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THE THEORETICAL X-RAY ABSORPTION OF BARATOL 76

AND

COMPOSITION B IN THE 22 MEV BETRATRON SPECTRUM

by

Arthur I. Berman

PUBLICLY RELEASABLE
Per J. Brown, FSS-16 Date: 11-8-95
By [illegible], CIC-14 Date: 11-15-95

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It is often of interest in radiography to know the fraction of primary intensity transmitted by any material in bremsstrahlung[1], since it is essentially the primary radiation which contributes to the high quality of the radiographic image.

To find this value for any thickness of any mixture or compound requires three separate procedures: (1) Calculation of the mass absorption coefficients of each element in the material for all energies in the betatron spectrum. (2) Calculation of the linear absorption coefficient of the material through the spectrum. (3) Calculation of the fractional transmission of the primary beam for a given object thickness, by integrating the variable linear absorption curve over the betatron energy spectrum.

Calculation 1 is computed from a knowledge of the Compton, photoelectric, and pair-triplet cross sections of the elements. Details of this calculation are explained in a separate paper by the writer.[2]

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[1] The ratio of the number of initial quanta at a given energy times the energy of each quantum, summated over all energies, transmitted through a given thickness, to that at zero thickness.

[2] The Absorption of High-Energy X-Rays, AECU report to be published.

[redacted]

Calculation 2 is carried out first by multiplying the ratio of the atomic mass of a given element to the atomic mass of the mixture by the density of the mixture to obtain the density of the element in the material. Multiplying this result by the mass absorption coefficient of the element at a particular energy yields the linear coefficient of the element. The sum of these coefficients of all elements present will yield the total linear absorption coefficient of the material at the energy considered. In this manner, the absorption coefficient as a function of energy can be computed.

Calculation 3 is realized by integrating over the betatron energy spectrum for each thickness of material. A "parabolic" spectral distribution was assumed, $I_{0\epsilon} = I_{00} \sqrt{1-\epsilon/22 \text{ Mev}}$, where the first subscript refers to zero absorber thickness. This approximated both the Schiff bremsstrahlung function[3] and the distribution experimentally found by Koch and Carter[4]. By evaluating this integral for several thicknesses, a transmission curve of $I_x/I_0 = f(x)$ is obtained for the material considered.

These procedures are used for calculating this function for Baratol and Composition B. In the curves

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[3] G. D. Adams, Phys. Rev. 74, 1707 (1948).

[4] H. W. Koch and R. E. Carter, Phys. Rev. 77, 165 (1950).

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following, the mass absorption coefficients of hydrogen, carbon, nitrogen, oxygen, and barium are plotted in the 0.1 to 25 Mev range, together with the resulting linear absorption coefficients of the two explosives. Composition B, density 1.71 g/cm^3, is assumed to be of 61 percent RDX and 39 percent TNT. Baratol, density 2.61 g/cm^3, is of 76 percent barium nitrate and 24 percent TNT. Table I summarizes the results of the numerical integration of calculation 3, from zero to 22 Mev, for various thicknesses of Composition B. At each thickness, values of μ_x, defined by the equation: $\exp(-\mu_x x) = I_x/I_o$, are given in addition. Included also is the first half-value thickness found by these calculations and, alternately, by film density measurements. These measurements, performed by J. E. Withrow, were made with the film cassette and specimen in contact using Kodak Industrial Type A X-Ray Film with 0.010 in. front and 0.005 in. rear lead intensifying screens. These results provide some measure of the scattered intensity which affects the emulsion under ordinary radiographic conditions. For example, experimentally $I_x/I_o = 0.50$ for Composition B when x = 8.8 in. The calculated result $I(8.8 \text{ in.})/I_o = 0.36$. The fractional intensity due to scatter is thus 0.14, assuming that the film blackening is directly proportional to intensity. This is not strictly true since some of the blackening is due to the direct action of Compton electrons from

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the absorber. Table II lists similar results for Baratol.

From the calculations above, curves are shown of percent transmitted intensity, $(I_x/I_o) \times 100 = f(x)$ at each thickness to 30 in. of Composition B and 15 in. of Baratol. The total absorption, assuming ideal conditions in which all scatter is removed, is expressed by these curves. Calculation sheets also are included.

TABLE I

<table>
<tr><th colspan="4">COMPOSITION B</th></tr>
<tr><td colspan="4">1st Half-Value Thickness = 5.80 Inches (Theor.), 8.8 Inches (Exp.)</td></tr>
<tr><td>Thickness cm</td><td>x in.</td><td>I (x)/I (0)</td><td>μ_x cm^{-1}</td></tr>
<tr><td>1</td><td>0.394</td><td>0.9054</td><td>0.0995</td></tr>
<tr><td>5</td><td>1.97</td><td>0.7617</td><td>0.0546</td></tr>
<tr><td>10</td><td>3.94</td><td>0.6166</td><td>0.0483</td></tr>
<tr><td>50</td><td>19.68</td><td>0.1326</td><td>0.0404</td></tr>
<tr><td>100</td><td>39.4</td><td>0.0238</td><td>0.0374</td></tr>
</table>

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TABLE II

BARATOL			
1st Half-Value Thickness = 2.75 Inches (Theor.), 4.5 Inches (Exp.)			
Thickness cm	x in.	I (x)/I (0)	μ_x cm^{-1}
1	0.394	0.8653	0.1447
5	1.97	0.6057	0.1006
10	3.94	0.3886	0.0945
25	9.84	0.0997	0.0924
50	19.68	0.0117	0.0890

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CALCULATION I: MASS ABSORPTION COEFFICIENTS FOR EACH ELEMENT

ELEMENT	Z	A	N_0/A	N_0Z/A	$N_0Z(Z+1)/A$
	ATOMIC NO.	ATOMIC MASS	ATOMS/GM	ELECTRONS/GM	PAIR-TRIPLET FACTOR
HYDROGEN	1	1.008	0.5975×10^{24}	0.5975×10^{24}	1.195×10^{24}
CARBON	6	12.010	0.05154 "	0.3009 "	2.107 "
NITROGEN	7	14.008	0.04300 "	0.3010 "	2.408 "
OXYGEN	8	16.000	0.03764 "	0.3011 "	2.710 "
BARIUM	56	137.36	0.004386 "	0.2456 "	14.00 "

QUANTUM ENERGY-MEV	COMPTON COEFFICIENT CM^2/GM		PAIR-TRIPLET COEFFICIENT CM^2/GM	
0.1	0.492	$\times 10^{-24}$ N_0Z/A	—	
0.15	0.445	"	—	
0.2	0.410	"	—	
0.3	0.355	"	—	
0.5	0.290	"	—	
1.0	0.214	"	—	
1.5	—		0.00005	$\times 10^{-24}$ $N_0Z(Z+1)/A$
2.0	0.146	"	0.00017	"
2.5	—		0.00033	"
3.0	0.113	"	0.00050	"
5.0	0.082	"	0.00112	"
10.0	0.051	"	0.00215	"
25.0	0.024	"	0.00368	"

QUANTUM ENERGY-MEV	PHOTOELECTRIC COEFFICIENT (CM^2/GM)				
	Z = 1	Z=6	Z=7	Z=8	Z =56
0.102	0.0000	0.0026	0.0034	0.0049	2.064
0.153	—	0.0013	0.0008	0.0011	0.640
0.255	—	—	—	—	0.153
0.511	—	—	—	—	0.024
0.920	—	—	—	—	0.006
2.04	—	—	—	—	0.002

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CALCULATION 2A: LINEAR ABSORPTION COEFFICIENT OF COMP. B

$\rho = 1.71 g/cm^3$ 61% RDX $C_3H_6N_6O_6$ = $(ELEMENT)_x$ = $H_6C_3N_6O_6$
39% TNT $(NO_2)_3$ $C_6H_2CH_3$ = " = $H_5C_7N_3O_6$

	$61x + 39x$	× A	= M	$M/\Sigma M$	$(M/\Sigma M)\rho_{COMP B}$
H	366+195 = 561	1.008	565.5	0.0252	0.043
C	183+273 = 456	12.010	5476.6	0.2444	0.418
N	366+1.77 = 483	14.008	6765.9	0.3019	0.516
O	366+234 = 600	16.000	9600.0	0.4289	0.733
			ΣM = 22,408.0	Σ = 0.9999	Σ = 1.710

	hν = 0.1 MEV		hν = 0.15		hν = 0.2	
	μ/ρ (FROM CURVES OF ELEMENTS) ↓	$\mu/\rho\left(\frac{M}{\Sigma M}\right)\rho_{COMP. B}$ ↓				
H	0.294	0.0126	0.266	0.0114	0.245	0.0105
C	0.148	0.0619	0.134	0.0560	0.123	0.0514
N	0.151	0.0779	0.138	0.0712	0.123	0.0635
O	0.153	0.1121	0.138	0.1011	0.123	0.0901
	$\Sigma = \mu_{COMP. B}$	= 0.2645		Σ = 0.2397		Σ = 0.2155

	hν = 0.3		hν = 0.5		hν = 1	
H	0.212	0.0091	0.173	0.0074	0.1279	0.00550
C	0.107	0.0447	0.087	0.0364	0.0643	0.02688
N	0.107	0.0552	0.087	0.0449	0.0644	0.03323
O	0.107	0.0784	0.087	0.0638	0.0644	0.04721
	Σ =	0.1874	Σ =	0.1525	Σ =	0.11282

	hν = 2		hν = 3		hν = 5	
H	0.0875	0.00376	0.0681	0.00293	0.0503	0.00216
C	0.0443	0.01851	0.0351	0.01467	0.0270	0.01129
N	0.0443	0.02286	0.0352	0.01816	0.0273	0.01409
O	0.0444	0.03254	0.0354	0.02595	0.0276	0.02023
	Σ =	0.07767		Σ = 0.06171		Σ = 0.04777

	hν = 10		hν = 25	
H	0.0331	0.00142	0.0187	0.00080
C	0.0198	0.00828	0.0149	0.00623
N	0.0205	0.01058	0.0161	0.00831
O	0.0211	0.01547	0.0171	0.01253
		Σ = 0.03575		Σ = 0.02787

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CALCULATION 2B: LINEAR ABSORPTION COEFFICIENT OF BARATOL

$\rho = 2.62 g/cm^2$ 76% BAR. NITR. $Ba NO_3 = (ELEMENT)_\chi$ NO_3 Ba
24% TNT $(NO_2)_3$ $C_6H_2CH_3 = (ELEMENT)_\chi$ $H_5C_7N_3O_6$

	$76\chi + 24\chi$			× A	= M	M/ΣM	(M/ΣM)ρ BARATOL
H	0+120	=	120	1.008	121.0	0.0059	0.015
C	0+168	=	168	12.010	2017.7	0.0979	0.255
N	76+72	=	148	14.008	2073.2	0.1006	0.263
O	228+144	=	372	16.000	5952.0	0.2889	0.754
Ba	76+0	=	76	137.36	10,439.4	0.5067	1.322
					ΣM=20,603.3	Σ = 1.000	Σ=2.609

μ/ρ (FROM CURVES OF ELEMENTS) ↓ $(\mu/\rho)\left(\frac{M}{\Sigma M}\right)\rho$ BARATOL ↓

	hν = 0.1 MEV		hν = 0.15		hν = 0.2	
H	0.294	0.0044	0.266	0.0040	0.245	0.0037
C	0.148	0.0377	0.134	0.0342	0.123	0.0314
N	0.151	0.0397	0.138	0.0363	0.123	0.0323
O	0.153	0.1154	0.138	0.1041	0.123	0.0927
Ba	2.200	2.9084	0.800	1.0576	0.386	0.5103
Σ = μ BARATOL		= 3.1056		Σ = 1.2362		Σ = 0.6704

	hν = 0.5		hν = 1		hν = 2	
H	0.173	0.0026	0.1279	0.00192	0.0875	0.00131
C	0.087	0.0222	0.0643	0.01640	0.0443	0.01130
N	0.087	0.0229	0.0644	0.01693	0.0443	0.01165
O	0.087	0.0656	0.0644	0.04856	0.0444	0.03348
Ba	0.097	0.1282	0.0583	0.07707	0.0394	0.05208
		Σ = 0.2415		Σ = 0.1609		Σ = 0.10982

	hν = 3		hν = 5		hν = 10	
H	0.0681	0.00102	0.0503	0.00075	0.0331	0.00050
C	0.0351	0.00895	0.0270	0.00689	0.0198	0.00505
N	0.0352	0.00926	0.0273	0.00718	0.0205	0.00539
O	0.0354	0.02669	0.0276	0.02081	0.0211	0.01591
Ba	0.0351	0.04640	0.0360	0.04759	0.0426	0.05632
		Σ = 0.09232		Σ = 0.09250		Σ = 0.09317

	hν = 15		hν = 20		hν = 25	
H	0.0250	0.00038	0.0213	0.00032	0.0187	0.00028
C	0.0168	0.00428	0.0155	0.00395	0.0149	0.00380
N	0.0173	0.00455	0.0163	0.00429	0.0161	0.00423
O	0.0185	0.01395	0.0177	0.01335	0.0171	0.01289
Ba	0.0486	0.06425	0.0534	0.07059	0.0573	0.07588
		Σ = 0.08741		Σ = 0.09250		Σ = 0.09708

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CALCULATION 3A: TRANSMISSION THROUGH COMPOSITION B

E MEV	$I/I_{E=0}\sqrt{I\frac{E}{E_{MAX}}}$	$\mu(E)$	$e^{-\mu(E)\cdot x}$	$(I/I_{E=0})\left(e^{-\mu(E)\cdot x}\right)$	
	E_{MAX}= 22 MEV	cm^{-1}	$x=1$ cm	SIMPSON'S RULE	
				EVEN	ODD
0	1.000	∞	0		
2.2	0.949	0.0730	0.9296	0.8821	
4.4	0.895	0.0510	0.9503		0.8505
6.6	0.837	0.0425	0.9584	0.8022	
8.8	0.774	0.0375	0.9632		0.7455
11.0	0.707	0.0340	0.9666	0.6834	
13.2	0.633	0.0318	0.9687		0.6132
15.4	0.547	0.0300	0.9705	0.5309	
17.6	0.447	0.0290	0.9714		0.4342
19.8	0.316	0.0285	0.9719	0.3071	
22.0	0.000	—	SUM	3.2057	2.6434
			EVEN×4; ODD×2	12.823	5.2868
			SUM	18.1098	
			$\times\frac{1}{3}(2.2)$	3.2799	
			$\div 22 = I_{AVE}$	0.60363	
			I_{AVE}/I_0	0.023790 =	$e^{-\mu x}$
			$\therefore \mu x = 3.74$	$\mu = 0.0374$	

$e^{-\mu(E)\cdot x}$	$(I/I_0)\left(e^{-\mu(E)\cdot x}\right)$		$e^{-\mu(E)\cdot x}$	$(I/I_0)\left(e^{-\mu(E)\cdot x}\right)$	
$x=5$ cm	EVEN	ODD	$x=10$ cm	EVEN	ODD
0.694	0.6586		0.482	0.4574	
0.775		0.6936	0.600		0.5370
0.809	0.6711		0.654	0.5473	
0.829		0.6416	0.687		0.5317
0.844	0.5967		0.712	0.5034	
0.853		0.5399	0.728		0.4608
0.861	0.9710		0.741	0.4053	
0.865		0.3867	0.748		0.3344
0.868	0.2743		0.752	0.2376	
	2.6777	2.2618		2.1510	1.8639
	10.7108	4.5236		8.604	3.728
	15.2344			12.332	
	11.1714			9.043	
	0.50779			0.4110	
	0.76168			0.6116	
	0.273			0.483	
	0.0546			0.0483	

COMPOSITION B: SIMPSON'S RULE (CONT'D)

$e^{-\mu(E)\cdot x}$	$(I/I_0)\ (e^{-\mu(E)\cdot x})$		$e^{\mu(E)\cdot x}$	$(I/I_0)\ (e^{-\mu(E)\cdot x})$	
$x = 50$ cm	EVEN	ODD	$x = 100$ cm	EVEN	ODD
0.0260	0.0247		0.000676	0.000641	
0.0781		0.0699	0.006097		0.005457
0.1194	0.0999		0.01426	0.01193	
0.1532		0.1186	0.02352		0.01820
0.1827	0.1292		0.03337	0.02359	
0.2039		0.1291	0.04160		0.02633
0.2231	0.1220		0.04979	0.02723	
0.2346		0.1049	0.05502		0.02459
0.2405	0.0760		0.05784	0.01828	
SUM	0.4518	0.4225		0.08167	0.07458
EVEN ×4; ODD ×2	1.8072	0.8450		0.32668	0.14916
SUM	2.6522			0.47584	
$\times \frac{1}{3}(2.2) = 0.7333$	1.9449			0.34893	
$\div 22 = I_{AVE}$	0.08840			0.01586	
I_{AVE}/I_0	0.13260	$= e^{-\mu(x)}$		0.023790	
μX	2.022			3.74	
μ	0.0404			0.0374	

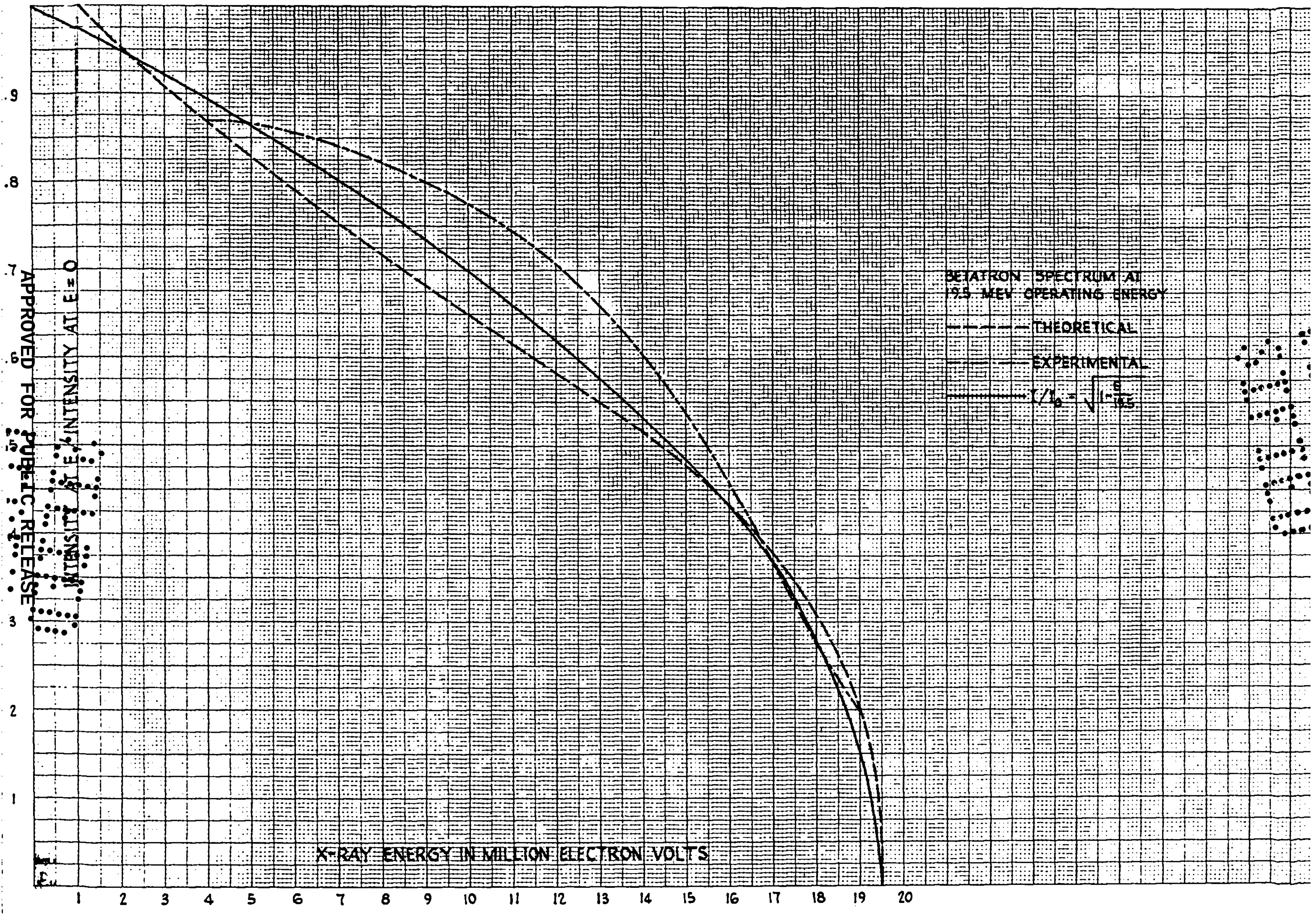
CALCULATION 3B: TRANSMISSION THROUGH BARATOL

$\mu(E)$	$e^{-\mu(E)\cdot x}$	$(I/I_0)\ (e^{-\mu(E)\cdot x})$	
cm^{-1}	$x = 1$ cm	EVEN	ODD
0.1050	0.9005	0.8546	
0.0845	0.9189		0.8224
0.0828	0.9205	0.7705	
0.0830	0.9203		0.7123
0.0840	0.9195	0.6501	
0.0858	0.9178		0.5810
0.0878	0.9160	0.5010	
0.0900	0.9140		0.4086
0.0923	0.9118	0.2881	
		3.0643	2.5253
		12.2572	5.0506
		17.3078	
		12.6923	
		0.5769	
		0.8653	
		0.1447	
		0.1447	

.BARATOL (CONT'D)

$e^{-\mu(E)\cdot x}$ $x=5$ cm	$(I/I_0)(e^{-\mu(E)\cdot x})$		$e^{-\mu(E)\cdot x}$ $x=10$ cm	$(I/I_0)(e^{-\mu(E)\cdot x})$	
	EVEN	ODD		EVEN	ODD
0.592	0.5618		0.350	0.3321	
0.655		0.5862	0.430		0.3848
0.661	0.5532		0.437	0.3658	
0.660		0.5108	0.436		0.3375
0.657	0.4645		0.432	0.3054	
0.651		0.4121	0.424		0.2684
0.645	0.3528		0.416	0.2276	
0.638		0.2852	0.407		0.1819
0.630	0.1991		0.398	0.1258	
SUM	2.1314	1.7943		1.3567	1.1726
EVEN×4;ODD×2	8.5256	3.5886		5.4268	2.3452
SUM	12.1142			7.7720	
$\times\frac{1}{3}(2.2)=0.7333$	8.88374			5.6994	
$\div 22 = I_{AVE}$	0.40381			0.25906	
I_{AVE}/I_0	0.60571			0.38858	
μx	0.503			0.945	
μ	0.1006			0.0945	

$x=25$ cm			$x=50$ cm		
0.0724	0.0687		0.00525	0.00498	
0.1210		0.1083	0.0147		0.01316
0.1262	0.1056		0.0159	0.01331	
0.1256		0.0972	0.0158		0.01223
0.1225	0.0866		0.0150	0.01061	
0.1170		0.0741	0.0137		0.00867
0.1113	0.0609		0.0124	0.00678	
0.1054		0.0471	0.0111		0.00496
0.0993	0.0314		0.0100	0.00316	
	0.3532	0.3267		0.03884	0.03902
	1.3413	0.6534		0.15536	0.07804
	1.9947			0.2334	
	1.4628			0.17116	
	0.066490			0.0077804	
	0.099734			0.011671	
	2.31			4.45	
	0.0924			0.0890	


BETATRON SPECTRUM AT
19.5 MEV OPERATING ENERGY
THEORETICAL
EXPERIMENTAL
$I/I_0 = \sqrt{1-\frac{E}{19.5}}$
INTENSITY AT E / INTENSITY AT E = O
X-RAY ENERGY IN MILLION ELECTRON VOLTS
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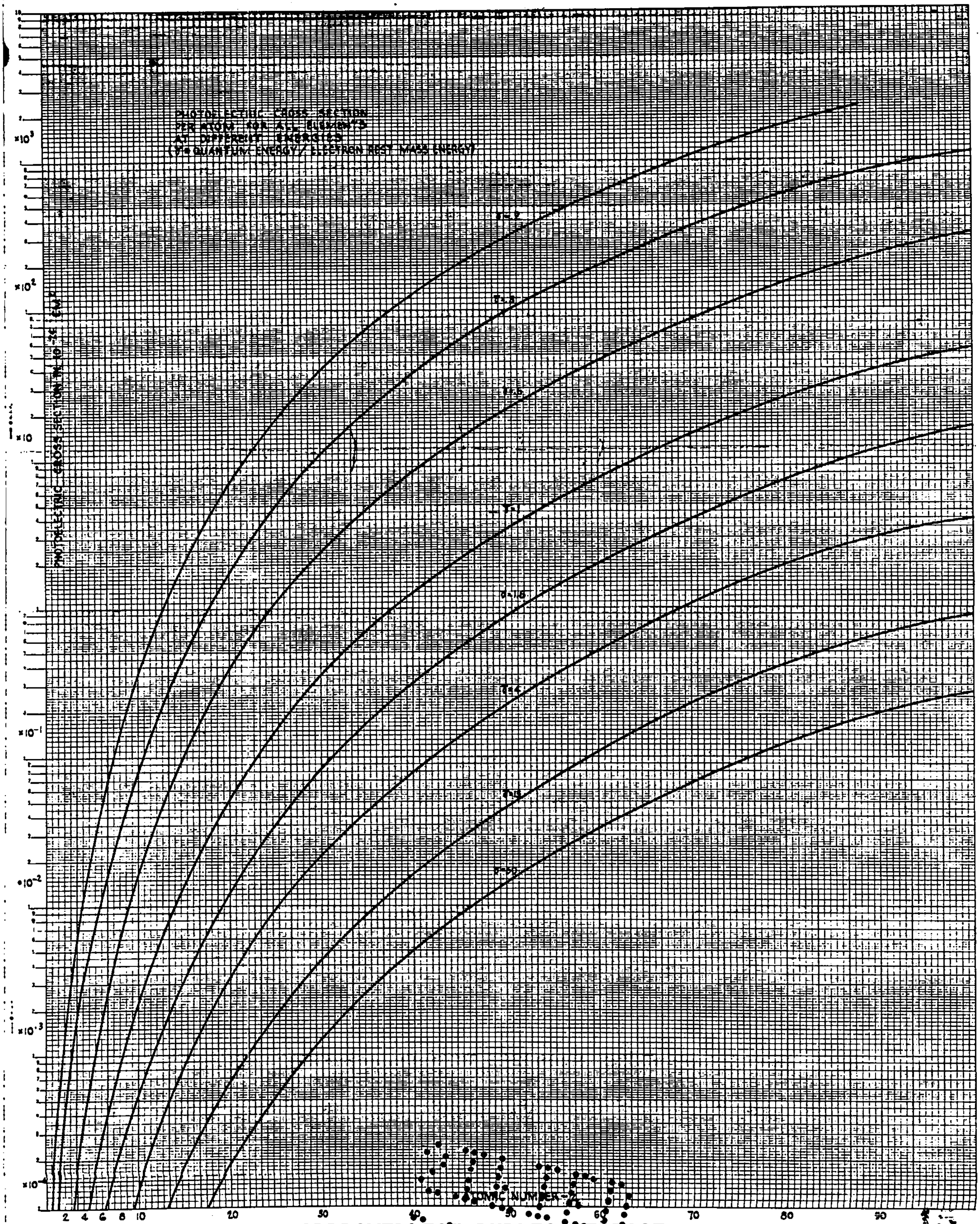
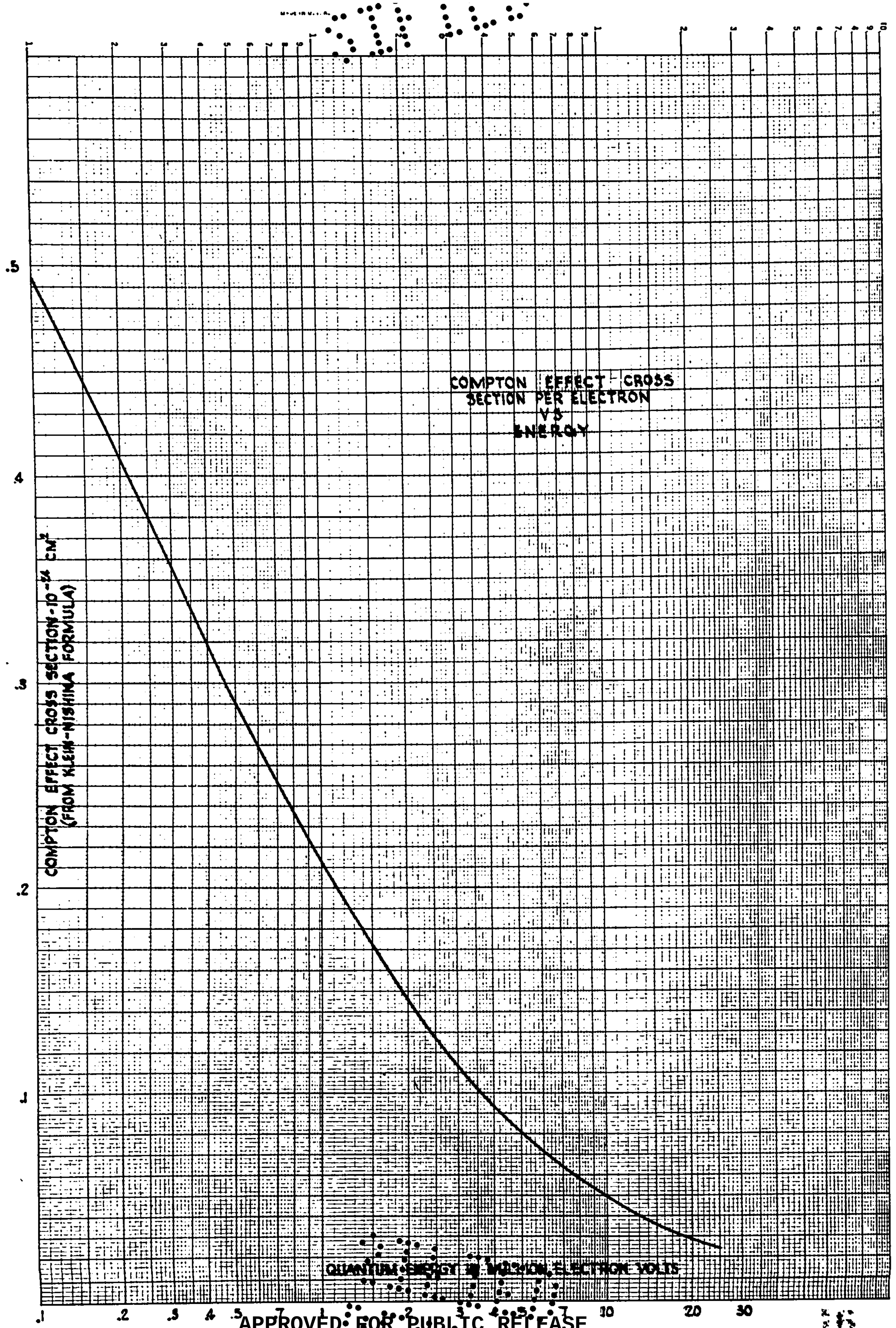
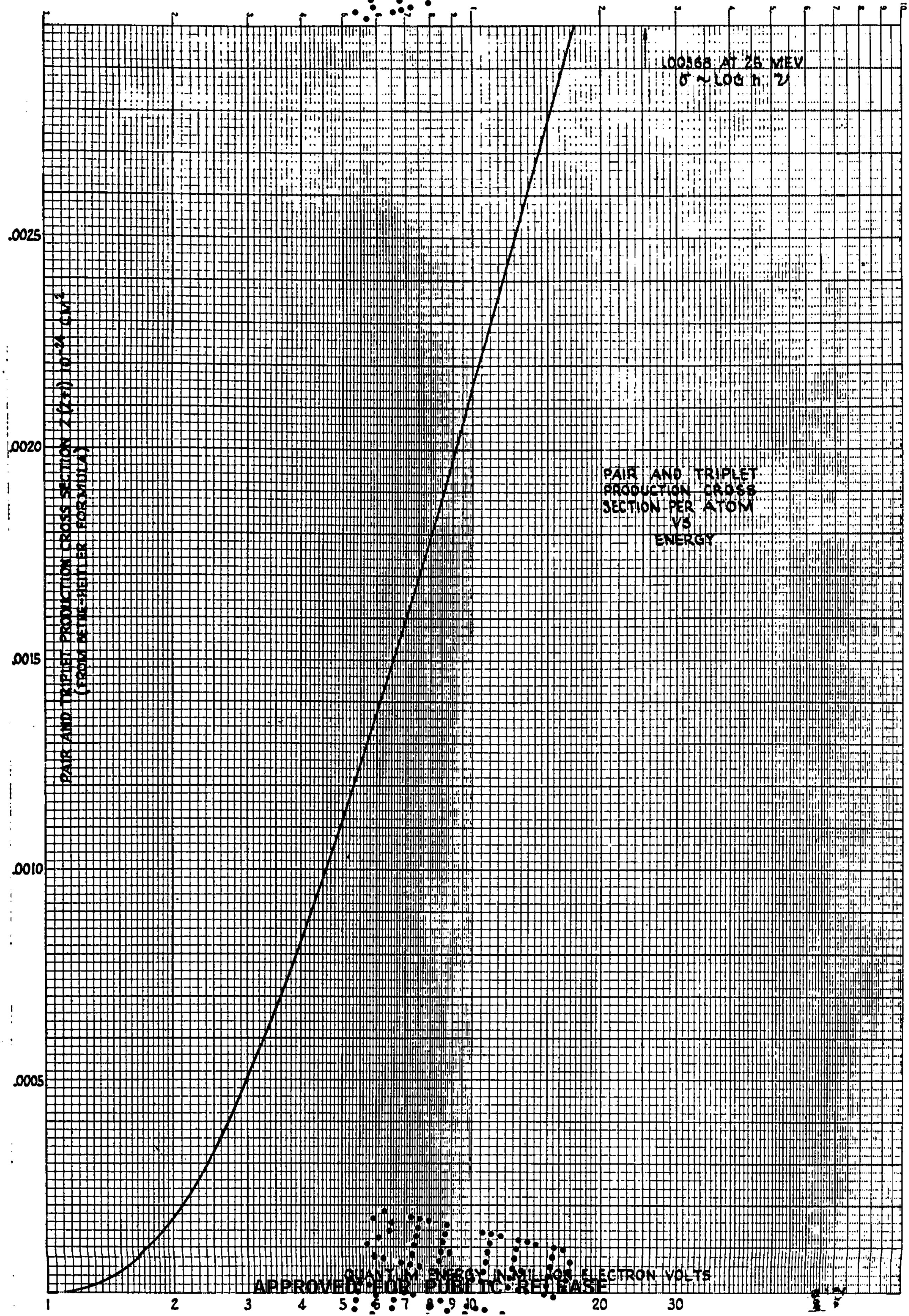
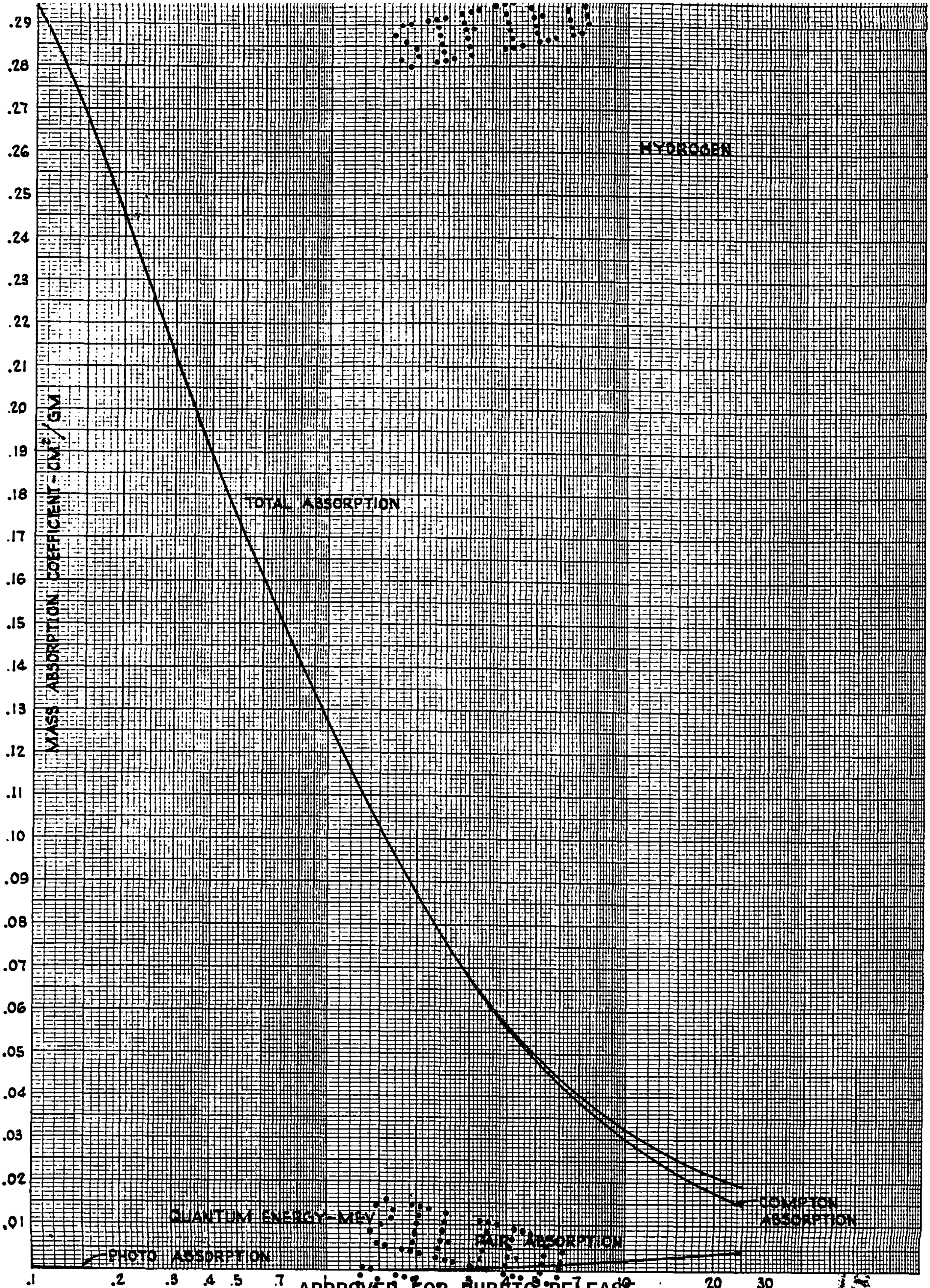
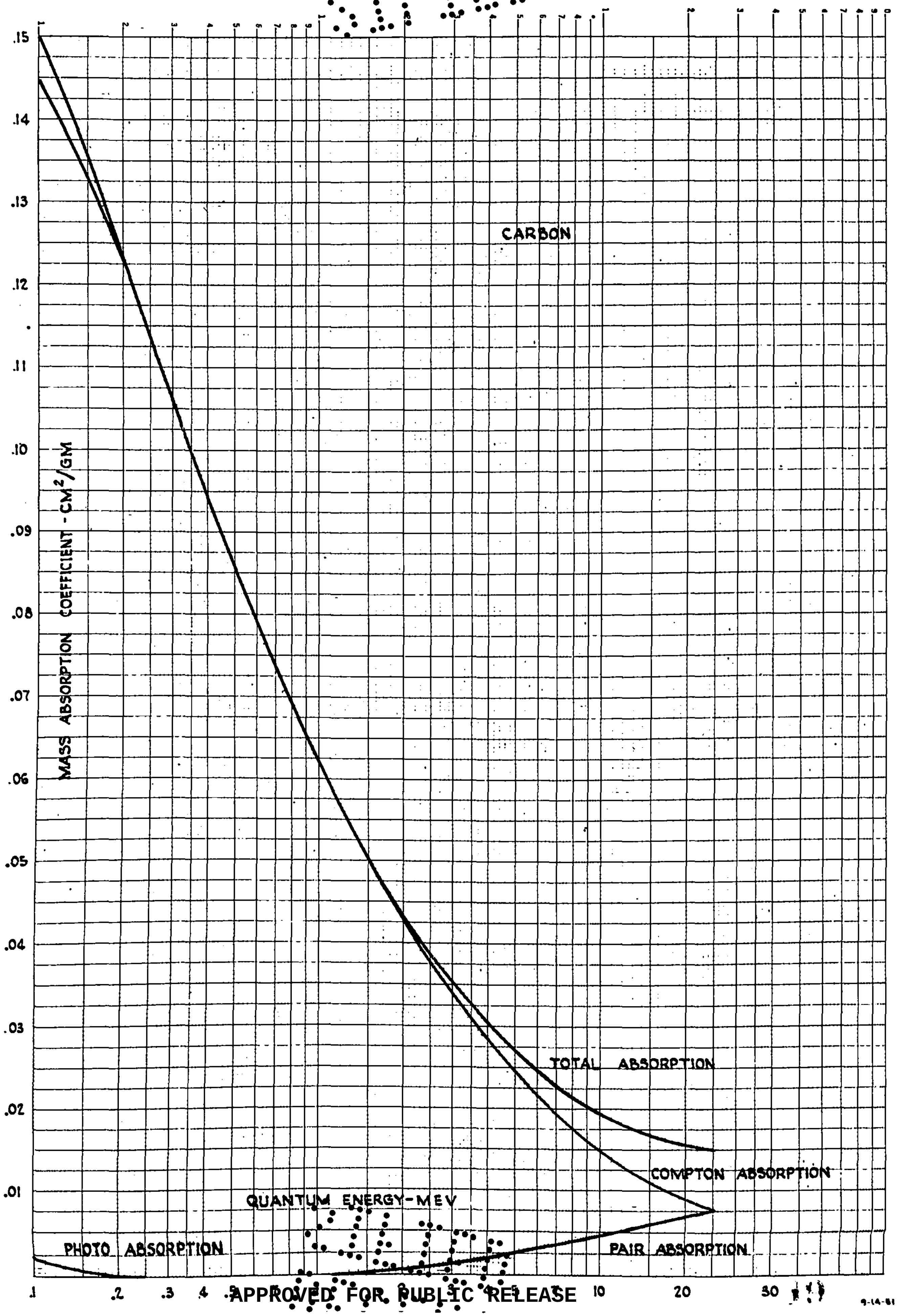

PHOTOELECTRIC CROSS SECTION
PER ATOM FOR ALL ELEMENTS
AT DIFFERENT ENERGIES
(γ = QUANTUM ENERGY/ ELECTRON REST MASS ENERGY)
γ=.2
γ=.3
γ=.5
γ=1
γ=1.5
γ=4
γ=10
PHOTOELECTRIC CROSS SECTION IN 10⁻²⁴ CM²
×10³
×10²
×10
×10⁻¹
×10⁻²
×10⁻³
×10⁻⁴
2
4
6
8
10
20
30
40
50
60
70
80
90
ATOMIC NUMBER-Z
3-18-60


COMPTON EFFECT CROSS
SECTION PER ELECTRON
VS
ENERGY
COMPTON EFFECT CROSS SECTION-10^{-24} CM^2
(FROM KLEIN-NISHINA FORMULA)
QUANTUM ENERGY IN MILLION ELECTRON VOLTS
.5
.4
.3
.2
.1
.1
.2
.3
.4
.5
.7
1
2
3
4
5
7
10
20
30

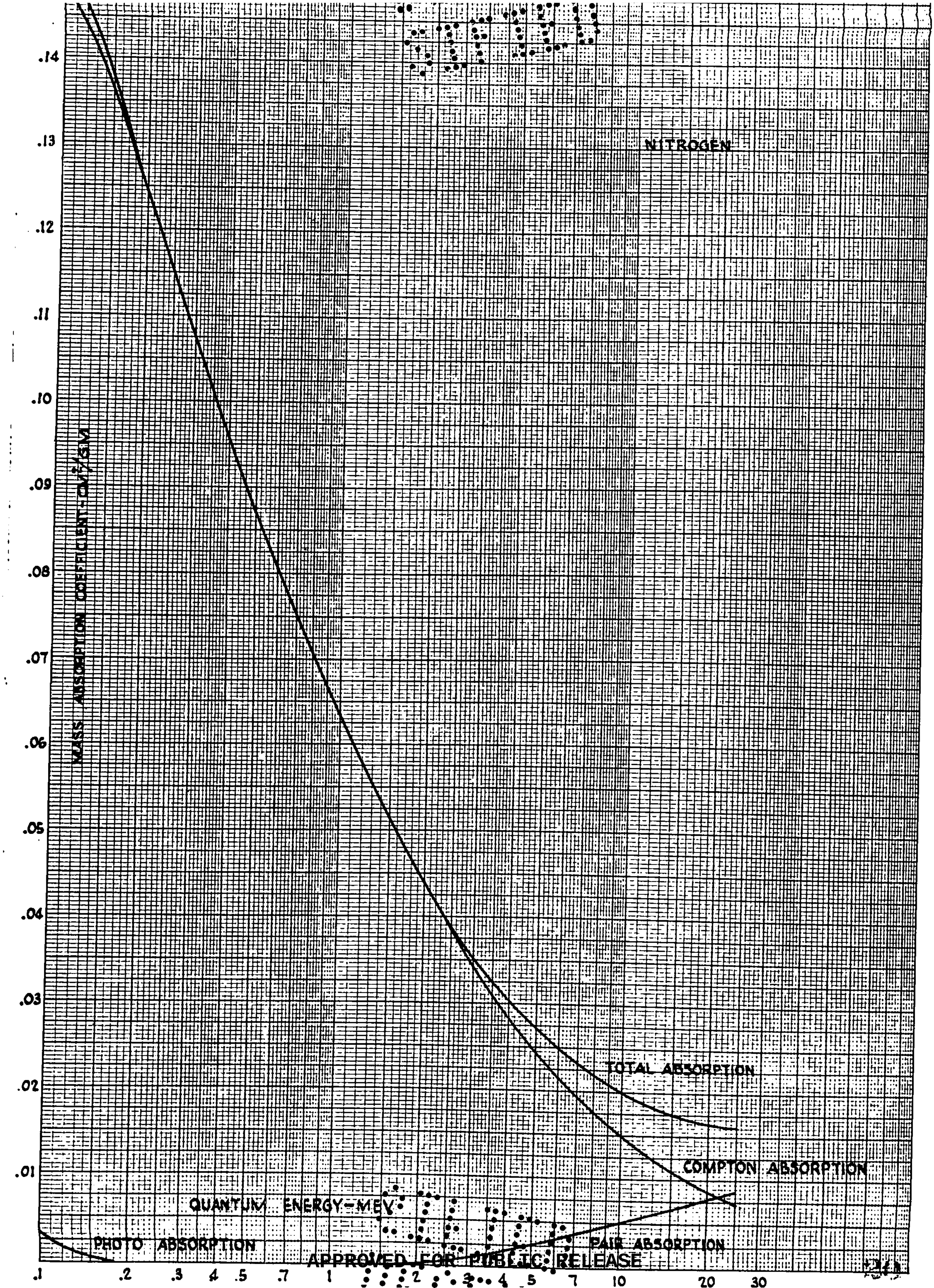
6-15-50

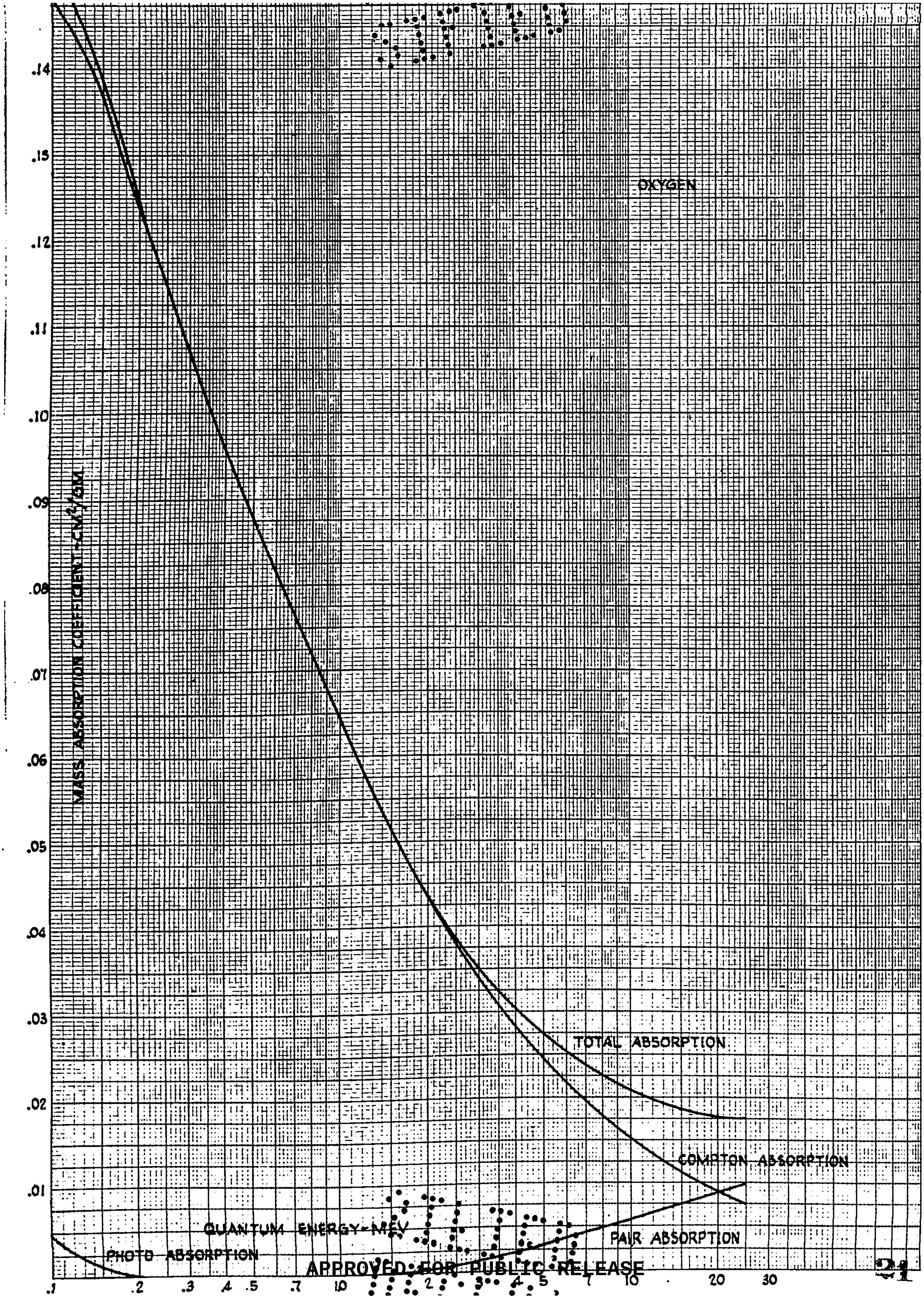

.00368 AT 25 MEV
σ ~ LOG hν
PAIR AND TRIPLET PRODUCTION CROSS SECTION VS ENERGY
PAIR AND TRIPLET PRODUCTION CROSS SECTION Z(Z+1) 10⁻²⁴ CM²
(FROM BETHE-HEITLER FORMULA)
.0025
.0020
.0015
.0010
.0005
QUANTUM ENERGY IN MILLION ELECTRON VOLTS
1
2
3
4
5
6
7
8
9
10
20
30

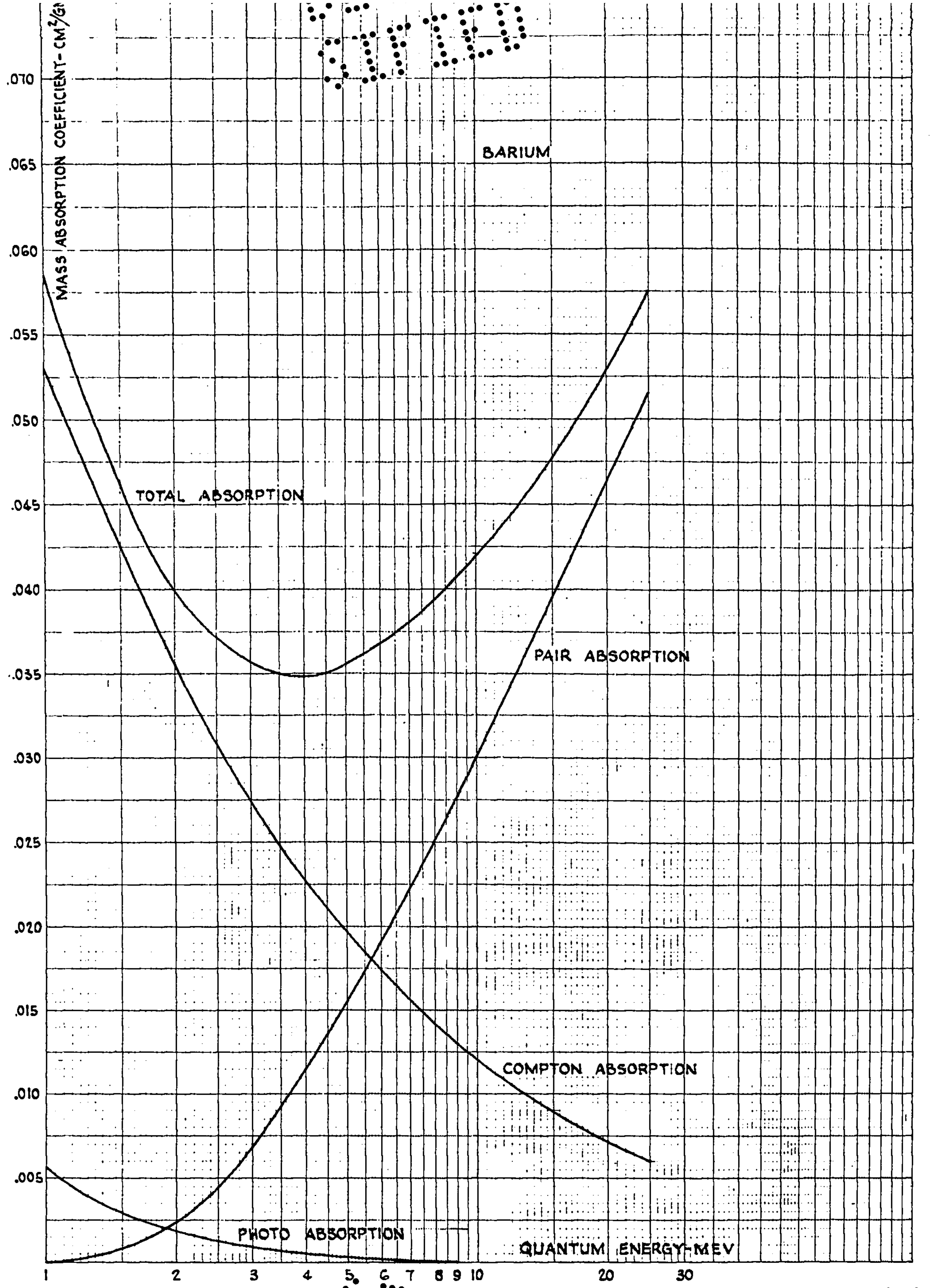

HYDROGEN
MASS ABSORPTION COEFFICENT - CM²/GM
TOTAL ABSORPTION
COMPTON ABSORPTION
PAIR ABSORPTION
PHOTO ABSORPTION
QUANTUM ENERGY-MEV
.29
.28
.27
.26
.25
.24
.23
.22
.21
.20
.19
.18
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
.1
.2
.3
.4
.5
.7
1
2
3
4
5
7
10
20
30


CARBON
MASS ABSORPTION COEFFICIENT - CM²/GM
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
TOTAL ABSORPTION
COMPTON ABSORPTION
PAIR ABSORPTION
PHOTO ABSORPTION
QUANTUM ENERGY-MEV
.1
.2
.3
.4
10
20
30

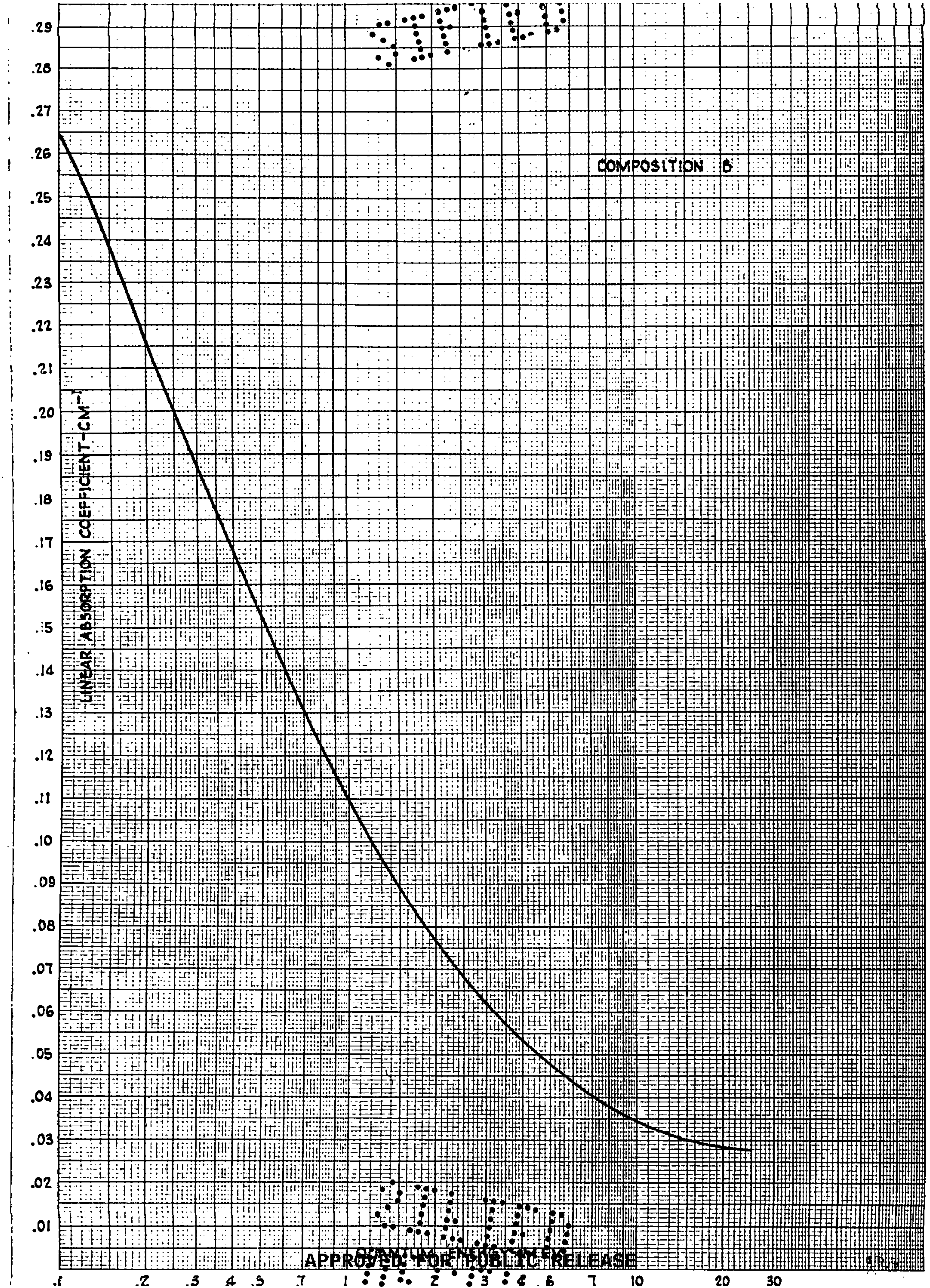
9-14-51


NITROGEN
MASS ABSORPTION COEFFICIENT-CM²/GM
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
TOTAL ABSORPTION
COMPTON ABSORPTION
QUANTUM ENERGY-MEV
PHOTO ABSORPTION
PAIR ABSORPTION
.1
.2
.3
.4
.5
.7
1
2
3
4
5
7
10
20
30

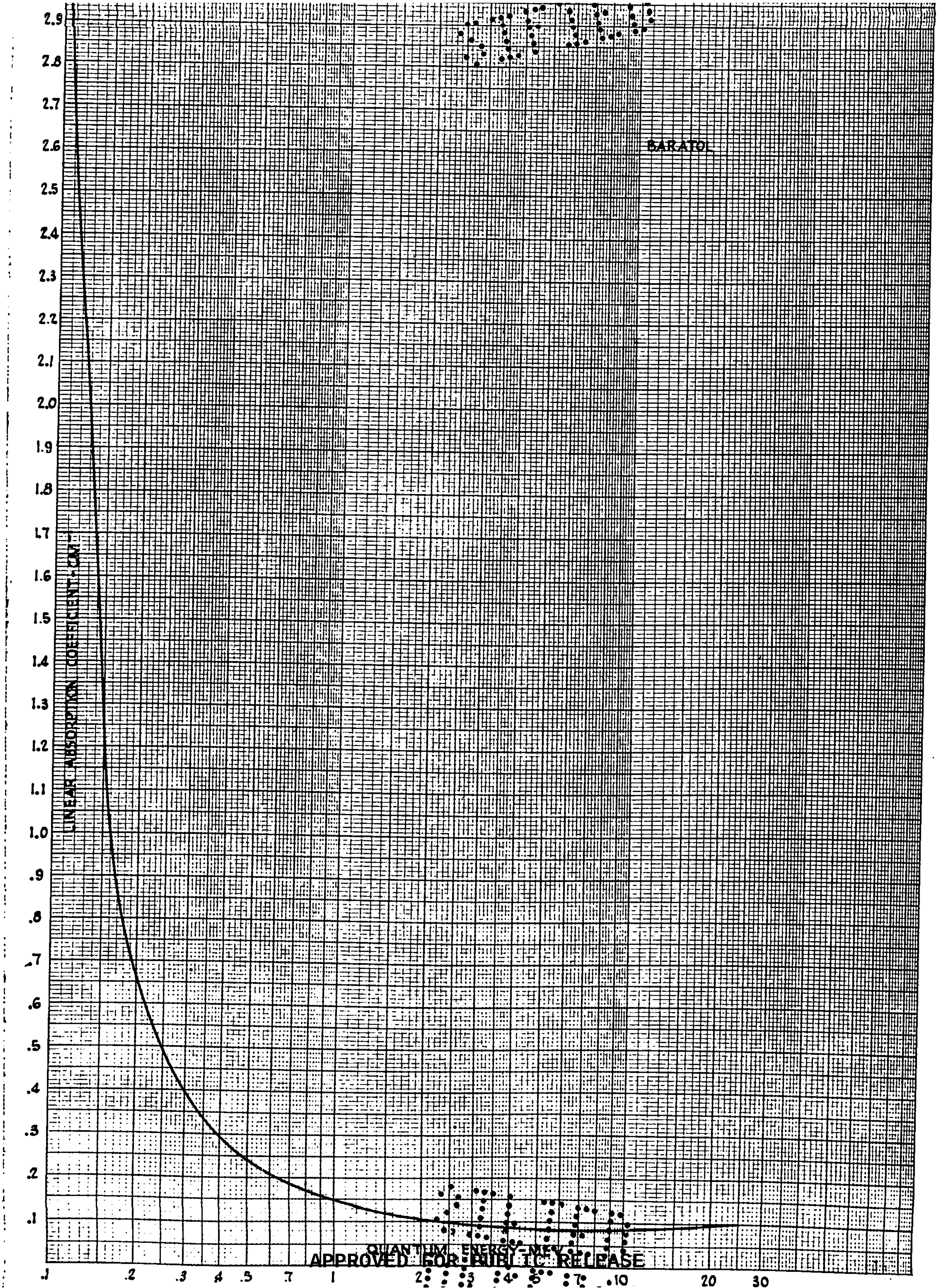

OXYGEN
MASS ABSORPTION COEFFICIENT-CM²/GM
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
TOTAL ABSORPTION
COMPTON ABSORPTION
PAIR ABSORPTION
PHOTO ABSORPTION
QUANTUM ENERGY-MEV
.1
.2
.3
.4
.5
.7
1.0
2
3
4
5
7
10
20
30

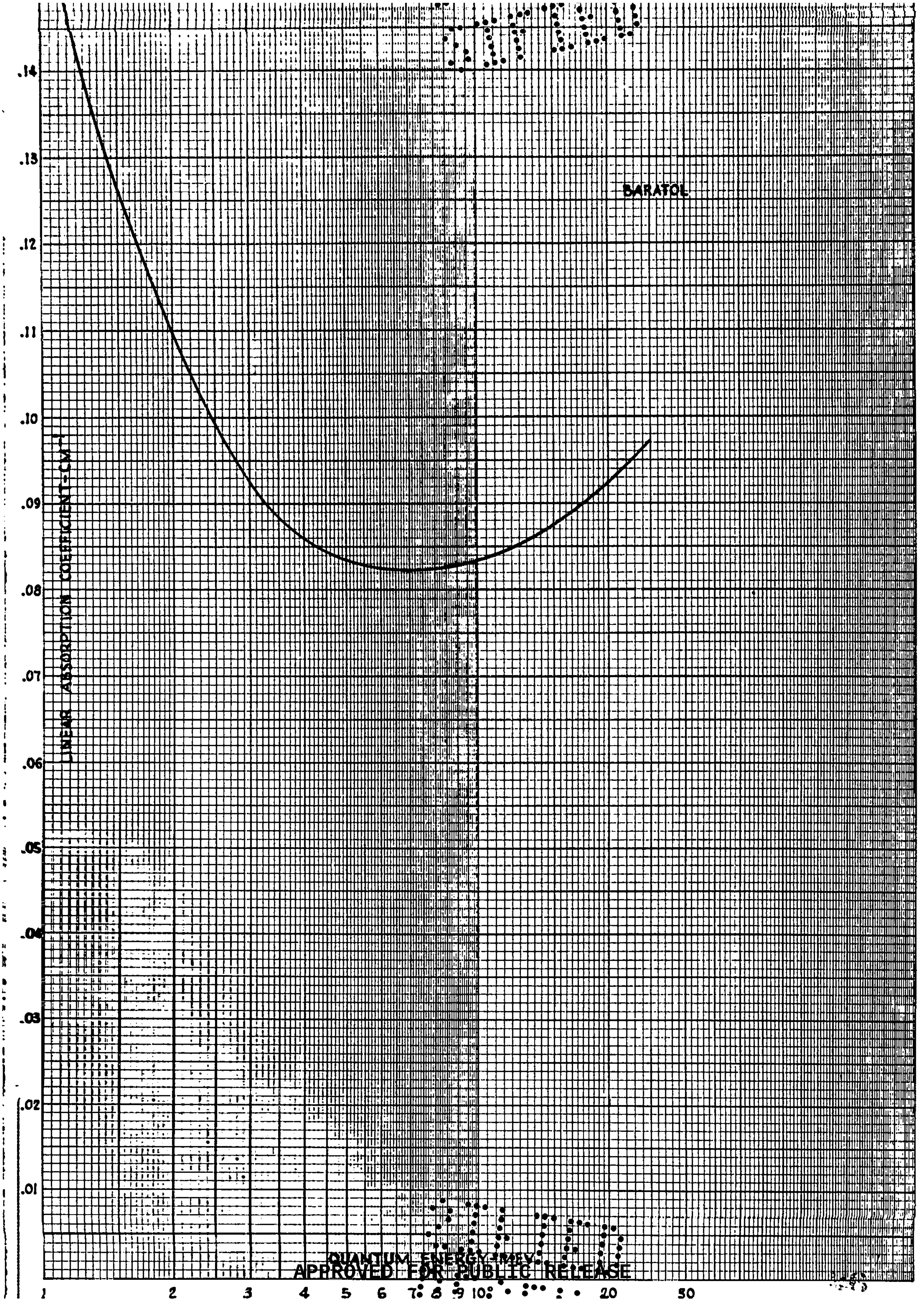

MASS ABSORPTION COEFFICIENT-CM²/GM
.070
.065
.060
.055
.050
.045
.040
.035
.030
.025
.020
.015
.010
.005
BARIUM
TOTAL ABSORPTION
PAIR ABSORPTION
COMPTON ABSORPTION
PHOTO ABSORPTION
QUANTUM ENERGY-MEV
1
2
3
4
5
6
7
8
9
10
20
30

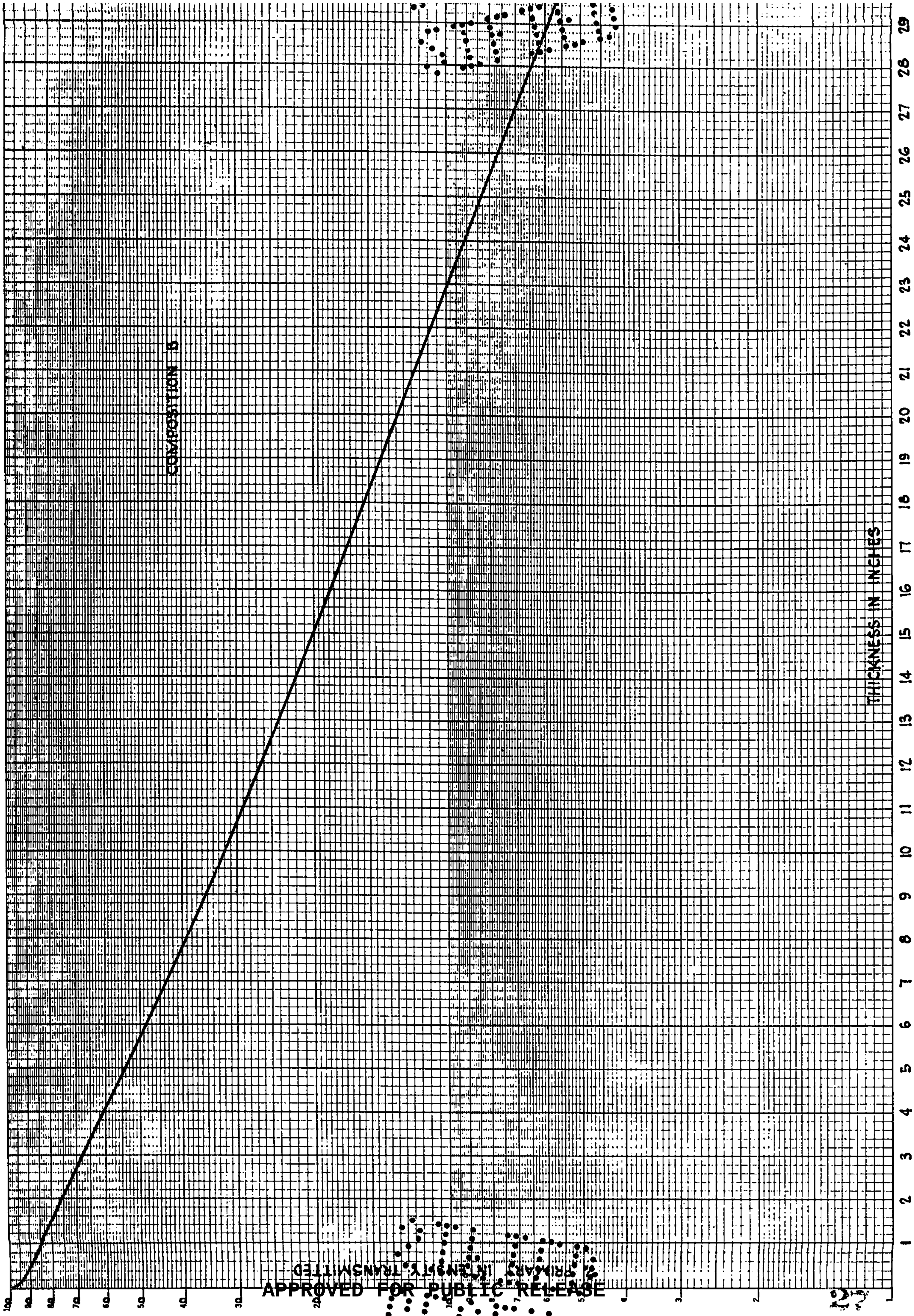
9-14-51

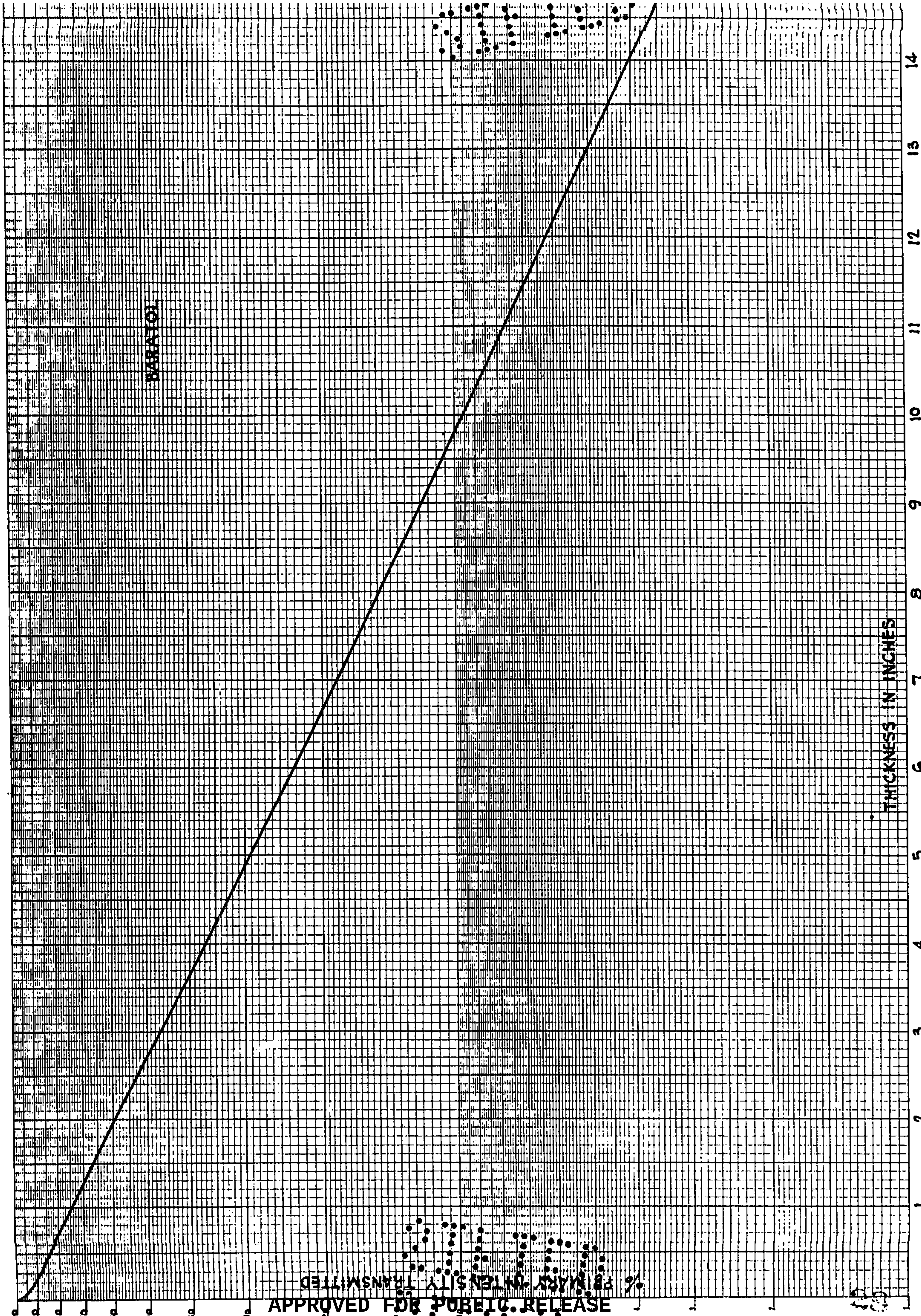


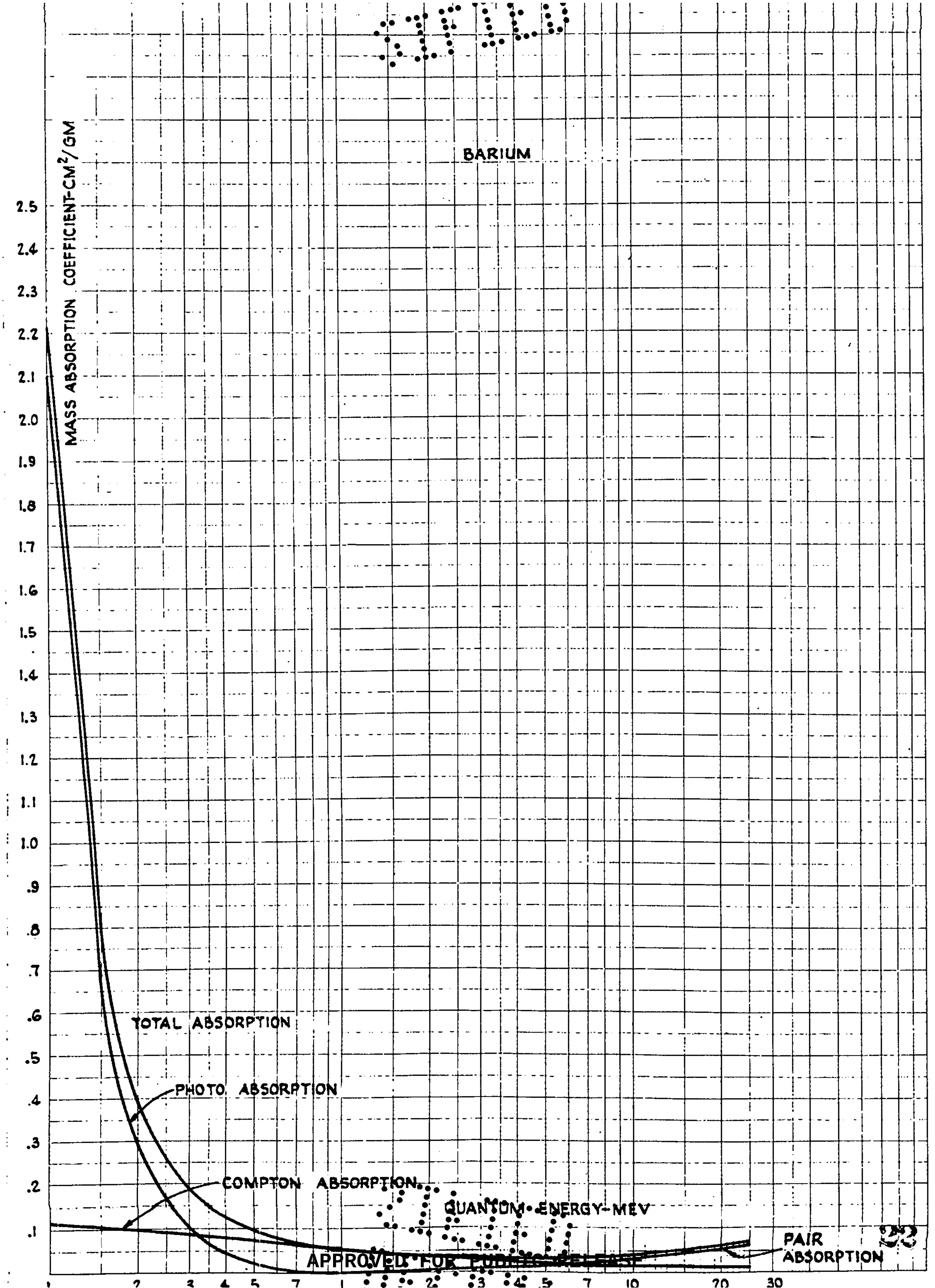
COMPOSITION B
LINEAR ABSORPTION COEFFICIENT-CM^{-1}
.29
.28
.27
.26
.25
.24
.23
.22
.21
.20
.19
.18
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
QUANTUM ENERGY IN MEV
.1
.2
.3
.4
.5
.7
1
2
3
4
5
7
10
20
30


BARATOL
LINEAR ABSORPTION COEFFICIENT-CM⁻¹
QUANTUM ENERGY-MEV
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.1
.2
.3
.4
.5
.7
1
2
3
4
5
7
10
20
30


.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
LINEAR ABSORPTION COEFFICIENT-CM⁻¹
BARATOL
QUANTUM ENERGY-MEV
1
2
3
4
5
6
7
8
9
10
20
30


COMPOSITION B
THICKNESS IN INCHES
% PRIMARY INTENSITY TRANSMITTED
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1


BARATOL
THICKNESS IN INCHES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
% PRIMARY INTENSITY TRANSMITTED
100
90
80
70
60
50
40
30
20
10


BARIUM
MASS ABSORPTION COEFFICIENT-CM²/GM
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
TOTAL ABSORPTION
PHOTO ABSORPTION
COMPTON ABSORPTION
QUANTUM ENERGY-MEV
PAIR ABSORPTION
1
2
3
4
5
7
1
2
3
4
5
7
10
20
30