	-.1042	3.62306E-04
6.000	8.000	-.665928	1781.663	-.1034	3.36913E-04
8.000	11.200	-.693389	1886.365	-.1094	3.13053E-04
11.200	16.500	-.718495	2004.317	-.1114	2.90326E-04
16.500	25.000	-.739762	2127.448	-.1079	2.70179E-04
25.000	39.500	-.758369	2258.766	-.1003	2.51778E-04
39.500	70.000	-.775243	2403.318	-.1039	2.34386E-04
70.000	200.000	-.783152	2485.444	.0831	2.25636E-04
ERROR= .3 0/0					
1.000	1.400	-.124199	1224.494	-.3188	7.26440E-04
1.400	2.100	-.404076	1345.410	-.4023	5.29365E-04
2.100	3.200	-.539900	1488.057	-.3230	4.36403E-04
3.200	5.000	-.601226	1598.081	-.3213	3.90795E-04
5.000	8.200	-.657368	1749.203	-.3160	3.44938E-04
8.200	15.000	-.704679	1932.295	-.3112	3.03588E-04
15.000	31.500	-.742569	2141.094	-.3009	2.68024E-04
31.500	81.000	-.773503	2382.237	-.3049	2.36692E-04
81.000	200.000	-.783138	2485.265	.0949	2.25654E-04
ERROR= .6 0/0					
1.000	1.500	-.166029	1224.494	-1.1715	7.00380E-04
1.500	2.200	-.423023	1358.974	-.6384	5.17103E-04
2.200	4.000	-.559613	1513.501	-.6230	4.23644E-04
4.000	7.800	-.641878	1696.334	-.6111	3.59044E-04
7.800	18.500	-.709373	1948.602	-.6167	3.00220E-04
18.500	60.000	-.759650	2256.487	-.6133	2.51849E-04
60.000	200.000	-.782804	2480.863	.0507	2.26096E-04
ERROR= 1.0 0/0					
1.000	1.500	-.166029	1224.494	-1.1715	7.00380E-04
1.500	2.400	-.441665	1369.285	-1.2492	5.06573E-04
2.400	5.200	-.583613	1550.472	-1.0283	4.07274E-04
5.200	14.400	-.683771	1828.848	-1.0015	3.24743E-04
14.400	64.000	-.755333	2213.465	-1.0143	2.57376E-04
64.000	200.000	-.782977	2483.150	.0662	2.25866E-04

STOPPING POWER S=C*E**ALPHA, RANGE R=CRL*E**((1-ALPHA)).

PARTICLE LI 7		ALPHA	C	MAX. DEV	CRL
LOWER E	UPPER E				
ERROR= .1 0/0					
1.000	1.300	.145035	1870.058	.2437	6.25456E-04
1.300	1.500	.074484	1904.996	-.5706	5.67181E-04
1.500	1.800	-.080263	2028.353	-.1521	4.56381E-04
1.800	2.200	-.031872	1971.472	-.1294	4.91568E-04
2.200	3.000	-.252848	2346.702	-.1022	3.40129E-04
3.000	3.300	-.228107	2283.774	.1302	3.56542E-04
3.300	4.600	-.204832	2221.187	-.2075	3.73670E-04
4.600	5.800	-.281061	2495.205	-.1915	3.12841E-04
5.800	8.600	-.414103	3152.638	-.1099	2.24308E-04
8.600	9.000	-.469883	3554.679	-.1039	1.91389E-04
9.000	11.600	-.563372	4365.279	-.1058	1.46530E-04
11.600	13.600	-.594882	4715.771	-.1013	1.32959E-04
13.600	18.500	-.629789	5165.601	-.1208	1.18781E-04
18.500	23.500	-.677590	5938.721	-.1050	1.00374E-04
23.500	35.500	-.729072	6986.801	-.1060	8.27768E-05
35.500	56.000	-.749989	7528.431	-.1050	7.59032E-05
56.000	93.000	-.768101	8097.812	-.1041	6.98434E-05
93.000	198.000	-.782680	8651.001	-.1008	6.48426E-05
198.000	200.000	-.785738	8792.067	.0000	6.36929E-05
ERROR= .3 0/0					
1.000	1.400	.146502	1870.058	.3661	6.26531E-04
1.400	1.800	-.060549	2004.984	-.3732	4.70282E-04
1.800	2.300	-.069684	2015.779	-.6103	4.63769E-04
2.300	3.600	-.236902	2317.025	.4191	3.48926E-04
3.600	5.000	-.223643	2278.003	-.4188	3.58749E-04
5.000	6.000	-.311082	2622.235	-.4115	2.90870E-04
6.000	9.200	-.427981	3233.234	-.3816	2.16591E-04
9.200	13.800	-.578224	4512.724	-.3194	1.40408E-04
13.800	20.500	-.640425	5313.012	-.3345	1.14737E-04
20.500	31.500	-.712813	6611.436	-.3078	8.83068E-05
31.500	68.000	-.751107	7545.228	-.3074	7.56859E-05
68.000	200.000	-.779428	8502.974	-.2751	6.60920E-05
ERROR= .6 0/0					
1.000	1.600	.095632	1870.058	-1.2878	5.91289E-04
1.600	2.400	-.097473	2047.726	-.8778	4.44974E-04
2.400	3.800	-.227901	2295.419	.6201	3.54793E-04
3.800	5.800	-.251531	2368.983	-.6550	3.37285E-04
5.800	9.600	-.436925	3281.689	-.7299	2.12065E-04
9.600	16.500	-.594031	4681.858	-.6058	1.33994E-04
16.500	27.000	-.682865	6005.814	-.6194	9.89416E-05
27.000	79.000	-.750540	7506.541	-.6032	7.61006E-05
79.000	200.000	-.781131	8580.057	-.1810	6.54356E-05
ERROR= 1.0 0/0					
1.000	1.600	.095632	1870.058	-1.2878	5.91289E-04
1.600	2.500	-.110012	2059.829	-1.3363	4.37362E-04
2.500	6.200	-.251569	2345.106	-1.0130	3.40708E-04
6.200	10.200	-.455958	3405.012	-1.1403	2.01712E-04
10.200	21.500	-.620342	4987.882	-1.0419	1.23731E-04
21.500	78.000	-.743112	7269.417	-1.0152	7.89178E-05
78.000	200.000	-.780998	8573.997	-.1880	6.54867E-05

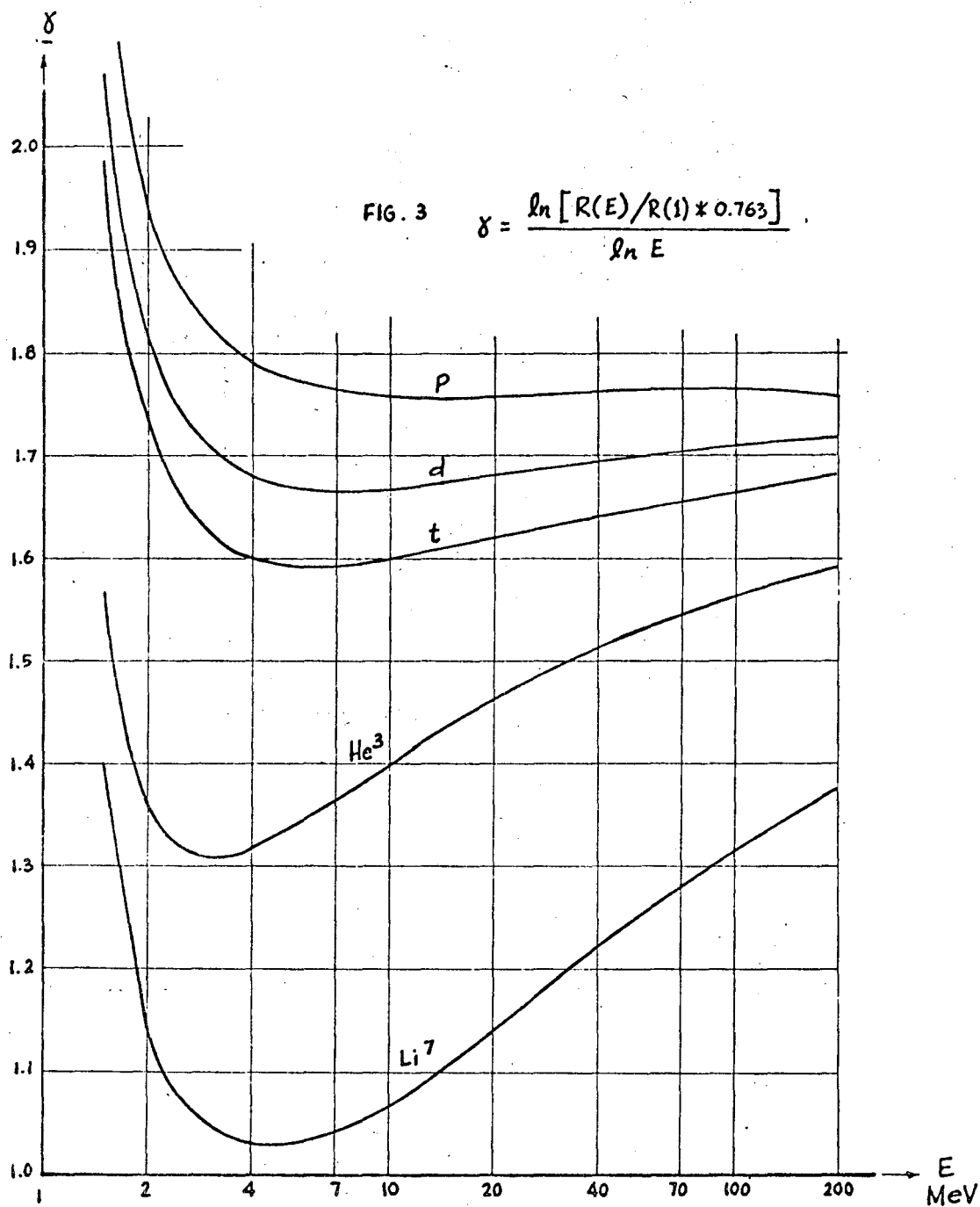


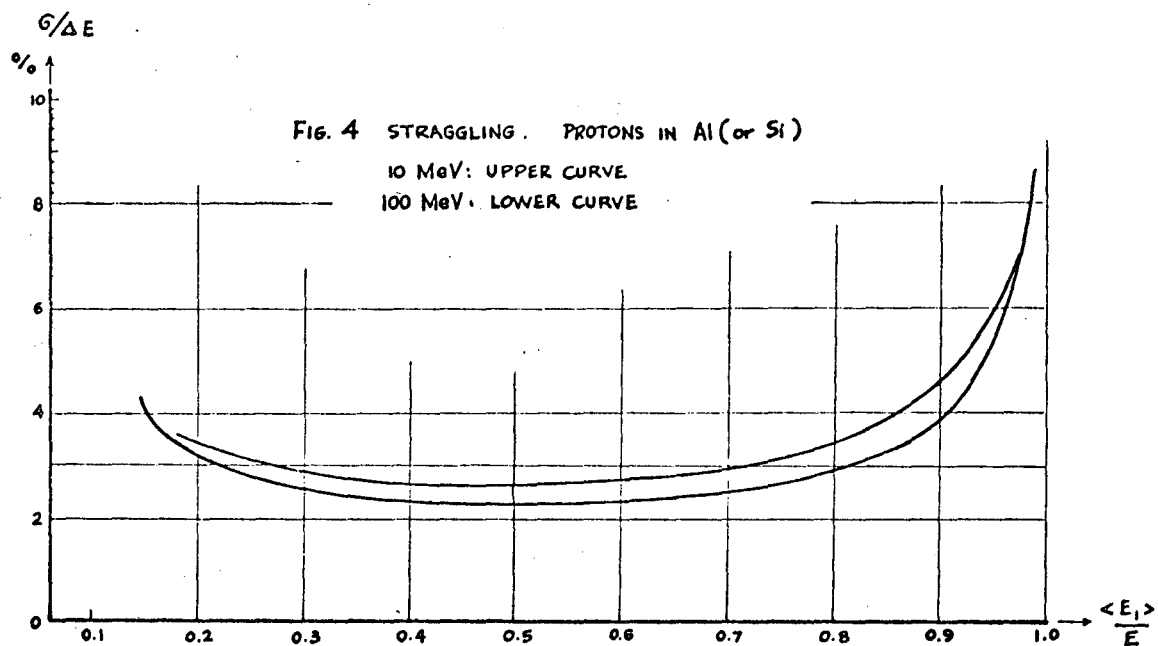
XBL 677-4253



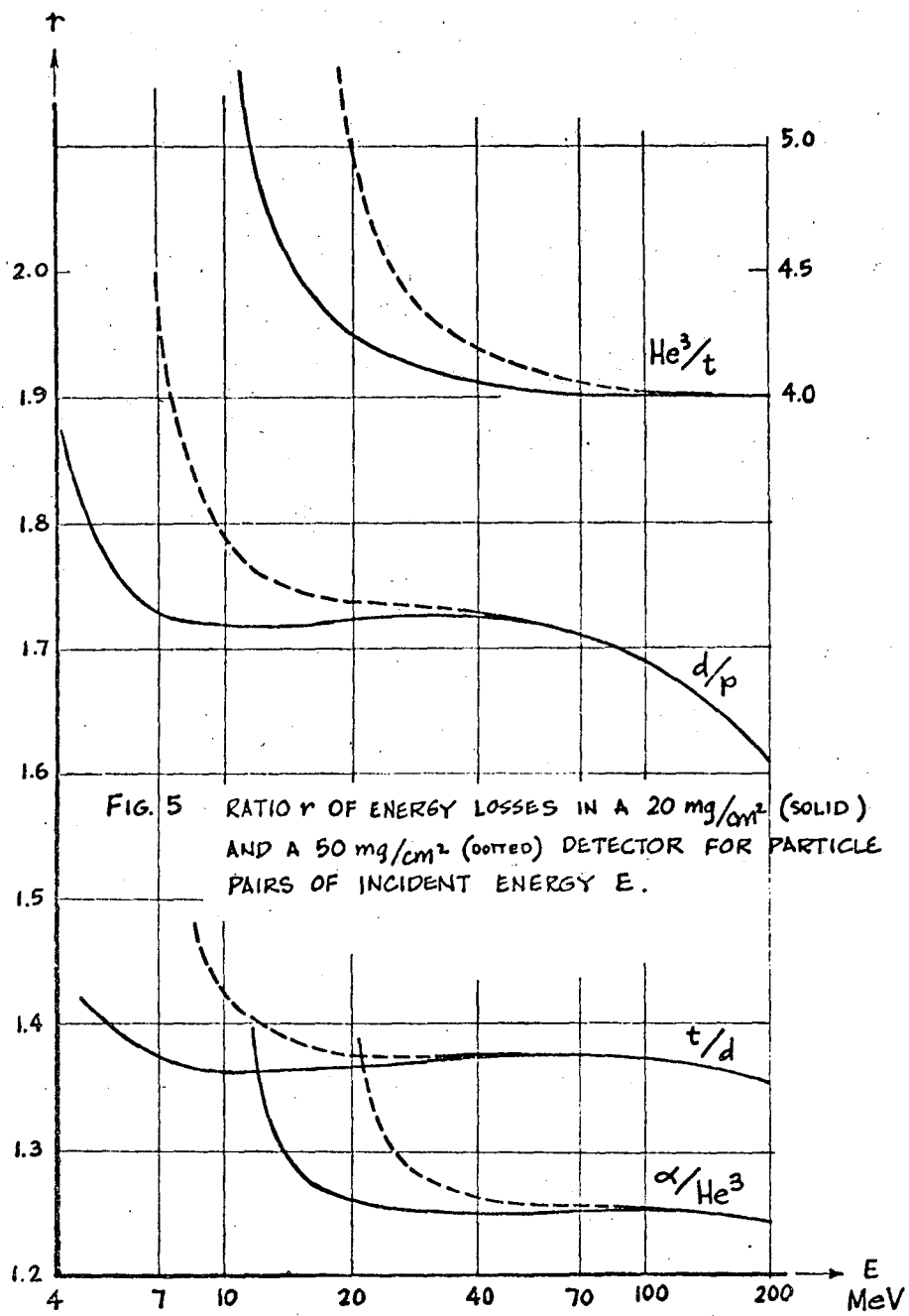
XBL 677-4256

Fig. 2

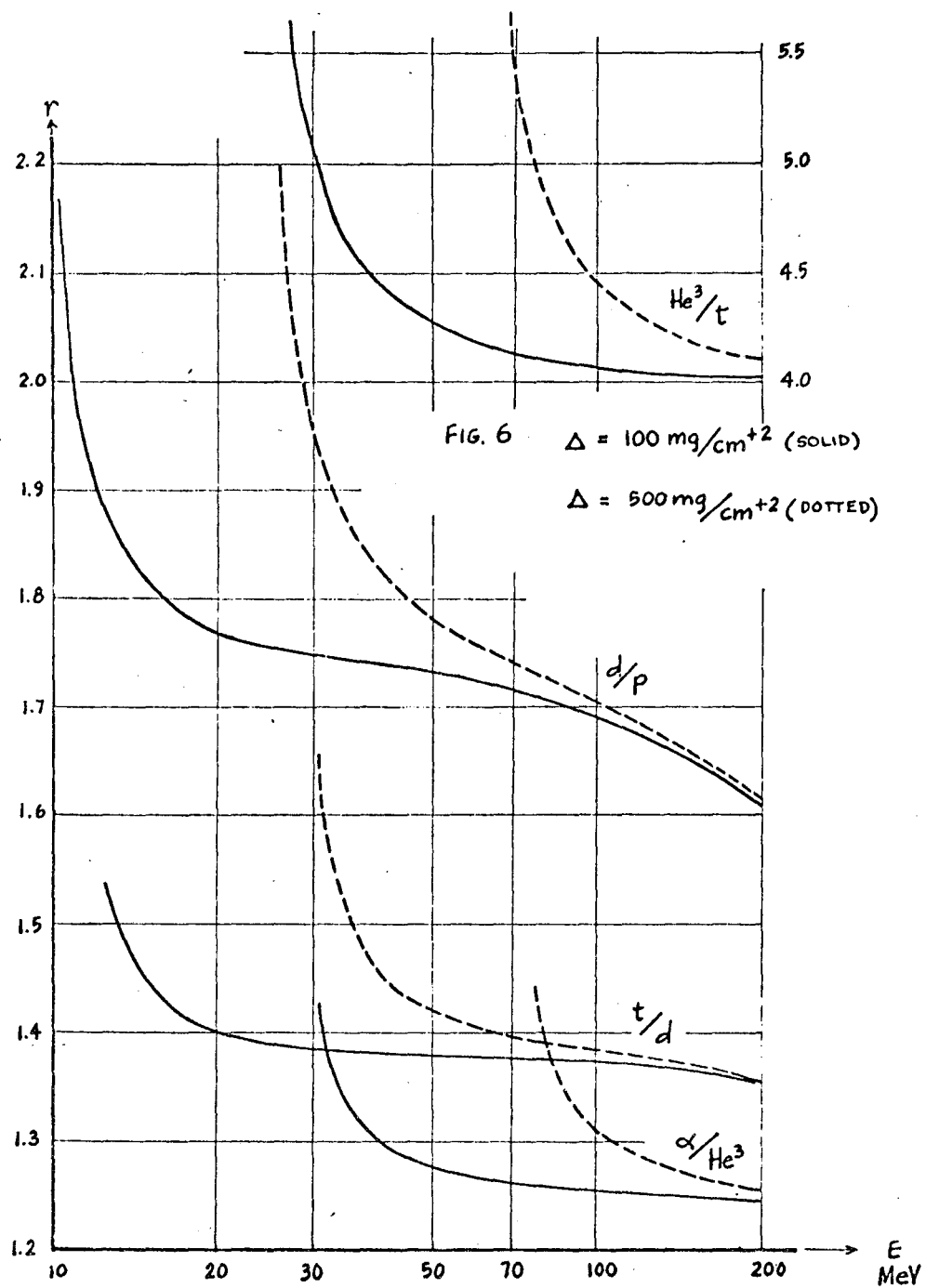




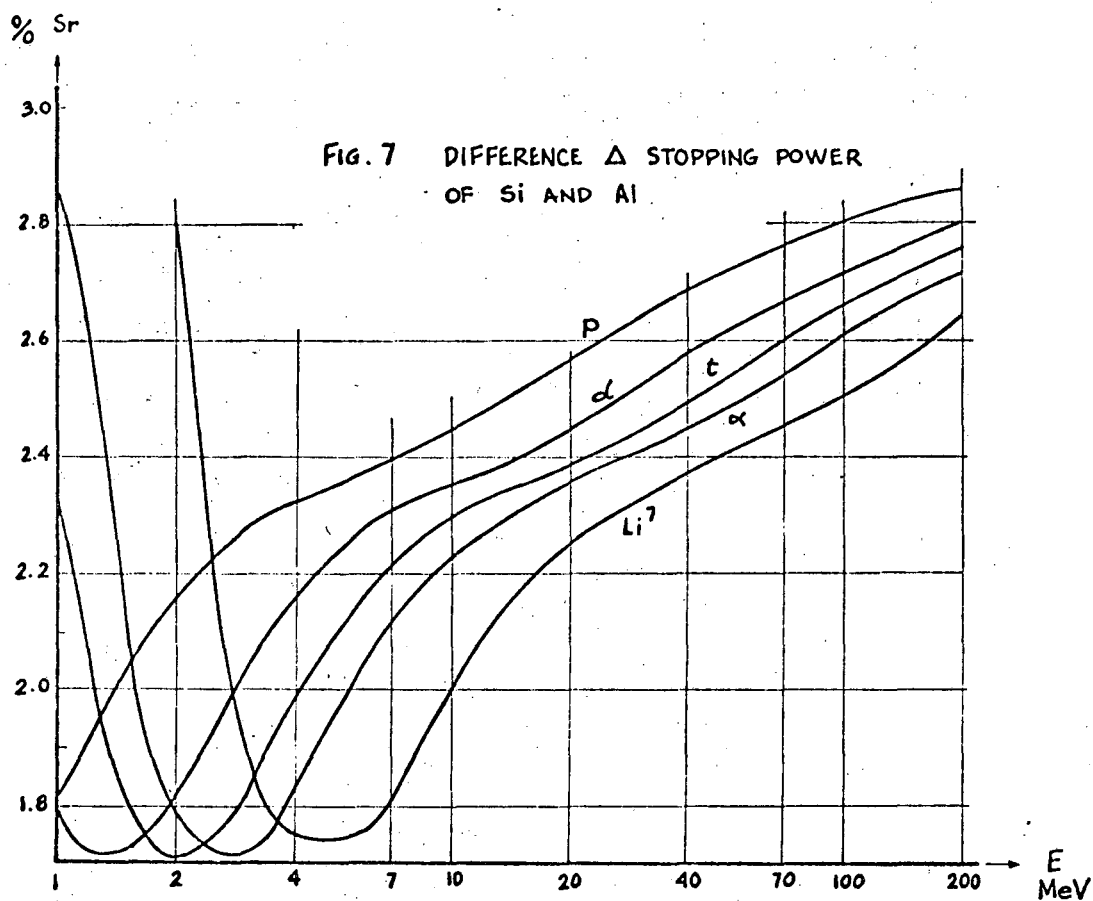
XBL 677-4254



XBL 677-4258



XBL 677-4259



XBL 677-4255

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