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CALCULATED EFFICIENCIES OF NaI CRYSTALS

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ABSTRACT

Probabilities for the interaction of gamma rays with NaI scintillation crystals have been calculated for the case of a point isotropic source situated on the axis of a cylindrical crystal. These results can be used in obtaining the absolute gamma-ray detection efficiency of a NaI scintillation counter by a method which does not require calibrated radioactive sources. Computations were made for eighteen commercially available crystal sizes and for a wide range of gamma-ray energies and source-to-crystal distances. The results are presented in both tabular and graphical form.

PROBLEM STATUS

This is the final report on the problem. The problem was closed 31 December 1955.

AUTHORIZATION

NRL Problem H01-04
Project No. NR 661-040

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CALCULATED EFFICIENCIES OF NaI CRYSTALS

Calculated efficiencies of NaI for gamma-ray interaction can be used for the measurement of absolute gamma-ray intensities. The method used for applying such efficiencies together with the estimated accuracy obtainable have been described by N. H. Lazar et al.[1] The present calculations were performed for the case of a point isotropic gamma-ray source situated on the axis of a cylindrical crystal.

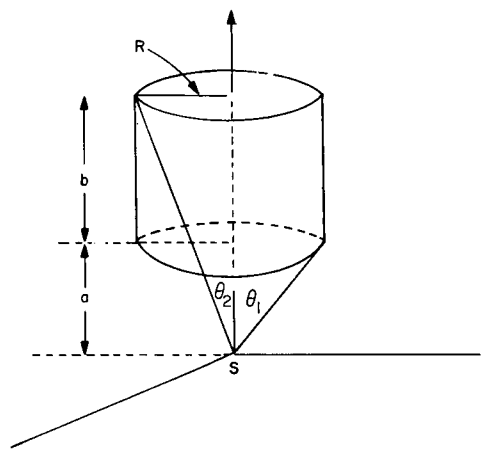

Fig. 1 - Source and crystal arrangement

Consider a cylindrical NaI crystal of radius R and length b, placed on the polar axis of the coordinate system (r, θ, ϕ). A source S is placed at the origin, a distance a from the near face of the crystal (Fig. 1). Let N_0 denote the number of gammas/sec radiated by the source, M the crystal density in g/cm³, and σ the gamma absorption cross section in cm²/g. The total number N of interactions in the crystal is

$$N = \frac{N_0}{2} \left\{ 1 - \cos\theta_1 - \int_0^{\theta_2} \sin\theta e^{-M\sigma b \sec\theta} d\theta - \int_{\theta_2}^{\theta_1} \sin\theta e^{-M\sigma (R \csc\theta - a \sec\theta)} d\theta \right\} \quad (1)$$

where

$$\theta_1 = \tan^{-1}\frac{R}{a}, \quad \theta_2 = \tan^{-1}\frac{R}{a+b}.$$

The crystal efficiency is defined as N/N_0. The value 3.667 g/cm³ was used for M.

[1] Lazar, N. H., Davis, R. C., and Bell, P. R., Nucleonics 14:52 (1956)

Since the interaction probability calculated for the set of parameters a, b, R, and σ equals that obtained for na, nb, nR, and σ/n where n is any number, it is possible to use the calculated results to obtain efficiencies for crystal sizes which were not included in the calculations. If R/b for the desired crystal size is different from that for any of the crystal sizes used, efficiencies can be obtained by interpolating between the known results for two crystals 1 and 2, such that.

$$\frac{R_1}{b_1} < \frac{R}{b} < \frac{R_2}{b_2} .$$

Computations were made for all combinations of the parameters listed in Table 1. Tables 2 through 19 give the results obtained for each of the crystal sizes while Figs. 2 through 19 show these results in graphical form.

ACKNOWLEDGMENTS

The calculations were performed on the SEAC computor of the National Bureau of Standards. We wish to express our appreciation to Dr. M. Abramowitz of NBS for his cooperation and interest in the problem. We are grateful also to H. Wagman, P. O'Neil, D. Kellogg, and R. Slaven for their assistance with this work.

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TABLE 1
Parameter Assignments

Crystal Sizes (in.)		Distance, a (cm)	γ-Ray Energies (Mev)	Mass Absorption* Coefficients, σ (cm^2/g)
Diameter	Thickness			
0.50	0.50	0.00	0.06	6.17
0.75	0.50	0.40	0.08	2.86
0.75	0.75	0.50	0.10	1.57
1.00	0.50	0.75	0.15	0.568
1.25	0.50	1.00	0.20	0.305
1.375	0.50	1.25	0.30	0.155
1.50	0.50	1.50	0.40	0.111
1.75	0.50	2.00	0.50	0.0901
1.00	1.00	3.00	0.60	0.0789
1.25	1.00	4.00	0.80	0.0657
1.50	1.00	6.00	1.0	0.0577
1.75	1.00	10.00	1.5	0.0465
1.50	1.50	15.00	2.0	0.0412
1.50	2.00	20.00	3.0	0.0367
1.75	2.00		4.0	0.0351
1.50	3.00		5.0	0.0347
3.00	3.00		6.0	0.0347
5.00	4.00		8.0	0.0354
			10.0	0.0366
			15.0	0.0400
			20.0	0.0430

* National Bureau of Standards, Circular 1003, and private communication from Miss G. White. Absorption coefficients have been corrected for coherent scattering.

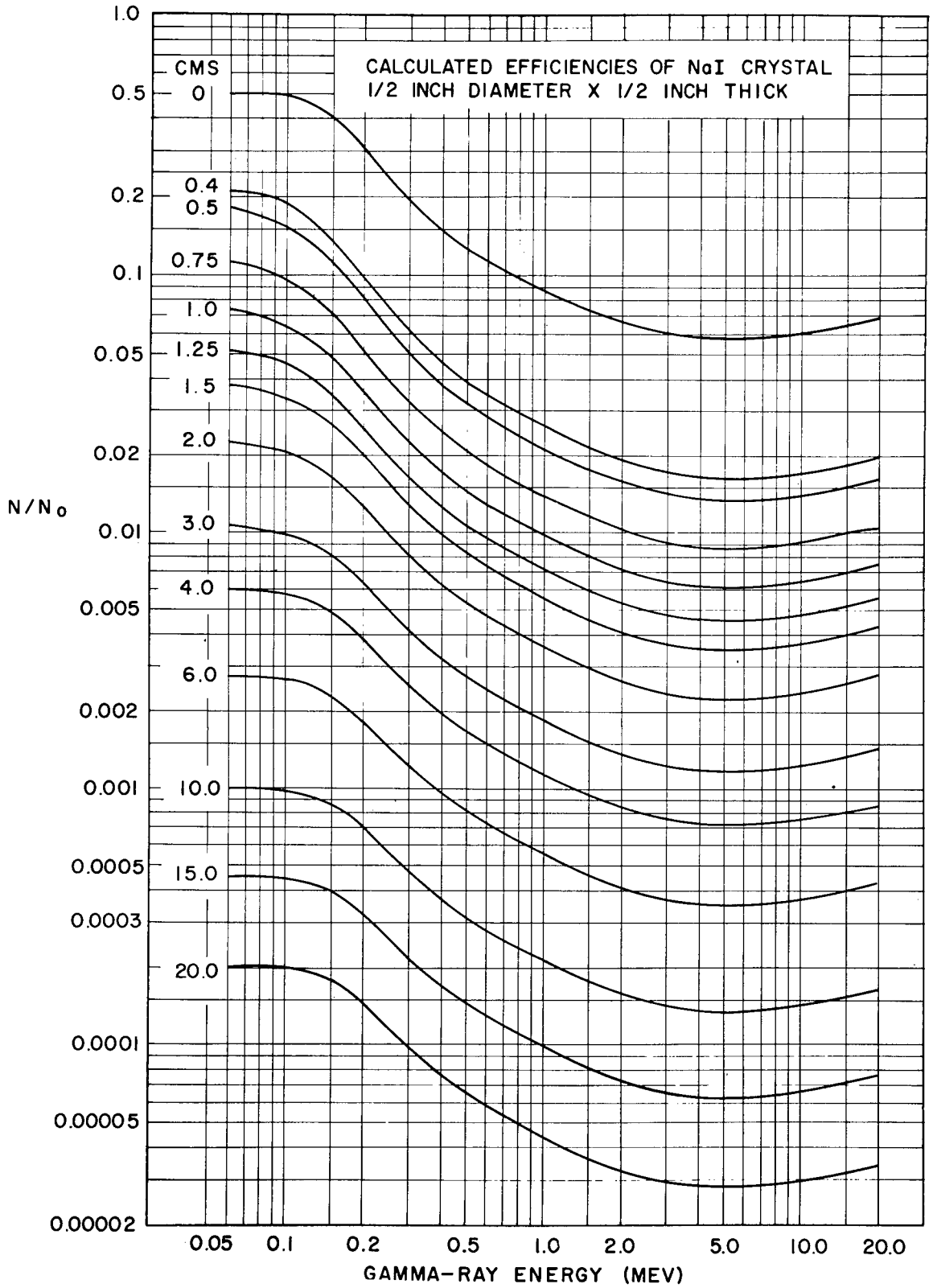

Fig. 2 - Calculated efficiencies of NaI crystal 1/2 inch diameter and 1/2 inch thick

TABLE 2
Calculated Efficiencies of NaI Crystal 1/2 Inch Diameter and 1/2 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-4}$	$\times 10^{-4}$	$\times 10^{-4}$
.06	5.00	2.22	1.80	1.12	7.37	5.15	3.80	2.26	1.06	6.07	2.76	9.96	4.47	1.99
.08	5.00	2.09	1.69	1.04	6.93	4.88	3.61	2.17	1.02	5.93	2.71	9.86	4.44	1.98
.10	4.93	1.90	1.53	.952	6.37	4.52	3.37	2.04	.981	5.73	2.65	9.71	4.40	1.96
.15	4.06	1.37	1.11	.704	4.81	3.48	2.64	1.64	.818	4.88	2.31	8.68	3.98	1.79
.20	3.02	.980	.798	.511	3.53	2.58	1.98	1.25	.633	3.82	1.83	6.95	3.20	1.44
.30	1.93	.607	.496	.320	2.23	1.64	1.26	.807	.414	2.52	1.22	4.65	2.15	.973
.40	1.49	.463	.379	.245	1.72	1.26	.976	.625	.321	1.96	.948	3.64	1.68	.762
.50	1.26	.388	.317	.206	1.44	1.06	.821	.527	.271	1.65	.802	3.08	1.43	.646
.60	1.14	.345	.283	.184	1.29	.950	.734	.471	.243	1.48	.719	2.76	1.28	.580
.80	.977	.293	.240	.156	1.10	.810	.626	.402	.207	1.27	.615	2.36	1.10	.497
1.0	.877	.261	.214	.139	.975	.721	.557	.358	.185	1.13	.549	2.11	.980	.444
1.5	.733	.214	.175	.114	.801	.593	.458	.295	.152	.932	.453	1.74	.809	.366
2.0	.663	.191	.157	.102	.716	.530	.410	.264	.136	.834	.406	1.56	.725	.328
3.0	.603	.171	.140	.0916	.643	.476	.368	.237	.123	.750	.365	1.40	.652	.296
4.0	.581	.164	.135	.0878	.617	.457	.353	.227	.118	.720	.350	1.35	.626	.284
5.0	.577	.163	.133	.0869	.610	.452	.350	.225	.117	.712	.347	1.33	.620	.281
6.0	.577	.163	.133	.0869	.610	.452	.350	.225	.117	.712	.347	1.33	.620	.281
8.0	.585	.166	.136	.0885	.622	.460	.356	.229	.119	.726	.353	1.36	.631	.286
10.0	.602	.171	.140	.0913	.642	.475	.368	.236	.122	.748	.364	1.40	.651	.295
15.0	.647	.186	.152	.0992	.697	.516	.399	.257	.133	.812	.395	1.52	.706	.320
20.0	.687	.199	.163	.106	.745	.552	.427	.274	.142	.868	.422	1.62	.754	.342

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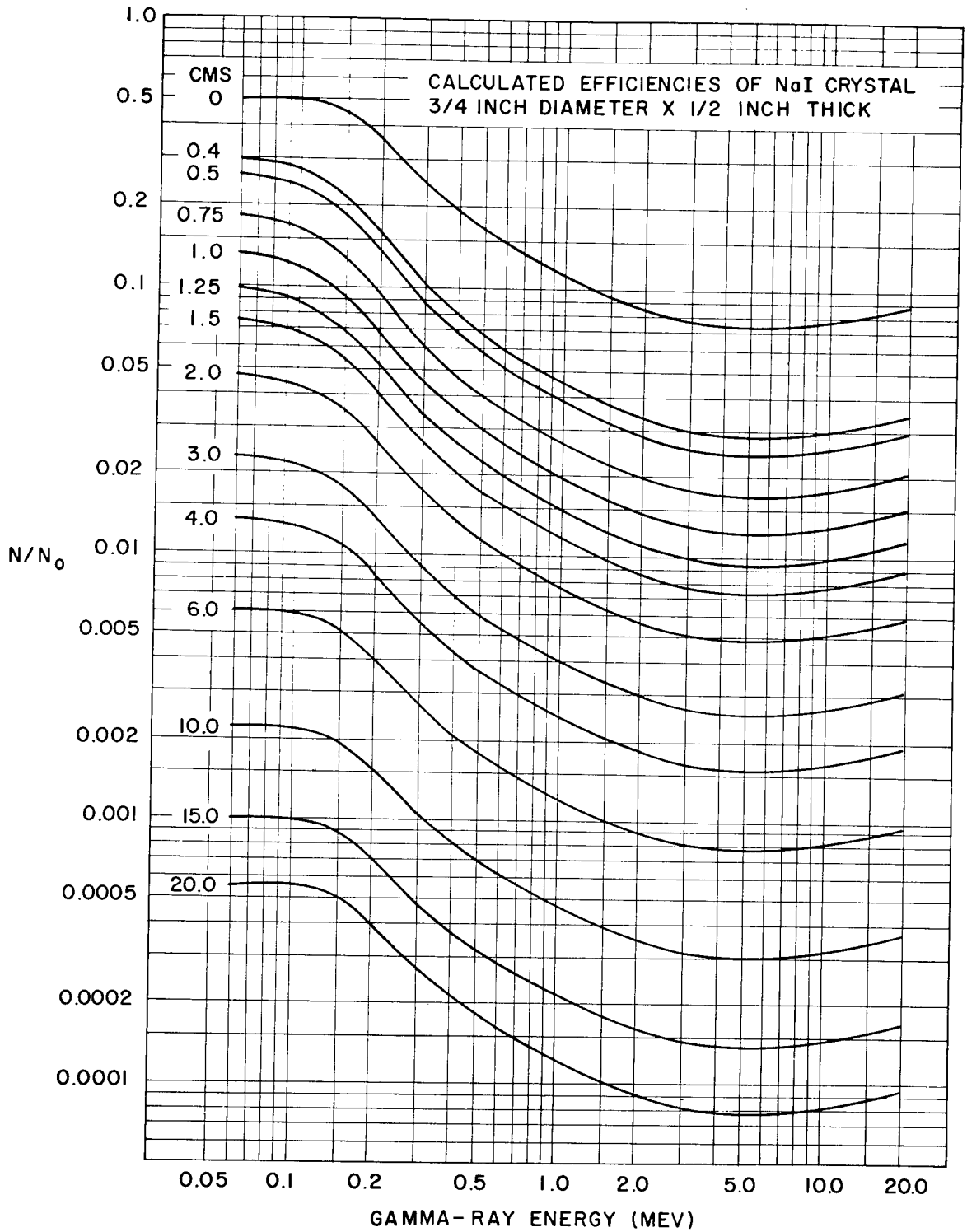

Fig. 3 - Calculated efficiencies of NaI crystal 3/4 inch diameter and 1/2 inch thick

TABLE 3
Calculated Efficiencies of NaI Crystal 3/4 Inch Diameter and 1/2 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-4}$	$\times 10^{-4}$
.06	5.00	2.99	2.50	1.84	1.32	9.32	7.49	4.69	2.28	1.33	6.11	2.23	9.94	5.54
.08	5.00	2.39	2.50	1.76	1.27	9.40	7.19	4.52	2.22	1.30	6.02	2.21	9.88	5.52
.10	4.99	2.74	2.36	1.64	1.18	8.81	6.76	4.29	2.12	1.26	5.88	2.18	9.77	5.50
.15	4.53	2.16	1.85	1.28	.928	6.98	5.41	3.50	1.78	1.08	5.14	1.94	8.84	5.01
.20	3.63	1.62	1.38	.957	.696	5.25	4.09	2.67	1.38	.844	4.07	1.56	7.12	4.05
.30	2.44	1.03	.879	.611	.446	3.38	2.64	1.74	.907	.557	2.71	1.04	4.78	2.72
.40	1.92	.796	.678	.471	.344	2.61	2.04	1.35	.705	.433	2.11	.815	3.75	2.13
.50	1.64	.670	.570	.396	.290	2.20	1.72	1.14	.596	.366	1.79	.690	3.18	1.81
.60	1.47	.599	.509	.354	.259	1.97	1.54	1.02	.533	.328	1.60	.619	2.85	1.62
.80	1.27	.510	.434	.302	.221	1.68	1.31	.867	.456	.281	1.37	.530	2.44	1.39
1.0	1.14	.455	.387	.269	.197	1.49	1.17	.773	.406	.250	1.22	.473	2.18	1.24
1.5	.952	.374	.318	.221	.162	1.23	.965	.636	.335	.206	1.00	.391	1.80	1.03
2.0	.859	.334	.284	.198	.145	1.10	.863	.570	.300	.185	.904	.350	1.61	.920
3.0	.779	.300	.256	.178	.130	.988	.775	.512	.270	.166	.814	.315	1.45	.828
4.0	.750	.288	.245	.170	.125	.948	.744	.491	.259	.160	.781	.302	1.39	.794
5.0	.743	.285	.242	.169	.123	.938	.736	.486	.256	.158	.772	.299	1.38	.786
6.0	.743	.285	.242	.169	.123	.938	.736	.486	.256	.158	.772	.299	1.38	.786
8.0	.756	.291	.247	.172	.126	.956	.750	.495	.261	.161	.787	.305	1.40	.801
10.0	.777	.300	.255	.177	.130	.986	.774	.511	.269	.166	.812	.314	1.45	.825
15.0	.838	.326	.277	.192	.141	1.07	.840	.554	.292	.180	.881	.341	1.57	.896
20.0	.891	.348	.296	.206	.150	1.14	.898	.593	.312	.192	.940	.364	1.68	.956

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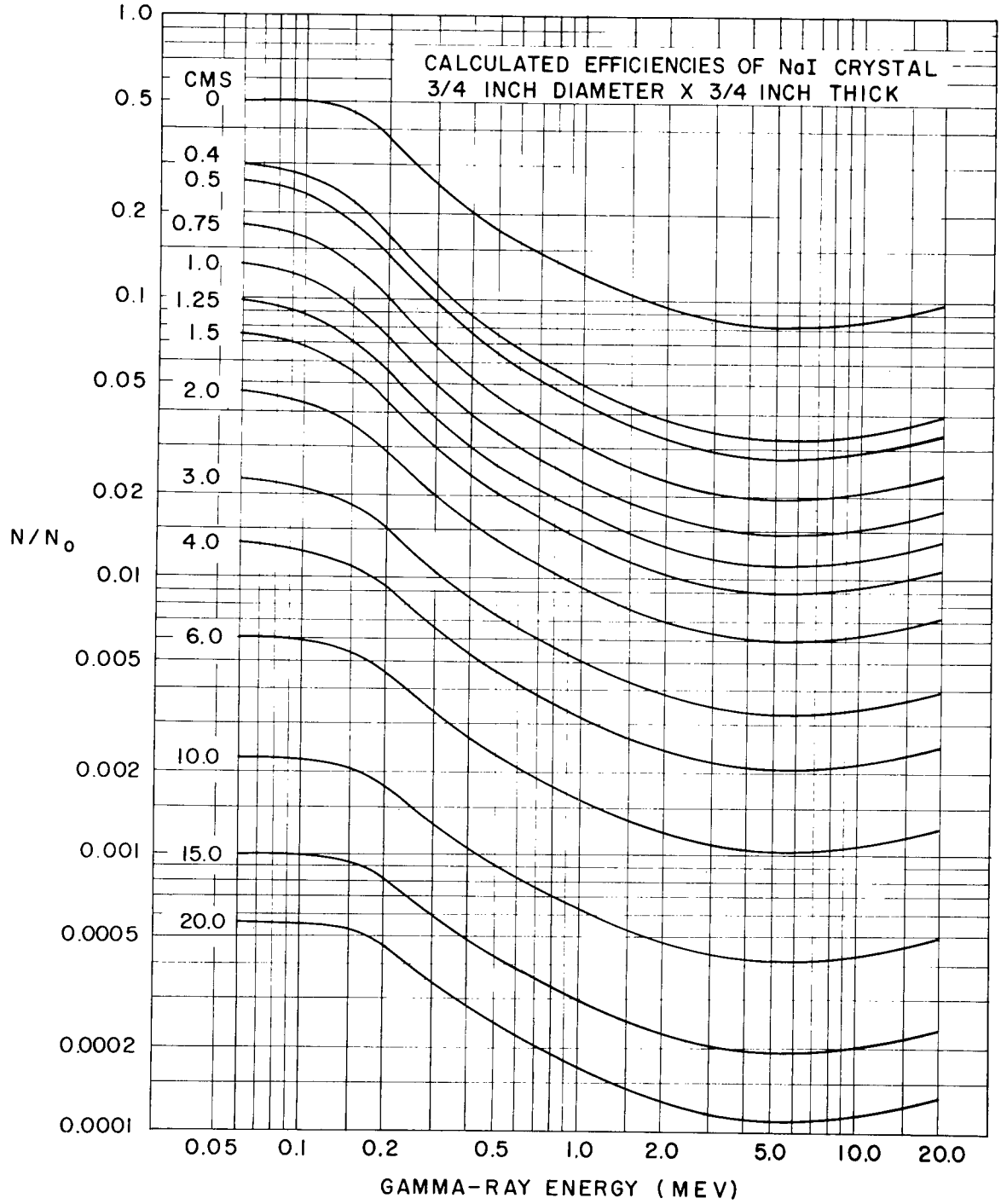

Fig. 4 - Calculated efficiencies of NaI crystal 3/4 inch diameter and 3/4 inch thick

TABLE 4
Calculated Efficiencies of NaI Crystal 3/4 Inch Diameter and 3/4 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-4}$	$\times 10^{-4}$
.06	5.00	2.99	2.60	1.83	1.32	9.82	7.49	4.69	2.28	1.33	6.11	2.23	9.94	5.58
.08	5.00	2.89	2.50	1.74	1.27	9.40	7.18	4.52	2.22	1.30	6.02	2.21	9.88	5.55
.10	4.99	2.74	2.36	1.64	1.18	8.81	6.76	4.29	2.12	1.26	5.88	2.18	9.78	5.51
.15	4.57	2.19	1.86	1.30	.944	7.11	5.52	3.58	1.84	1.11	5.35	2.03	9.27	5.26
.20	3.72	1.68	1.43	1.00	.734	5.58	4.37	2.88	1.51	.932	4.56	1.77	8.13	4.64
.30	2.56	1.11	.948	.667	.492	3.77	2.97	1.99	1.06	.662	3.29	1.29	5.99	3.43
.40	2.03	.867	.741	.523	.387	2.97	2.35	1.58	.849	.531	2.65	1.04	4.86	2.79
.50	1.74	.735	.629	.444	.329	2.53	2.01	1.35	.727	.456	2.28	.900	4.19	2.41
.60	1.57	.658	.564	.399	.296	2.28	1.80	1.21	.656	.411	2.05	.814	3.80	2.18
.80	1.36	.564	.483	.342	.254	1.95	1.55	1.05	.566	.355	1.78	.705	3.29	1.89
1.0	1.23	.505	.432	.306	.227	1.75	1.39	.938	.508	.319	1.60	.635	2.97	1.70
1.5	1.03	.414	.357	.253	.188	1.45	1.15	.778	.422	.266	1.33	.529	2.48	1.43
2.0	.929	.371	.321	.227	.169	1.30	1.04	.699	.380	.239	1.20	.477	2.23	1.28
3.0	.844	.337	.289	.204	.152	1.18	.934	.631	.343	.216	1.09	.431	2.02	1.16
4.0	.813	.323	.277	.196	.146	1.13	.896	.605	.329	.207	1.04	.414	1.94	1.12
5.0	.805	.320	.274	.194	.145	1.12	.887	.599	.326	.205	1.03	.410	1.92	1.10
6.0	.805	.320	.274	.194	.145	1.12	.887	.599	.326	.205	1.03	.410	1.92	1.10
8.0	.819	.326	.279	.198	.147	1.14	.903	.610	.332	.209	1.05	.417	1.95	1.12
10.0	.842	.336	.288	.204	.152	1.17	.931	.629	.342	.215	1.08	.430	2.01	1.16
15.0	.906	.364	.309	.221	.164	1.27	1.01	.681	.370	.223	1.17	.465	2.17	1.25
20.0	.962	.389	.333	.236	.175	1.35	1.08	.727	.394	.248	1.25	.495	2.31	1.33

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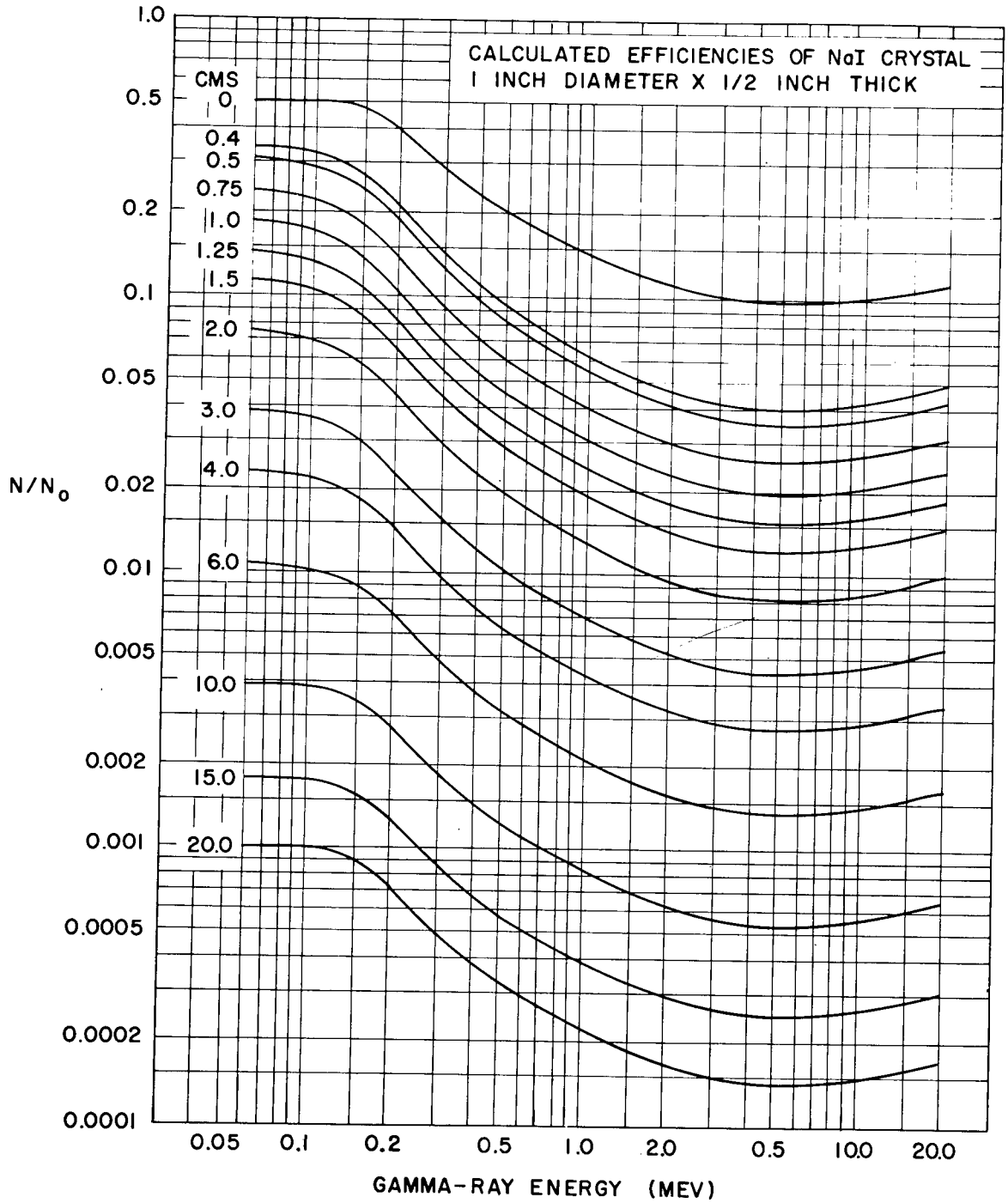

Fig. 5 - Calculated efficiencies of NaI crystal 1 inch diameter and 1/2 inch thick

TABLE 5
Calculated Efficiencies of NaI Crystal 1 Inch Diameter and 1/2 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	3.45	3.12	2.40	1.85	1.45	1.15	7.57	3.85	2.30	1.07	3.97	1.79	9.96
.08	5.00	3.39	3.05	2.33	1.79	1.40	1.11	7.33	3.76	2.25	1.05	3.93	1.78	9.91
.10	5.00	3.28	2.93	2.21	1.71	1.33	1.06	6.99	3.62	2.18	1.03	3.87	1.76	9.83
.15	4.75	2.76	2.44	1.82	1.39	1.08	.863	5.78	3.05	1.87	.902	3.46	1.59	8.95
.20	4.02	2.15	1.90	1.39	1.06	.831	.663	4.46	2.38	1.47	.715	2.77	1.28	7.23
.30	2.86	1.41	1.24	.911	.693	.541	.432	2.92	1.56	.971	.476	1.86	.862	4.87
.40	2.31	1.10	.963	.708	.537	.420	.335	2.27	1.22	.757	.371	1.45	.675	3.81
.50	2.00	.932	.814	.597	.454	.354	.283	1.91	1.03	.640	.314	1.23	.572	3.23
.60	1.82	.834	.729	.534	.406	.317	.253	1.71	.922	.573	.282	1.10	.513	2.90
.80	1.59	.714	.623	.456	.347	.271	.216	1.46	.788	.490	.241	.944	.439	2.48
1.0	1.44	.637	.556	.407	.309	.241	.193	1.30	.703	.438	.215	.843	.393	2.22
1.5	1.22	.525	.459	.335	.255	.199	.159	1.08	.579	.361	.178	.696	.324	1.83
2.0	1.12	.471	.411	.300	.228	.178	.142	.963	.519	.323	.159	.624	.291	1.64
3.0	1.02	.423	.369	.270	.205	.160	.128	.865	.466	.291	.143	.561	.261	1.48
4.0	.992	.406	.354	.259	.197	.153	.123	.830	.448	.279	.137	.538	.251	1.42
5.0	.983	.402	.350	.257	.195	.152	.121	.822	.443	.276	.136	.533	.248	1.40
6.0	.983	.402	.350	.257	.195	.152	.121	.822	.443	.276	.136	.533	.248	1.40
8.0	.998	.409	.357	.261	.198	.155	.124	.837	.451	.281	.138	.543	.253	1.43
10.0	1.02	.422	.368	.269	.204	.160	.128	.863	.466	.290	.143	.560	.261	1.48
15.0	1.09	.458	.400	.293	.222	.173	.138	.937	.505	.315	.155	.607	.283	1.60
20.0	1.16	.490	.427	.313	.237	.185	.148	1.00	.540	.336	.165	.648	.302	1.71

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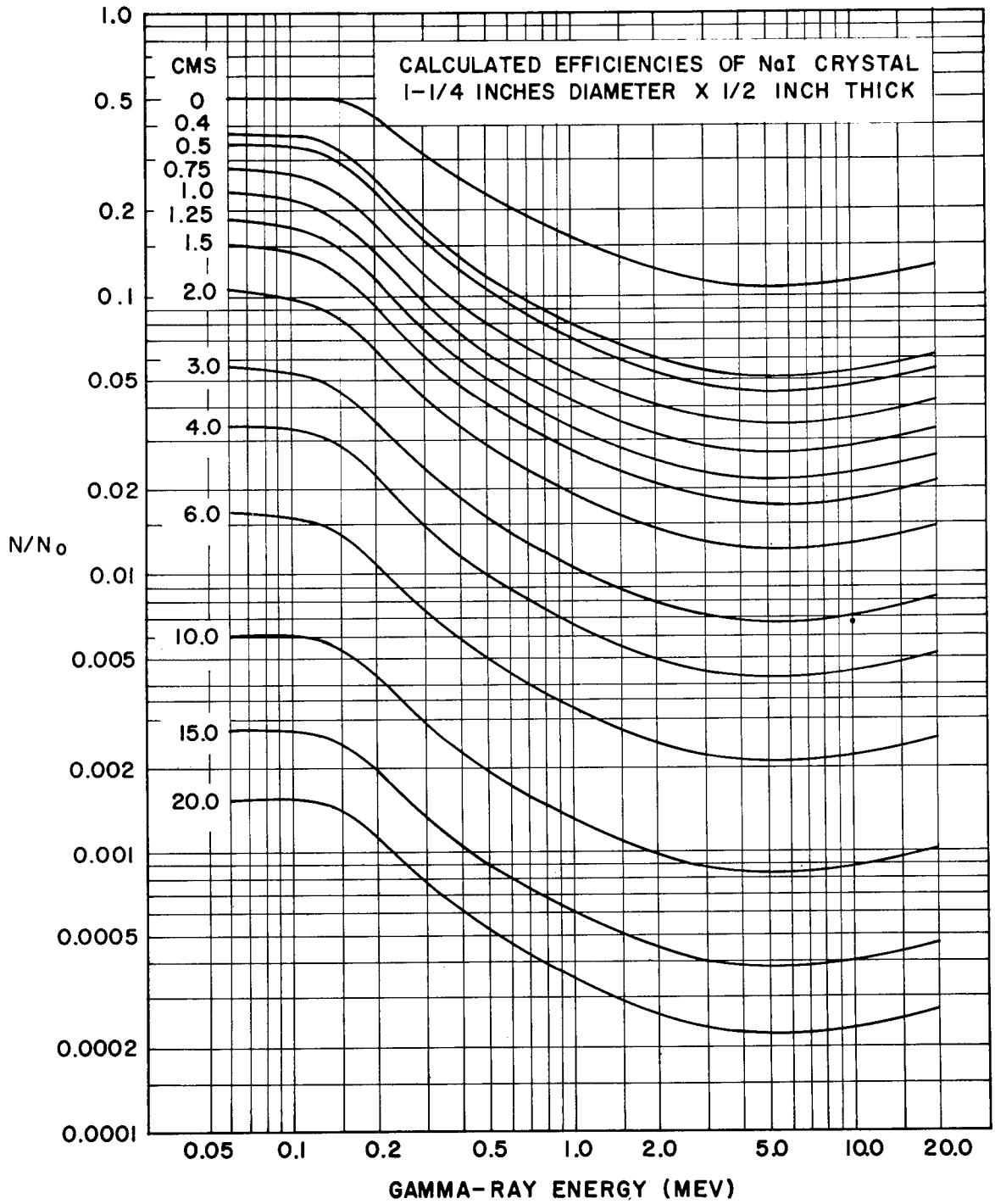

Fig. 6 - Calculated efficiencies of NaI crystal 1-1/4 inches diameter and 1/2 inch thick

TABLE 6
Calculated Efficiencies of NaI Crystal 1-1/4 Inches Diameter and 1/2 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	3.75	3.46	2.81	2.31	1.86	1.53	1.06	5.67	3.46	1.64	6.14	2.75	1.56
.08	5.00	3.70	3.41	2.76	2.23	1.82	1.49	1.03	5.54	3.39	1.62	6.09	2.74	1.56
.10	5.00	3.63	3.33	2.67	2.15	1.74	1.43	.988	5.34	3.29	1.58	6.00	2.70	1.54
.15	4.84	3.20	2.90	2.27	1.81	1.46	1.20	.829	4.55	2.84	1.39	5.37	2.45	1.40
.20	4.23	2.57	2.31	1.79	1.42	1.14	.930	.646	3.56	2.23	1.09	4.30	1.97	1.13
.30	3.11	1.74	1.55	1.19	.938	.752	.613	.426	2.35	1.48	.734	2.88	1.33	.764
.40	2.53	1.37	1.22	.933	.731	.586	.477	.331	1.83	1.16	.573	2.26	1.04	.599
.50	2.20	1.16	1.03	.790	.619	.496	.404	.280	1.55	.977	.486	1.92	.881	.508
.60	2.00	1.04	.928	.708	.555	.444	.361	.251	1.39	.875	.435	1.71	.790	.456
.80	1.75	.895	.796	.604	.475	.380	.310	.214	1.19	.749	.373	1.47	.677	.390
1.0	1.59	.800	.712	.542	.424	.339	.275	.192	1.06	.669	.333	1.31	.605	.349
1.5	1.35	.662	.588	.447	.350	.280	.228	.158	.875	.552	.275	1.08	.499	.288
[illegible]	1.23	.594	.528	.401	.314	.251	.204	.142	.784	.494	.246	.970	.448	.258
3.0	1.12	.534	.475	.361	.282	.225	.183	.127	.705	.444	.221	.872	.401	.232
4.0	1.09	.513	.455	.346	.270	.216	.176	.122	.676	.426	.212	.837	.386	.223
5.0	1.08	.507	.451	.343	.268	.214	.174	.121	.669	.422	.210	.828	.382	.221
6.0	1.08	.507	.451	.343	.268	.214	.174	.121	.669	.422	.210	.828	.382	.221
8.0	1.09	.517	.459	.349	.273	.218	.177	.123	.681	.430	.214	.843	.390	.225
10.0	1.12	.533	.473	.360	.281	.225	.183	.127	.703	.443	.221	.870	.402	.232
15.0	1.20	.578	.513	.390	.305	.244	.198	.138	.763	.481	.240	.943	.436	.251
20.0	1.27	.619	.548	.417	.326	.260	.212	.147	.815	.514	.256	1.01	.465	.269

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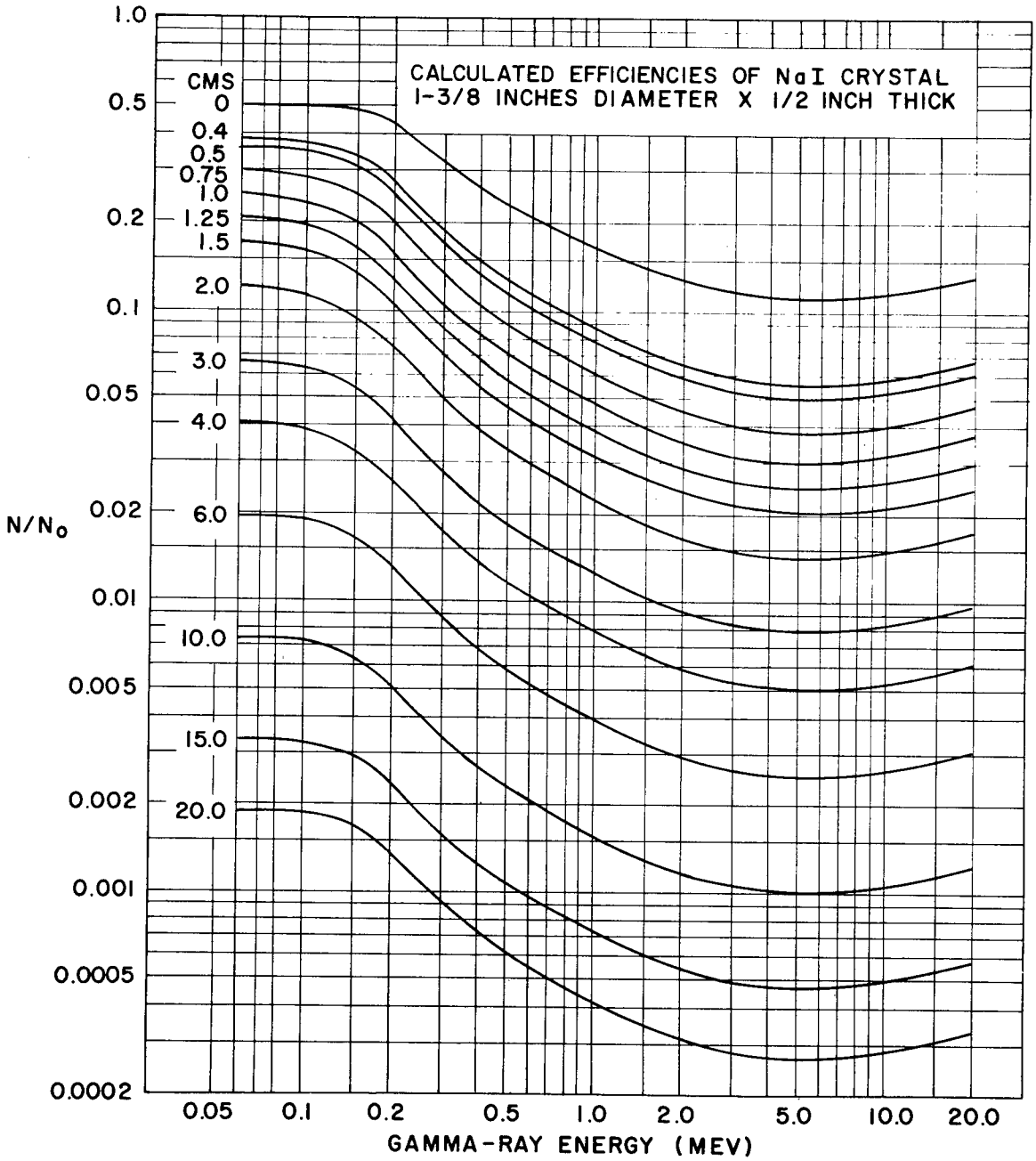

Fig. 7 - Calculated efficiencies of NaI crystal 1-3/8 inches diameter and 1/2 inch thick

TABLE 7
Calculated Efficiencies of NaI Crystal 1-3/8 Inches Diameter and 1/2 Inch Thick

γ-Ray Energies (mev)	Distance (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-2}	X 10^{-2}	X 10^{-2}	X 10^{-3}	X 10^{-3}	X 10^{-3}
.06	5.00	3.86	3.59	2.99	2.47	2.05	1.71	1.21	6.64	4.10	1.96	7.39	3.33	1.88
.08	5.00	3.82	3.55	2.94	2.42	2.00	1.67	1.18	6.49	4.02	1.93	7.32	3.31	1.87
.10	5.00	3.76	3.48	2.86	2.34	1.93	1.60	1.13	6.27	3.90	1.89	7.21	3.27	1.86
.15	4.86	3.37	3.08	2.48	2.01	1.64	1.36	.959	5.36	3.38	1.66	6.46	2.97	1.69
.20	4.31	2.75	2.49	1.97	1.58	1.29	1.06	.751	4.21	2.66	1.32	5.17	2.39	1.37
.30	3.21	1.88	1.70	1.33	1.06	.857	.706	.497	2.79	1.77	.881	3.47	1.61	.921
.40	2.63	1.49	1.34	1.04	.827	.669	.551	.387	2.17	1.38	.688	2.71	1.26	.721
.50	2.28	1.27	1.14	.882	.701	.567	.466	.328	1.84	1.17	.583	2.30	1.07	.612
.60	2.08	1.14	1.02	.792	.628	.508	.418	.294	1.65	1.05	.522	2.06	.956	.549
.80	1.82	.977	.876	.679	.538	.435	.357	.251	1.41	.895	.447	1.76	.819	.470
1.0	1.65	.875	.784	.607	.481	.389	.319	.224	1.26	.799	.399	1.58	.732	.420
1.5	1.40	.725	.648	.501	.397	.321	.263	.185	1.04	.660	.330	1.30	.604	.341
2.0	1.28	.650	.582	.450	.356	.287	.236	.166	.931	.591	.295	1.17	.542	.311
3.0	1.17	.586	.524	.405	.320	.259	.212	.149	.837	.531	.266	1.05	.487	.280
4.0	1.13	.563	.503	.388	.307	.248	.204	.143	.804	.510	.255	1.01	.468	.269
5.0	1.12	.556	.498	.384	.304	.245	.202	.142	.795	.504	.252	.996	.463	.266
6.0	1.12	.556	.498	.384	.304	.245	.202	.142	.795	.504	.252	.996	.463	.266
8.0	1.14	.567	.507	.391	.310	.250	.205	.144	.810	.514	.257	1.01	.471	.271
10.0	1.17	.584	.523	.404	.320	.258	.212	.149	.835	.530	.265	1.05	.486	.279
15.0	1.25	.633	.566	.438	.347	.280	.230	.161	.906	.575	.288	1.14	.527	.303
20.0	1.32	.676	.604	.467	.370	.299	.245	.172	.967	.614	.307	1.21	.563	.323

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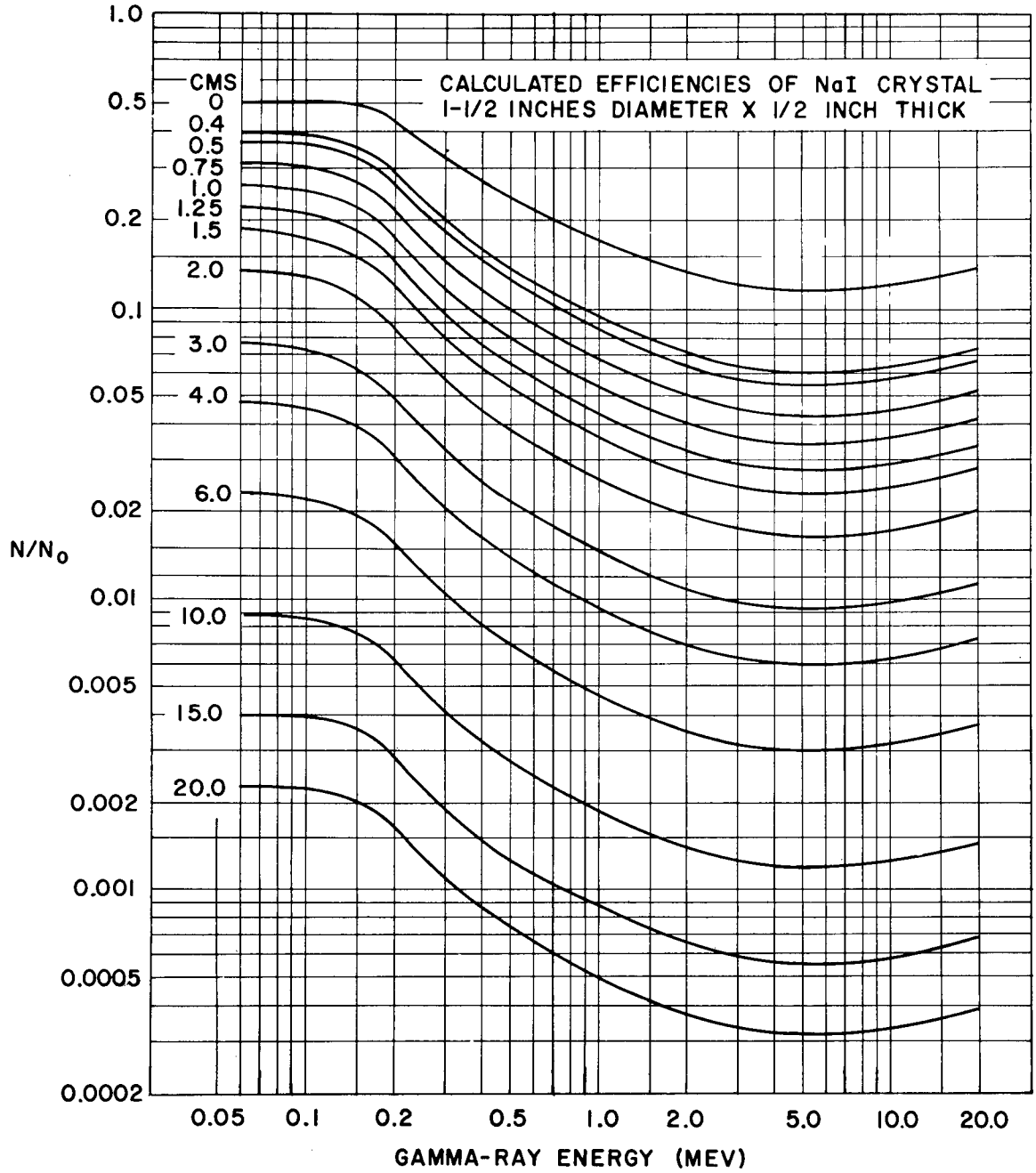

Fig. 8 - Calculated efficiencies of NaI crystal 1-1/2 inches diameter and 1/2 inch thick

TABLE 8
Calculated Efficiencies of NaI Crystal 1-1/2 Inches Diameter and 1/2 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	3.95	3.70	3.14	2.64	2.22	1.87	1.35	7.63	4.78	2.32	8.78	3.98	2.24
.08	5.00	3.92	3.67	3.09	2.59	2.17	1.83	1.32	7.47	4.69	2.28	8.69	3.95	2.23
.10	5.00	3.86	3.61	3.02	2.52	2.11	1.77	1.28	7.23	4.55	2.23	8.56	3.92	2.21
.15	4.88	3.52	3.24	2.66	2.19	1.81	1.52	1.09	6.21	3.95	1.96	7.67	3.54	2.01
.20	4.36	2.90	2.65	2.14	1.74	1.44	1.20	.857	4.89	3.12	1.56	6.15	2.85	1.63
.30	3.29	2.01	1.83	1.45	1.17	.960	.797	.569	3.25	2.07	1.04	4.12	1.92	1.10
.40	2.71	1.60	1.44	1.14	.919	.752	.624	.445	2.53	1.62	.814	3.23	1.50	.859
.50	2.36	1.36	1.23	.970	.780	.637	.528	.377	2.15	1.37	.690	2.74	1.27	.728
.60	2.15	1.23	1.11	.872	.700	.572	.474	.337	1.92	1.23	.618	2.45	1.14	.653
.80	1.89	1.05	.951	.748	.600	.490	.406	.289	1.65	1.05	.529	2.10	.978	.559
1.0	1.71	.944	.852	.669	.536	.438	.363	.258	1.47	.940	.473	1.88	.874	.500
1.5	1.45	.784	.705	.553	.443	.361	.300	.213	1.21	.775	.390	1.55	.722	.413
2.0	1.32	.704	.633	.497	.398	.324	.268	.191	1.09	.695	.349	1.39	.647	.370
3.0	1.21	.634	.570	.447	.358	.292	.241	.172	.977	.625	.315	1.25	.582	.333
4.0	1.17	.609	.548	.429	.344	.280	.232	.165	.937	.600	.302	1.20	.559	.320
5.0	1.16	.603	.542	.425	.340	.277	.229	.163	.927	.593	.299	1.19	.553	.316
6.0	1.16	.603	.542	.425	.340	.277	.229	.163	.927	.593	.299	1.19	.553	.316
8.0	1.18	.614	.552	.433	.346	.282	.234	.166	.945	.604	.304	1.21	.563	.322
10.0	1.21	.632	.569	.446	.357	.291	.241	.171	.975	.623	.314	1.25	.581	.332
15.0	1.29	.685	.617	.483	.387	.316	.261	.186	1.06	.676	.340	1.35	.630	.360
20.0	1.37	.731	.658	.516	.413	.337	.279	.198	1.13	.722	.364	1.44	.673	.385

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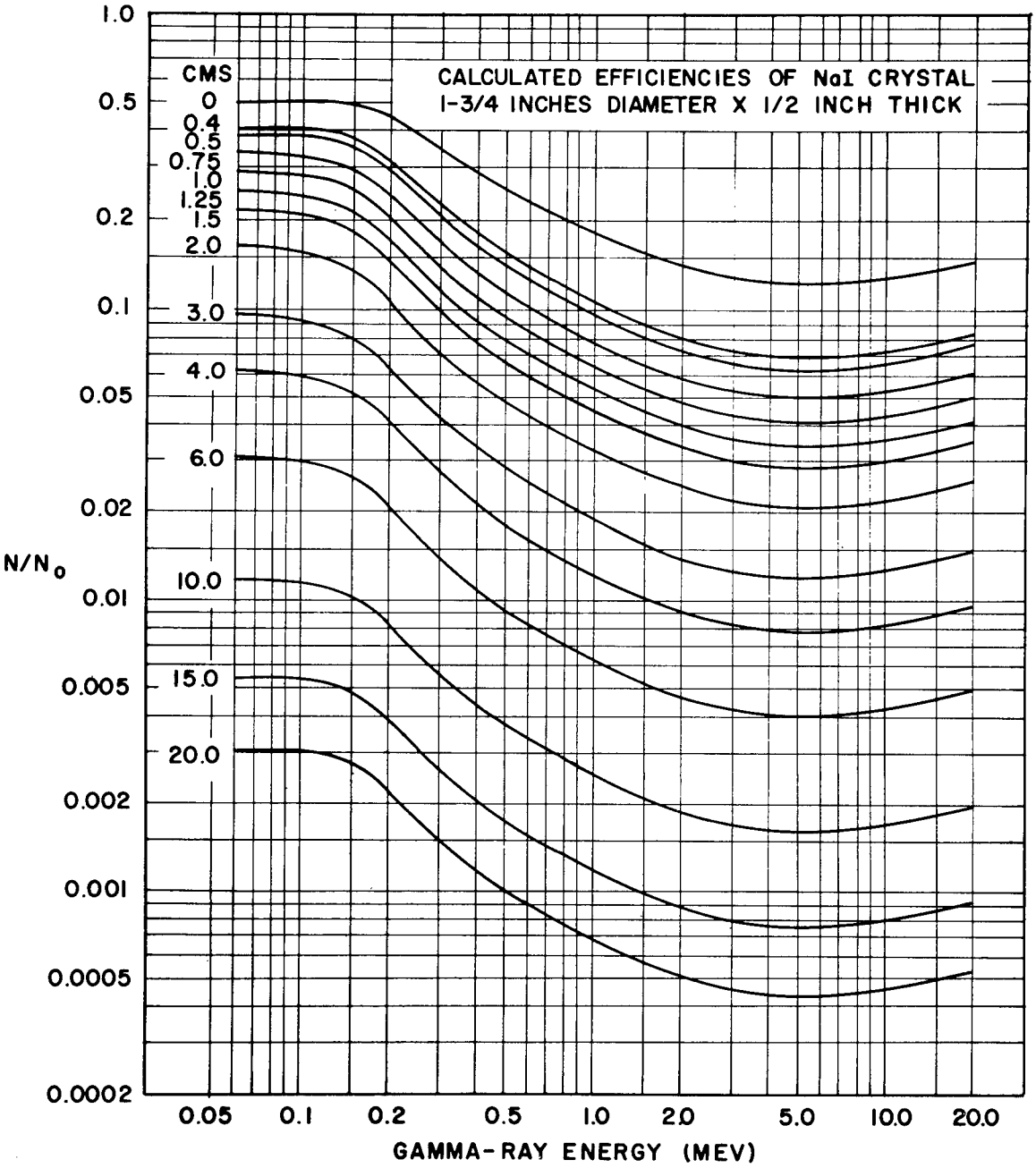

Fig. 9 - Calculated efficiencies of NaI crystal 1-3/4 inches diameter and 1/2 inch thick

TABLE 9
Calculated Efficiencies of NaI Crystal 1-3/4 Inches Diameter and 1/2 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	4.10	3.88	3.37	2.92	2.52	2.17	1.63	9.64	6.20	3.08	1.18	5.37	3.05
.08	5.00	4.07	3.86	3.34	2.88	2.48	2.13	1.60	9.46	6.09	3.03	1.17	5.33	3.04
.10	5.00	4.04	3.81	3.28	2.82	2.41	2.08	1.55	9.18	5.93	2.97	1.15	5.28	3.01
.15	4.90	3.75	3.50	2.96	2.50	2.12	1.81	1.34	7.96	5.17	2.62	1.03	4.78	2.76
.20	4.45	3.16	2.93	2.43	2.03	1.71	1.45	1.07	6.31	4.12	2.09	.829	3.86	2.22
.30	3.43	2.24	2.06	1.68	1.39	1.16	.979	.716	4.21	2.74	1.40	.556	2.59	1.49
.40	2.84	1.79	1.64	1.33	1.09	.911	.768	.561	3.29	2.14	1.09	.435	2.03	1.17
.50	2.49	1.53	1.40	1.13	.931	.775	.653	.476	2.79	1.81	.925	.369	1.72	.993
.60	2.27	1.38	1.26	1.02	.837	.696	.586	.427	2.50	1.62	.829	.331	1.54	.891
.80	2.00	1.19	1.09	.877	.718	.597	.502	.366	2.14	1.39	.710	.283	1.32	.763
1.0	1.81	1.07	.976	.785	.643	.534	.449	.327	1.91	1.24	.634	.253	1.18	.682
1.5	1.54	.891	.811	.651	.532	.442	.371	.270	1.58	1.03	.523	.209	.976	.563
2.0	1.40	.801	.728	.584	.478	.396	.333	.242	1.42	.919	.469	.187	.875	.505
3.0	1.28	.722	.657	.526	.430	.356	.299	.218	1.27	.826	.422	.169	.787	.454
4.0	1.24	.694	.631	.506	.413	.342	.287	.209	1.22	.794	.405	.162	.755	.436
5.0	1.23	.687	.624	.500	.409	.339	.284	.207	1.21	.785	.401	.160	.747	.431
6.0	1.23	.687	.624	.500	.409	.339	.284	.207	1.21	.785	.401	.160	.747	.431
8.0	1.25	.699	.636	.509	.416	.345	.290	.211	1.23	.800	.408	.163	.761	.440
10.0	1.28	.721	.655	.525	.429	.356	.299	.217	1.27	.824	.421	.168	.785	.453
15.0	1.37	.780	.710	.569	.465	.386	.324	.236	1.38	.895	.457	.182	.852	.491
20.0	1.45	.832	.757	.607	.496	.412	.346	.252	1.47	.956	.487	.195	.909	.525

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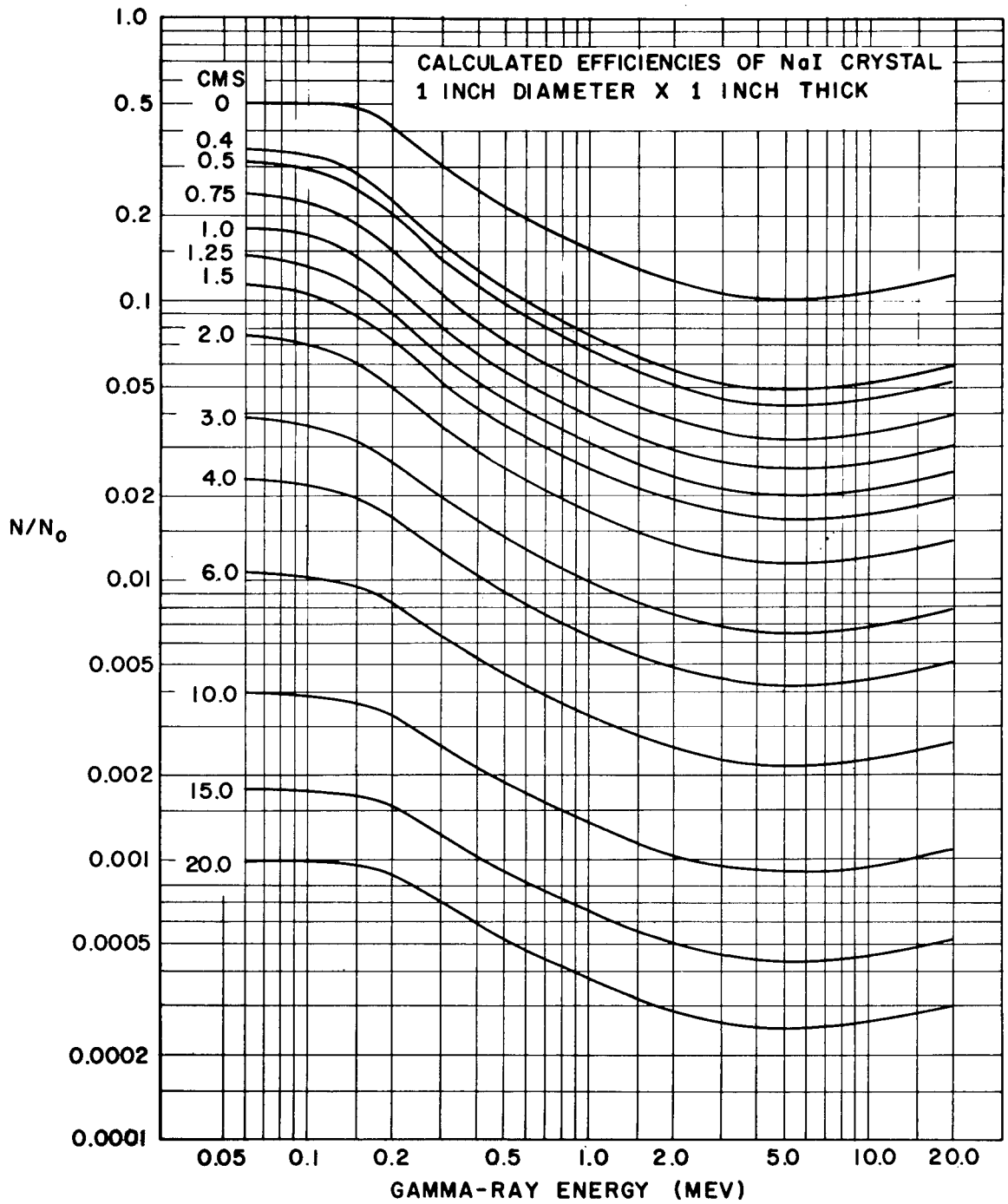

Fig. 10 - Calculated efficiencies of NaI crystal 1 inch diameter and 1 inch thick

TABLE 10
Calculated Efficiencies of NaI Crystal 1 Inch Diameter and 1 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-4}$
.06	5.00	3.45	3.11	2.40	1.81	1.45	1.15	7.57	3.87	2.30	1.07	3.96	1.79	9.96
.08	5.00	3.39	3.05	2.33	1.79	1.40	1.11	7.33	3.76	2.25	1.05	3.93	1.78	9.91
.10	5.00	3.28	2.93	2.22	1.71	1.33	1.06	7.00	3.62	2.18	1.03	3.87	1.76	9.83
.15	4.80	2.81	2.48	1.85	1.42	1.11	.885	5.96	3.17	1.95	.945	3.66	1.69	9.51
.20	4.16	2.27	2.00	1.50	1.15	.901	.724	4.94	2.69	1.68	.835	3.30	1.55	8.78
.30	3.05	1.59	1.40	1.05	.806	.637	.516	3.57	1.98	1.26	.638	2.57	1.22	6.97
.40	2.48	1.27	1.12	.834	.647	.513	.416	2.89	1.62	1.03	.527	2.14	1.02	5.83
.50	2.15	1.09	.958	.718	.556	.441	.359	2.50	1.40	.900	.460	1.88	.892	5.12
.60	1.95	.982	.866	.648	.503	.400	.325	2.26	1.27	.818	.419	1.71	.817	4.68
.80	1.70	.848	.748	.561	.437	.346	.281	1.96	1.11	.712	.366	1.50	.716	4.11
1.0	1.54	.762	.672	.504	.391	.312	.253	1.77	1.00	.644	.331	1.36	.649	3.73
1.5	1.30	.635	.560	.420	.326	.260	.212	1.48	.838	.540	.278	1.14	.547	3.14
2.0	1.18	.571	.504	.378	.293	.234	.191	1.33	.757	.488	.252	1.03	.496	2.85
3.0	1.07	.516	.455	.342	.265	.211	.172	1.21	.685	.442	.228	.938	.450	2.59
4.0	1.03	.495	.434	.328	.255	.203	.166	1.16	.659	.425	.220	.903	.433	2.49
5.0	1.02	.491	.431	.325	.252	.201	.164	1.15	.652	.421	.217	.894	.429	2.46
6.0	1.02	.491	.431	.325	.252	.201	.164	1.15	.652	.421	.217	.894	.429	2.46
8.0	1.04	.500	.439	.331	.257	.205	.167	1.17	.664	.429	.221	.910	.436	2.51
10.0	1.07	.515	.453	.340	.264	.211	.172	1.20	.683	.441	.228	.936	.449	2.58
15.0	1.15	.557	.490	.368	.286	.228	.186	1.30	.738	.476	.245	1.01	.483	2.78
20.0	1.22	.593	.523	.392	.305	.243	.198	1.38	.785	.506	.261	1.07	.514	2.95

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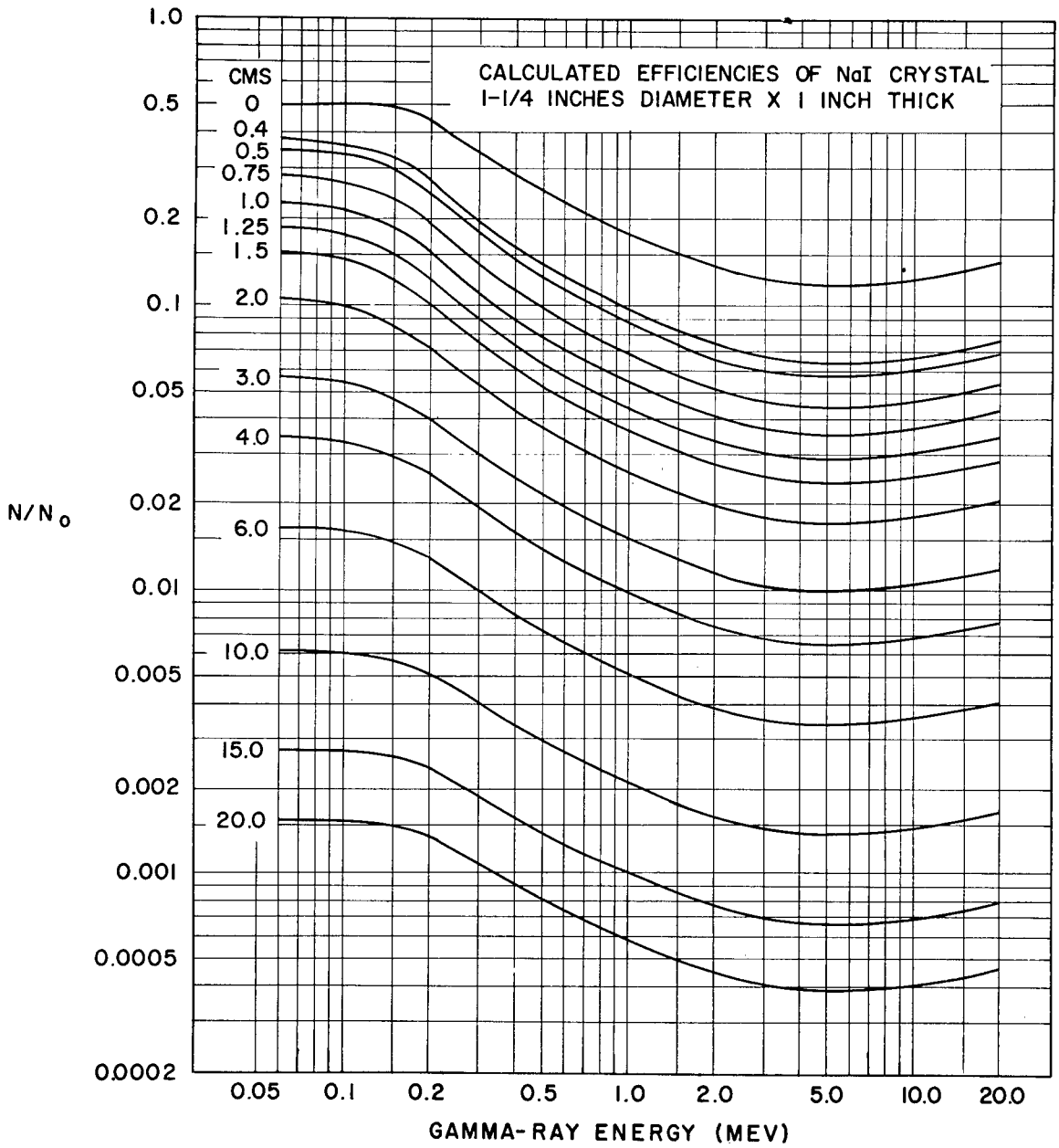

Fig. 11 - Calculated efficiencies of NaI crystal 1-1/4 inches diameter and 1 inch thick

TABLE 11
Calculated Efficiencies of NaI Crystal 1-1/4 Inches Diameter and 1 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	3.75	3.46	2.82	2.28	1.86	1.53	1.06	5.67	3.46	1.64	6.14	2.75	1.56
.08	5.00	3.70	3.41	2.76	2.23	1.82	1.49	1.03	5.54	3.39	1.62	6.09	2.74	1.55
.10	5.00	3.63	3.33	2.67	2.15	1.74	1.43	.987	5.35	3.29	1.58	6.00	2.71	1.54
.15	4.90	3.25	2.95	2.32	1.85	1.50	1.23	.852	4.72	2.96	1.46	5.67	2.60	1.49
.20	4.43	2.74	2.47	1.93	1.54	1.24	1.02	.717	4.03	2.56	1.29	5.13	2.38	1.38
.30	3.40	1.98	1.78	1.39	1.10	.894	.738	.523	2.97	1.92	.985	4.00	1.88	1.09
.40	2.81	1.60	1.44	1.12	.892	.724	.598	.425	2.44	1.58	.814	3.33	1.57	.914
.50	2.45	1.38	1.24	.966	.770	.625	.517	.368	2.12	1.38	.711	2.91	1.38	.804
.60	2.24	1.25	1.13	.875	.698	.568	.469	.334	1.93	1.25	.648	2.66	1.26	.735
.80	1.96	1.09	.976	.759	.606	.491	.407	.290	1.68	1.09	.566	2.33	1.10	.644
1.0	1.78	.980	.879	.685	.546	.443	.366	.262	1.52	.987	.513	2.11	1.00	.585
1.5	1.50	.818	.734	.571	.456	.370	.307	.219	1.27	.828	.431	1.78	.844	.494
2.0	1.36	.738	.662	.515	.411	.334	.276	.198	1.15	.748	.389	1.61	.764	.447
3.0	1.24	.667	.598	.466	.371	.302	.250	.179	1.04	.678	.353	1.46	.693	.406
4.0	1.20	.642	.576	.448	.358	.290	.241	.172	.999	.652	.340	1.40	.667	.391
5.0	1.18	.634	.570	.443	.354	.288	.238	.170	.989	.646	.337	1.39	.660	.387
6.0	1.18	.634	.570	.443	.354	.288	.238	.170	.989	.646	.337	1.39	.660	.387
8.0	1.20	.646	.580	.451	.360	.292	.242	.173	1.01	.657	.342	1.42	.672	.394
10.0	1.24	.665	.598	.464	.371	.301	.249	.178	1.04	.676	.352	1.46	.691	.405
15.0	1.33	.719	.646	.502	.401	.326	.269	.193	1.12	.730	.380	1.57	.745	.436
20.0	1.41	.766	.688	.534	.427	.346	.287	.205	1.19	.776	.404	1.67	.791	.463

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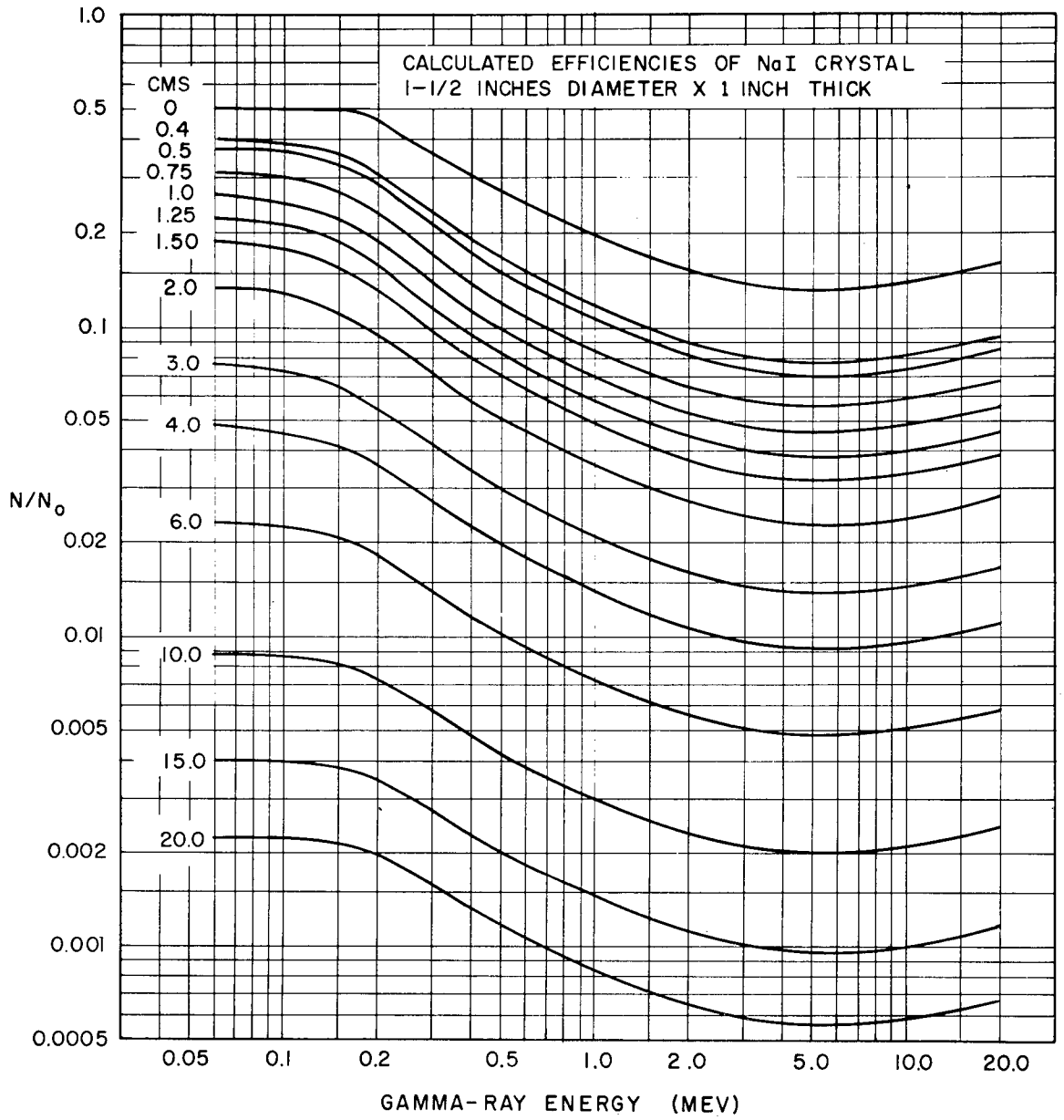

Fig. 12 - Calculated efficiencies of NaI crystal 1-1/2 inches diameter and 1 inch thick

TABLE 12
Calculated Efficiencies of NaI Crystal 1-1/2 Inches Diameter and 1 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	3.95	3.70	3.12	2.64	2.22	1.87	1.34	7.63	4.78	2.31	8.78	3.98	2.24
.08	5.00	3.92	3.67	3.08	2.59	2.18	1.83	1.32	7.47	4.69	2.28	8.70	3.95	2.23
.10	5.00	3.86	3.61	3.01	2.52	2.11	1.77	1.28	7.23	4.55	2.23	8.57	3.91	2.21
.15	4.95	3.58	3.30	2.70	2.23	1.86	1.56	1.12	6.44	4.11	2.06	8.10	3.76	2.14
.20	4.60	3.11	2.85	2.30	1.89	1.57	1.32	.952	5.53	3.58	1.83	7.33	3.44	1.98
.30	3.66	2.32	2.12	1.70	1.39	1.15	.965	.702	4.13	2.70	1.40	5.72	2.72	1.57
.40	3.07	1.90	1.73	1.38	1.13	.948	.787	.573	3.39	2.22	1.16	4.76	2.27	1.31
.50	2.70	1.65	1.50	1.20	.981	.813	.682	.497	2.94	1.94	1.01	4.17	1.99	1.15
.60	2.47	1.50	1.36	1.09	.891	.736	.619	.453	2.68	1.76	.921	3.81	1.82	1.05
.80	2.17	1.31	1.19	.947	.775	.642	.539	.393	2.33	1.54	.805	3.34	1.60	.926
1.0	1.98	1.18	1.07	.854	.699	.579	.487	.355	2.11	1.39	.729	3.02	1.45	.839
1.5	1.68	.990	.898	.716	.586	.485	.407	.297	1.77	1.17	.613	2.55	1.22	.708
2.0	1.52	.893	.812	.646	.528	.438	.368	.269	1.60	1.06	.554	2.30	1.10	.642
3.0	1.39	.809	.734	.585	.478	.396	.333	.243	1.45	.956	.503	2.09	1.00	.583
4.0	1.34	.778	.707	.563	.460	.381	.320	.234	1.39	.920	.484	2.01	.964	.561
5.0	1.33	.771	.699	.557	.455	.377	.317	.230	1.38	.910	.479	1.99	.955	.555
6.0	1.33	.771	.699	.557	.455	.377	.317	.230	1.38	.910	.479	1.99	.955	.555
8.0	1.35	.784	.712	.569	.463	.384	.322	.236	1.40	.926	.487	2.03	.972	.565
10.0	1.39	.808	.733	.584	.477	.395	.332	.243	1.44	.953	.501	2.08	1.00	.581
15.0	1.49	.872	.791	.630	.515	.427	.358	.261	1.56	1.03	.540	2.25	1.08	.628
20.0	1.58	.927	.841	.670	.548	.454	.381	.279	1.66	1.09	.574	2.39	1.14	.665

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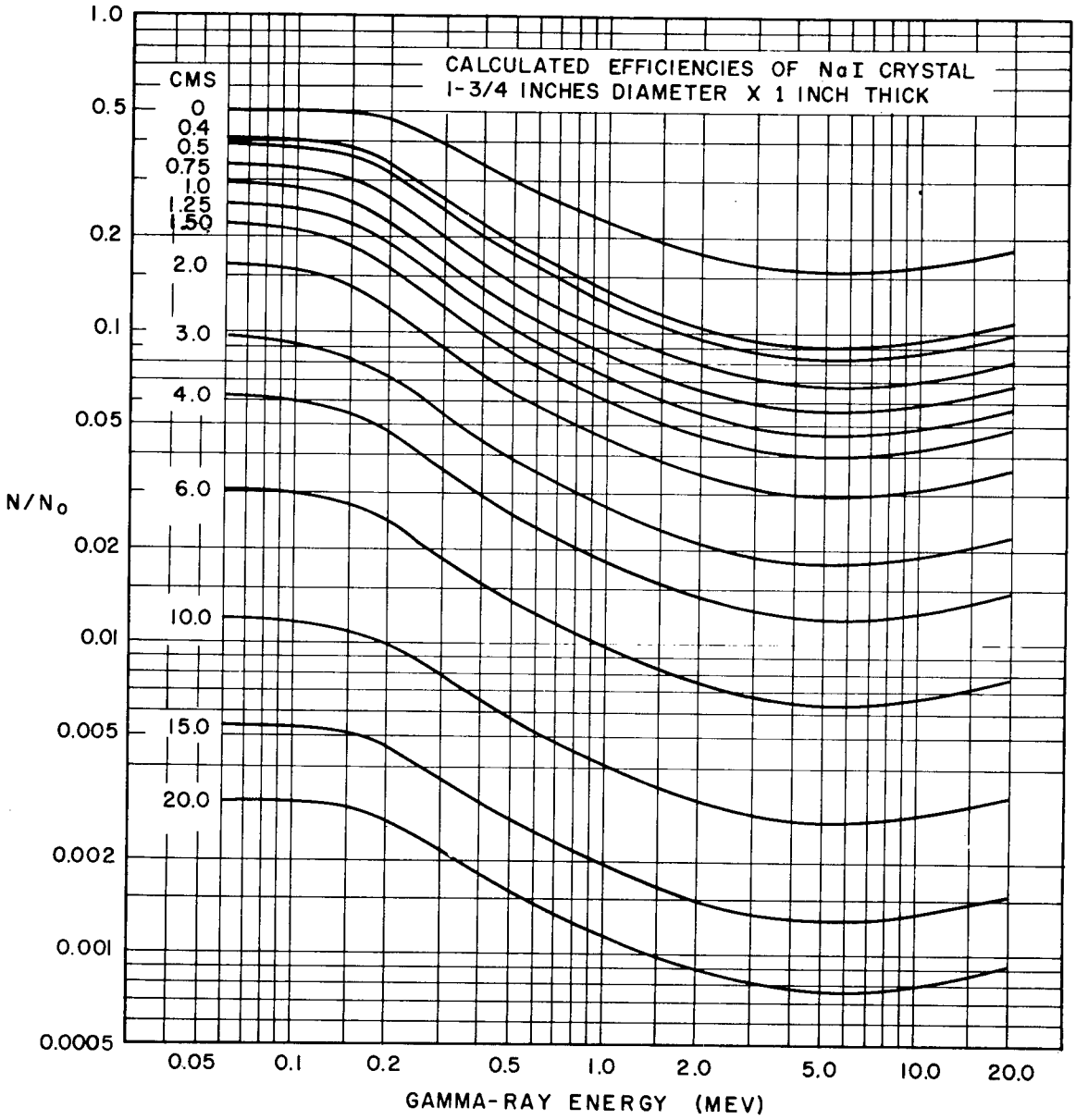

Fig. 13 - Calculated efficiencies of NaI crystal 1-3/4 inches diameter and 1 inch thick

TABLE 13
Calculated Efficiencies of NaI Crystal 1-3/4 Inches Diameter and 1 Inch Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-2}	X 10^{-2}	X 10^{-2}	X 10^{-2}	X 10^{-3}	X 10^{-3}
.06	5.00	4.10	3.88	3.37	2.92	2.52	2.17	1.63	9.64	6.20	3.08	1.18	5.37	3.05
.08	5.00	4.07	3.86	3.34	2.88	2.48	2.13	1.60	9.46	6.09	3.03	1.17	5.33	3.04
.10	5.00	4.04	3.81	3.28	2.82	2.42	2.08	1.55	9.19	5.93	2.97	1.15	5.28	3.01
.15	4.98	3.82	3.57	3.02	2.56	2.18	1.86	1.38	8.25	5.38	2.75	1.09	5.07	2.92
.20	4.73	3.40	3.16	2.63	2.21	1.87	1.60	1.19	7.15	4.70	2.44	.988	4.65	2.69
.30	3.90	2.61	2.41	1.98	1.66	1.40	1.19	.888	5.37	3.56	1.87	.771	3.67	2.14
.40	3.33	2.16	1.99	1.63	1.36	1.15	.977	.728	4.41	2.94	1.55	.642	3.07	1.79
.50	2.97	1.89	1.73	1.42	1.18	.998	.849	.633	3.84	2.56	1.36	.562	2.69	1.57
.60	2.74	1.72	1.58	1.29	1.08	.907	.773	.576	3.50	2.33	1.24	.514	2.46	1.44
.80	2.44	1.50	1.38	1.13	.940	.791	.673	.502	3.05	2.04	1.08	.450	2.16	1.26
1.0	2.23	1.36	1.25	1.02	.849	.715	.608	.453	2.76	1.84	.978	.408	1.96	1.14
1.5	1.92	1.15	1.05	.858	.713	.600	.511	.380	2.32	1.55	.823	.343	1.65	.966
2.0	1.76	1.04	.950	.776	.644	.542	.461	.344	2.09	1.40	.744	.311	1.49	.875
3.0	1.62	.940	.862	.703	.584	.491	.418	.311	1.90	1.27	.675	.282	1.35	.794
4.0	1.57	.905	.829	.676	.562	.472	.402	.300	1.82	1.22	.650	.271	1.30	.765
5.0	1.55	.896	.821	.670	.556	.468	.398	.297	1.81	1.21	.643	.269	1.29	.757
6.0	1.55	.896	.821	.670	.556	.468	.398	.297	1.81	1.21	.643	.269	1.29	.757
8.0	1.58	.912	.835	.681	.566	.476	.405	.302	1.84	1.23	.654	.273	1.31	.770
10.0	1.62	.938	.860	.701	.582	.490	.417	.311	1.89	1.26	.673	.281	1.35	.792
15.0	1.72	1.01	.927	.757	.628	.528	.450	.335	2.04	1.36	.726	.303	1.46	.854
20.0	1.82	1.07	.985	.804	.668	.562	.478	.356	2.17	1.45	.772	.322	1.55	.906

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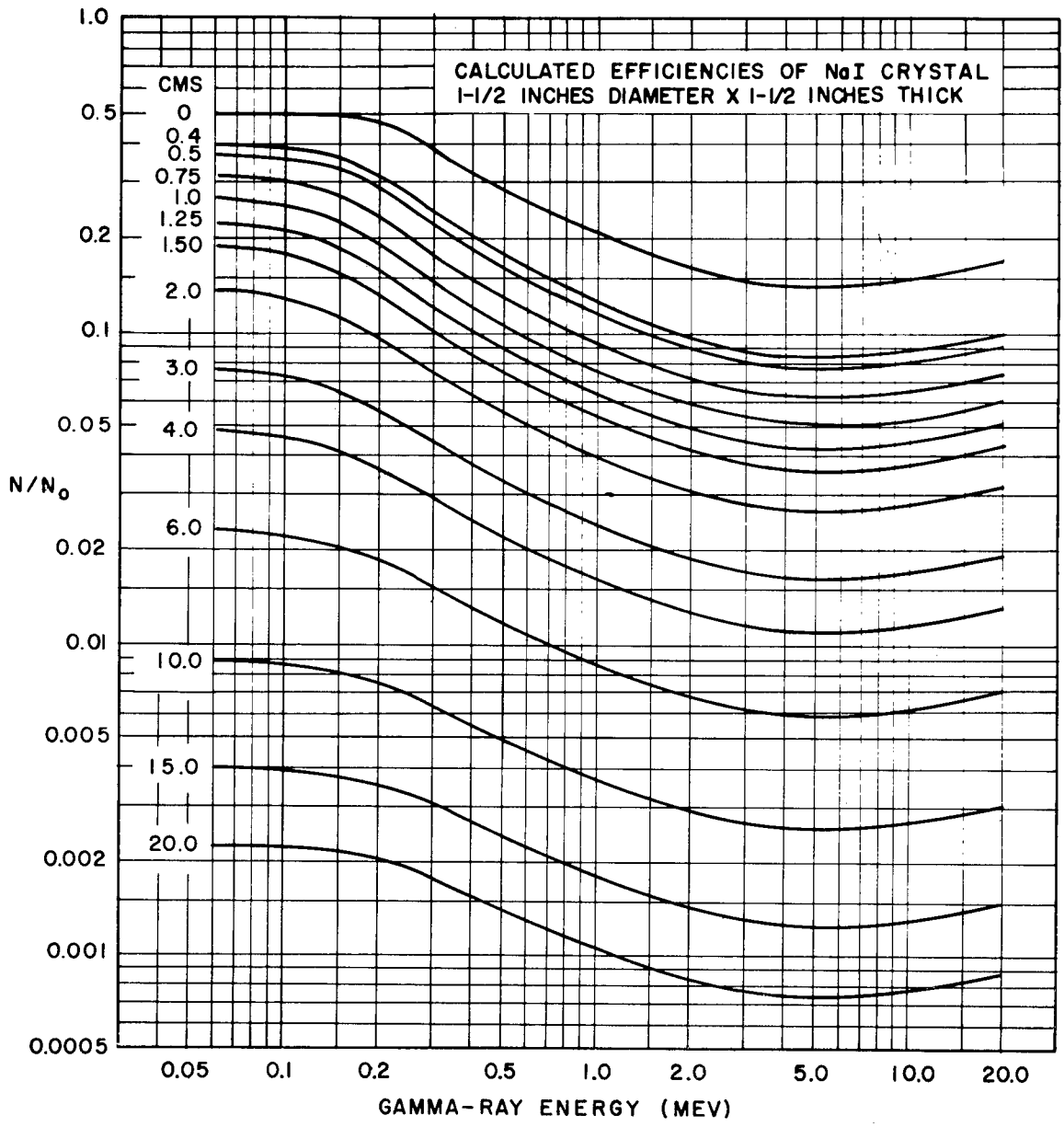

Fig. 14 - Calculated efficiencies of NaI crystal 1-1/2 inches diameter and 1-1/2 inches thick

TABLE 14
Calculated Efficiencies of NaI Crystal 1-1/2 Inches Diameter and 1-1/2 Inches Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-1}	X 10^{-2}	X 10^{-2}	X 10^{-2}	X 10^{-3}	X 10^{-3}	X 10^{-3}
.06	5.00	3.95	3.70	3.13	2.64	2.22	1.87	1.35	7.63	4.78	2.31	8.78	3.98	2.24
.08	5.00	3.92	3.67	3.09	2.59	2.17	1.83	1.32	7.47	4.69	2.28	8.68	3.95	2.23
.10	5.00	3.86	3.61	3.02	2.52	2.11	1.77	1.28	7.23	4.56	2.23	8.56	3.91	2.21
.15	4.95	3.58	3.31	2.71	2.24	1.86	1.56	1.12	6.45	4.12	2.06	8.12	3.77	2.15
.20	4.63	3.13	2.87	2.33	1.91	1.59	1.33	.966	5.63	3.65	1.87	7.56	3.56	2.05
.30	3.75	2.39	2.18	1.76	1.45	1.20	1.01	.740	4.40	2.91	1.53	6.36	3.05	1.77
.40	3.18	1.99	1.81	1.46	1.20	.998	.842	.619	3.71	2.46	1.31	5.51	2.66	1.56
.50	2.81	1.74	1.59	1.28	1.05	.875	.738	.545	3.28	2.19	1.17	4.94	2.40	1.40
.60	2.59	1.59	1.45	1.17	.960	.801	.676	.498	3.01	2.01	1.07	4.58	2.22	1.30
.80	2.29	1.40	1.27	1.02	.842	.702	.594	.439	2.66	1.78	.956	4.08	1.99	1.17
1.0	2.09	1.27	1.15	.930	.754	.638	.540	.399	2.42	1.62	.874	3.73	1.83	1.07
1.5	1.78	1.07	.974	.785	.644	.538	.456	.338	2.06	1.38	.745	3.20	1.57	.921
2.0	1.62	.968	.882	.711	.585	.488	.414	.307	1.87	1.26	.679	2.92	1.43	.841
3.0	1.48	.880	.802	.646	.531	.444	.376	.279	1.70	1.15	.620	2.67	1.31	.770
4.0	1.43	.846	.772	.622	.512	.428	.362	.269	1.64	1.11	.598	2.58	1.26	.743
5.0	1.42	.838	.764	.616	.506	.423	.359	.266	1.62	1.09	.592	2.55	1.25	.737
6.0	1.42	.838	.764	.616	.506	.423	.359	.266	1.62	1.09	.592	2.55	1.25	.737
8.0	1.44	.853	.777	.627	.515	.431	.365	.271	1.65	1.11	.602	2.59	1.27	.748
10.0	1.48	.877	.800	.645	.530	.446	.375	.278	1.70	1.14	.619	2.66	1.31	.768
15.0	1.59	.944	.861	.694	.570	.477	.404	.299	1.82	1.23	.664	2.85	1.40	.822
20.0	1.68	1.00	.914	.737	.606	.506	.428	.318	1.93	1.30	.702	3.02	1.48	.869

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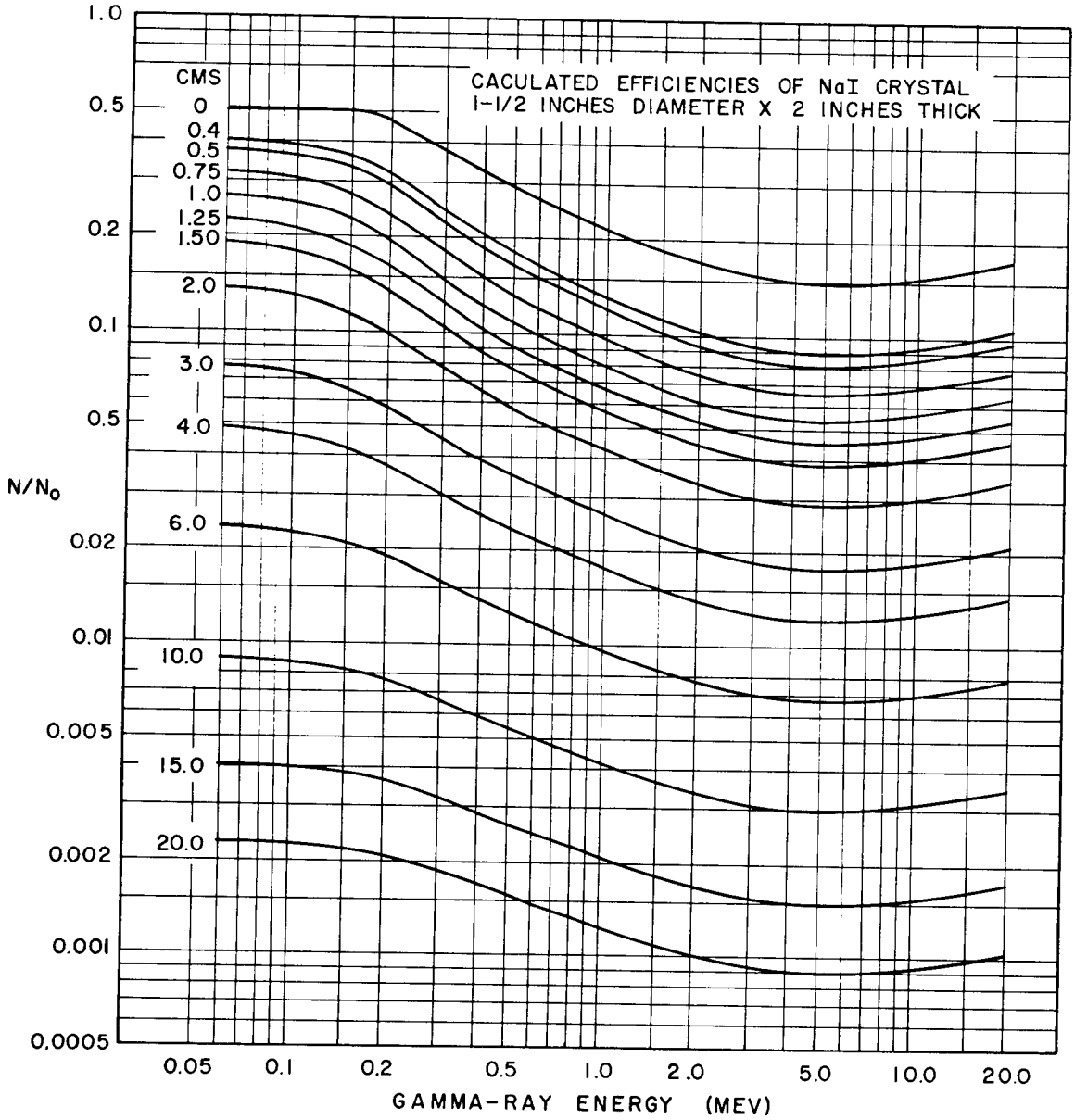

Fig. 15 - Calculated efficiencies of NaI crystal 1-1/2 inches diameter and 2 inches thick

TABLE 15
Calculated Efficiencies of NaI Crystal 1-1/2 Inches Diameter and 2 Inches Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	3.95	3.70	3.13	2.64	2.22	1.87	1.35	7.63	4.78	2.31	8.77	3.97	2.24
.08	5.00	3.92	3.67	3.09	2.59	2.17	1.83	1.32	7.47	4.69	2.28	8.69	3.95	2.23
.10	5.00	3.86	3.61	3.02	2.52	2.11	1.77	1.28	7.23	4.56	2.23	8.56	3.91	2.21
.15	4.95	3.57	3.30	2.71	2.24	1.86	1.56	1.12	6.45	4.12	2.06	8.13	3.77	2.15
.20	4.64	3.14	2.88	2.34	1.92	1.59	1.33	.968	5.65	3.67	1.88	7.61	3.59	2.07
.30	3.77	2.41	2.20	1.78	1.46	1.22	1.03	.753	4.50	2.98	1.58	6.61	3.19	1.86
.40	3.22	2.02	1.84	1.49	1.22	1.02	.862	.637	3.84	2.57	1.38	5.88	2.87	1.69
.50	2.86	1.78	1.62	1.31	1.08	.900	.762	.564	3.43	2.31	1.25	5.36	2.63	1.55
.60	2.64	1.63	1.49	1.20	.990	.826	.702	.520	3.17	2.16	1.16	5.02	2.47	1.46
.80	2.34	1.43	1.31	1.06	.872	.730	.620	.461	2.82	1.91	1.04	4.53	2.24	1.33
1.0	2.14	1.30	1.19	.963	.794	.665	.565	.421	2.59	1.75	.962	4.20	2.08	1.23
1.5	1.83	1.11	1.01	.817	.674	.565	.481	.359	2.22	1.51	.830	3.64	1.81	1.08
2.0	1.67	1.00	.916	.742	.613	.514	.437	.327	2.02	1.38	.761	3.35	1.67	.990
3.0	1.53	.913	.834	.676	.558	.469	.399	.299	1.85	1.26	.698	3.08	1.53	.913
4.0	1.48	.880	.804	.652	.538	.452	.385	.288	1.79	1.22	.675	2.98	1.48	.884
5.0	1.46	.871	.796	.645	.533	.448	.381	.285	1.77	1.21	.668	2.95	1.47	.875
6.0	1.46	.871	.796	.645	.533	.448	.381	.285	1.77	1.21	.668	2.95	1.47	.875
8.0	1.49	.886	.809	.656	.542	.455	.387	.290	1.80	1.23	.679	2.99	1.49	.889
10.0	1.53	.911	.832	.677	.557	.468	.398	.298	1.85	1.26	.696	3.07	1.53	.910
15.0	1.63	.979	.895	.725	.599	.502	.427	.320	1.98	1.35	.744	3.28	1.63	.968
20.0	1.73	1.04	.950	.768	.634	.532	.453	.338	2.09	1.43	.785	3.45	1.72	1.02

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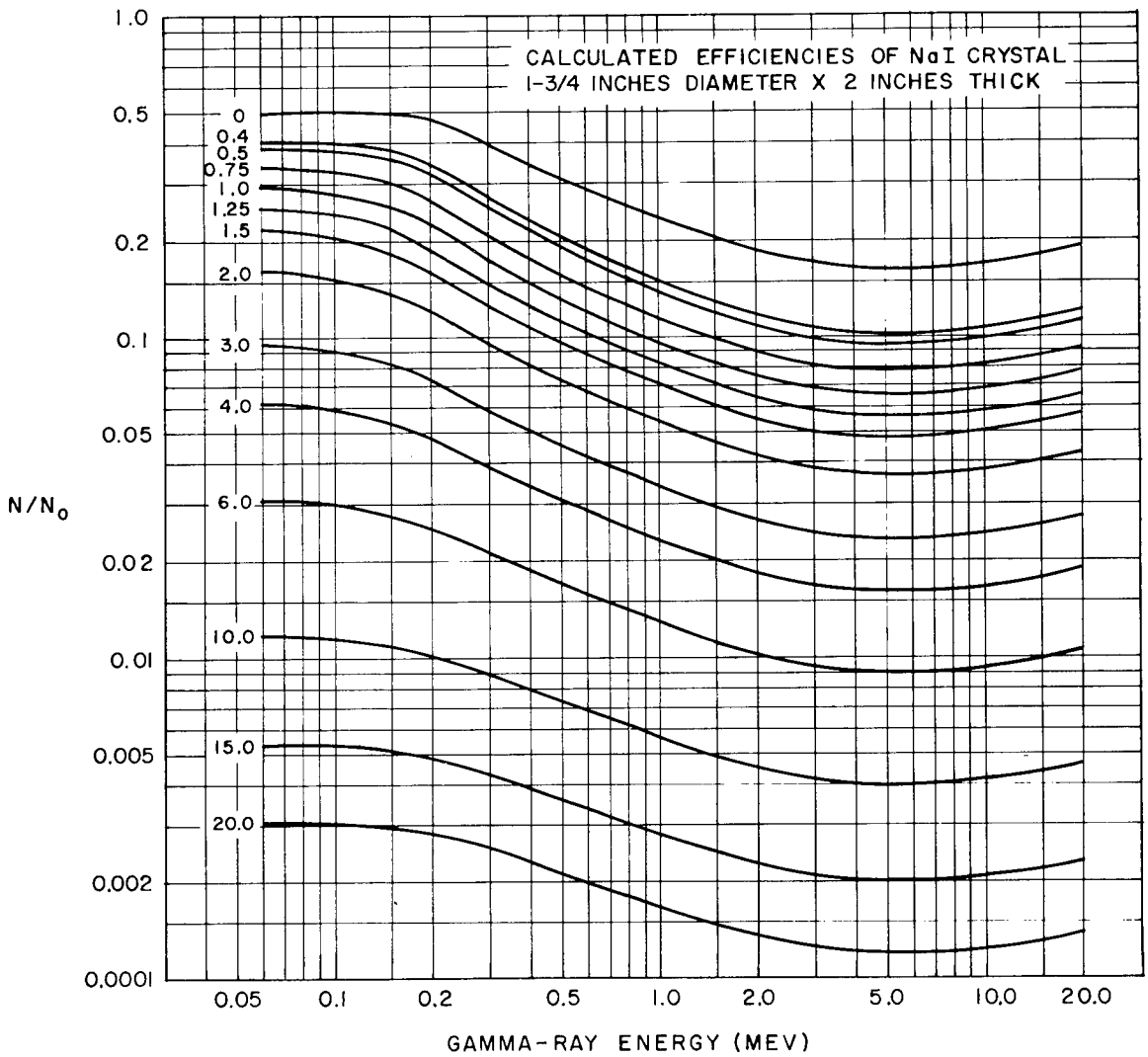

Fig. 16 - Calculated efficiencies of NaI crystal 1-3/4 inches diameter and 2 inches thick

TABLE 16
Calculated Efficiencies of NaI Crystal 1-3/4 Inches Diameter and 2 Inches Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	4.10	3.88	3.37	2.92	2.52	2.17	1.63	9.64	6.20	3.08	1.18	5.37	3.05
.08	5.00	4.08	3.86	3.34	2.88	2.48	2.13	1.60	9.46	6.09	3.03	1.17	5.33	3.03
.10	5.00	4.04	3.81	3.28	2.82	2.42	2.08	1.55	9.19	5.93	2.97	1.15	5.28	3.01
.15	4.98	3.82	3.57	3.02	2.56	2.18	1.86	1.39	8.26	5.39	2.75	1.09	5.09	2.92
.20	4.76	3.43	3.19	2.66	2.24	1.90	1.62	1.21	7.29	4.82	2.51	1.02	4.85	2.82
.30	4.00	2.72	2.52	2.09	1.75	1.48	1.27	.953	5.85	3.94	2.11	.891	4.31	2.54
.40	3.46	2.31	2.13	1.76	1.48	1.25	1.08	.811	5.02	3.40	1.85	.793	3.88	2.30
.50	3.10	2.05	1.89	1.56	1.31	1.11	.954	.721	4.49	3.06	1.67	.723	3.56	2.11
.60	2.88	1.88	1.74	1.44	1.20	1.02	.879	.666	4.16	2.84	1.56	.677	3.34	1.99
.80	2.57	1.67	1.54	1.27	1.07	.907	.779	.591	3.71	2.54	1.40	.612	3.03	1.81
1.0	2.35	1.52	1.40	1.16	.974	.828	.712	.541	3.40	2.33	1.29	.566	2.81	1.68
1.5	2.02	1.30	1.19	.987	.830	.706	.608	.462	2.91	2.01	1.12	.492	2.45	1.46
2.0	1.85	1.18	1.09	.898	.755	.643	.554	.421	2.66	1.84	1.02	.452	2.25	1.35
3.0	1.70	1.08	.991	.819	.689	.587	.505	.385	2.43	1.68	.938	.415	2.08	1.24
4.0	1.64	1.04	.956	.790	.664	.566	.487	.371	2.35	1.62	.907	.402	2.01	1.20
5.0	1.63	1.03	.947	.783	.658	.561	.483	.368	2.33	1.61	.899	.398	1.99	1.19
6.0	1.63	1.03	.947	.783	.658	.561	.483	.368	2.33	1.61	.899	.398	1.99	1.19
8.0	1.65	1.04	.962	.796	.669	.570	.491	.374	2.37	1.64	.913	.404	2.02	1.21
10.0	1.69	1.07	.989	.817	.687	.585	.504	.384	2.43	1.68	.937	.414	2.07	1.24
15.0	1.81	1.15	1.06	.878	.738	.628	.541	.412	2.60	1.80	1.00	.442	2.21	1.32
20.0	1.91	1.22	1.12	.929	.781	.665	.572	.436	2.75	1.90	1.06	.466	2.32	1.39

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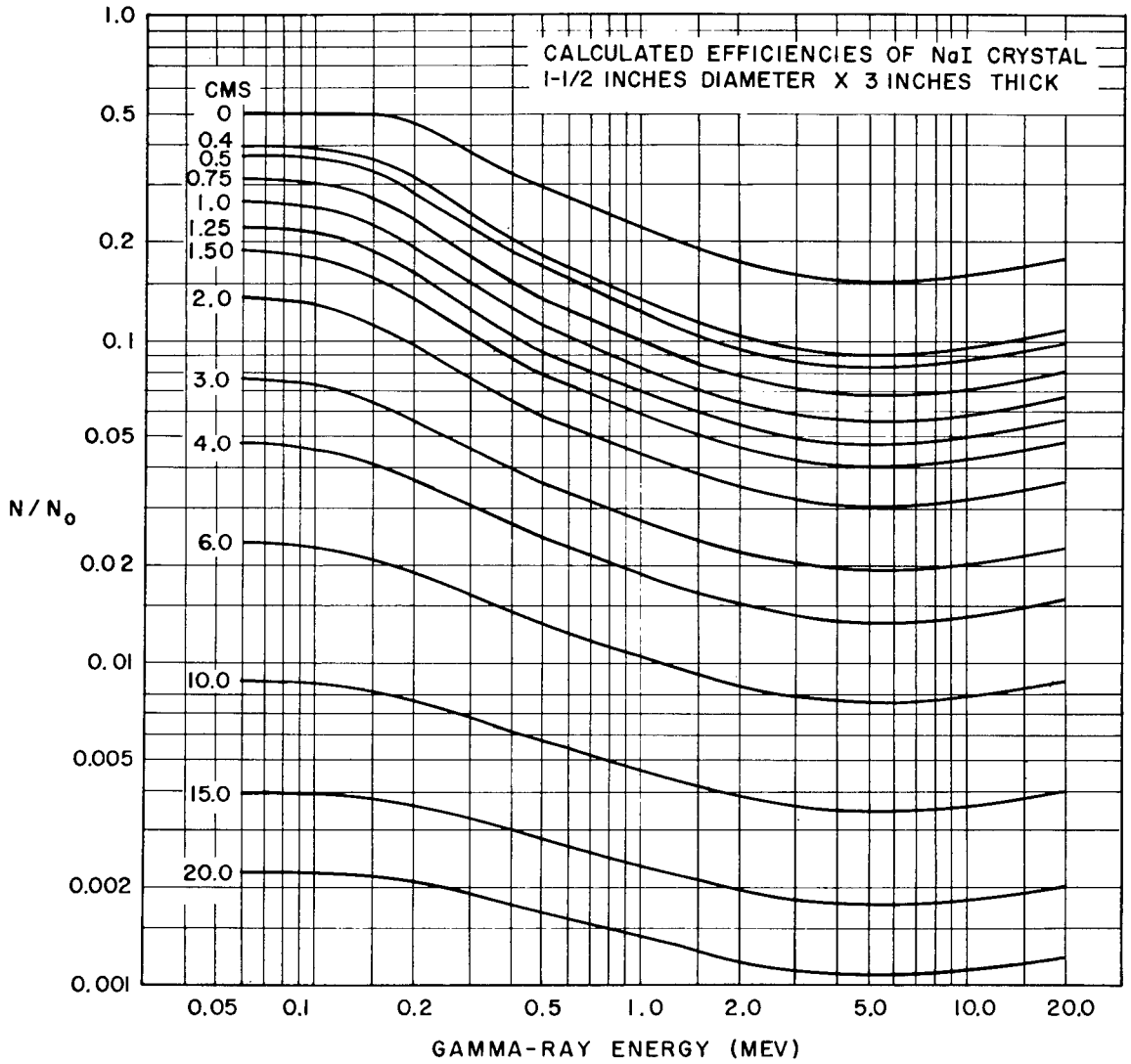

Fig. 17 - Calculated efficiencies of NaI crystal 1-1/2 inches diameter and 3 inches thick

TABLE 17
Calculated Efficiencies of NaI Crystal 1-1/2 Inches Diameter and 3 Inches Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
.06	5.00	3.95	3.70	3.13	2.64	2.22	1.87	1.35	7.63	4.78	2.32	8.78	3.98	2.24
.08	5.00	3.92	3.67	3.09	2.59	2.18	1.83	1.32	7.47	4.69	2.28	8.70	3.95	2.23
.10	5.00	3.86	3.61	3.02	2.52	2.11	1.77	1.28	7.23	4.56	2.23	8.57	3.90	2.21
.15	4.95	3.58	3.30	2.71	2.24	1.86	1.56	1.12	6.45	4.12	2.06	8.14	3.77	2.15
.20	4.64	3.14	2.88	2.34	1.92	1.59	1.34	.969	5.65	3.67	1.88	7.62	3.60	2.07
.30	3.79	2.42	2.21	1.79	1.47	1.22	1.03	.756	4.54	3.02	1.60	6.76	3.28	1.92
.40	3.24	2.03	1.86	1.50	1.24	1.03	.875	.648	3.93	2.64	1.43	6.16	3.04	1.79
.50	2.89	1.79	1.64	1.33	1.10	.918	.778	.579	3.54	2.40	1.31	5.73	2.85	1.69
.60	2.67	1.65	1.51	1.22	1.01	.846	.719	.536	3.30	2.24	1.23	5.43	2.71	1.62
.80	2.37	1.46	1.33	1.08	.895	.752	.640	.479	2.96	2.03	1.12	5.00	2.51	1.50
1.0	2.18	1.33	1.22	.989	.818	.688	.586	.440	2.74	1.88	1.05	4.68	2.36	1.42
1.5	1.87	1.13	1.04	.844	.700	.590	.503	.379	2.37	1.64	.914	4.15	2.11	1.27
2.0	1.71	1.03	.945	.769	.638	.538	.460	.347	2.18	1.51	.846	3.85	1.96	1.18
3.0	1.57	.942	.862	.702	.583	.492	.421	.318	2.00	1.39	.782	3.58	1.83	1.10
4.0	1.52	.909	.832	.678	.562	.475	.406	.307	1.94	1.34	.757	3.47	1.78	1.07
5.0	1.50	.900	.824	.672	.558	.471	.403	.304	1.92	1.33	.751	3.45	1.76	1.07
6.0	1.50	.900	.824	.672	.558	.471	.403	.304	1.92	1.33	.751	3.45	1.76	1.07
8.0	1.53	.915	.838	.683	.566	.478	.409	.309	1.95	1.35	.762	3.49	1.79	1.08
10.0	1.57	.940	.860	.701	.582	.491	.420	.317	2.00	1.38	.780	3.57	1.82	1.10
15.0	1.67	1.01	.923	.752	.624	.526	.450	.339	2.13	1.48	.829	3.78	1.92	1.16
20.0	1.77	1.07	.977	.796	.660	.556	.475	.358	2.24	1.55	.869	3.96	2.01	1.21

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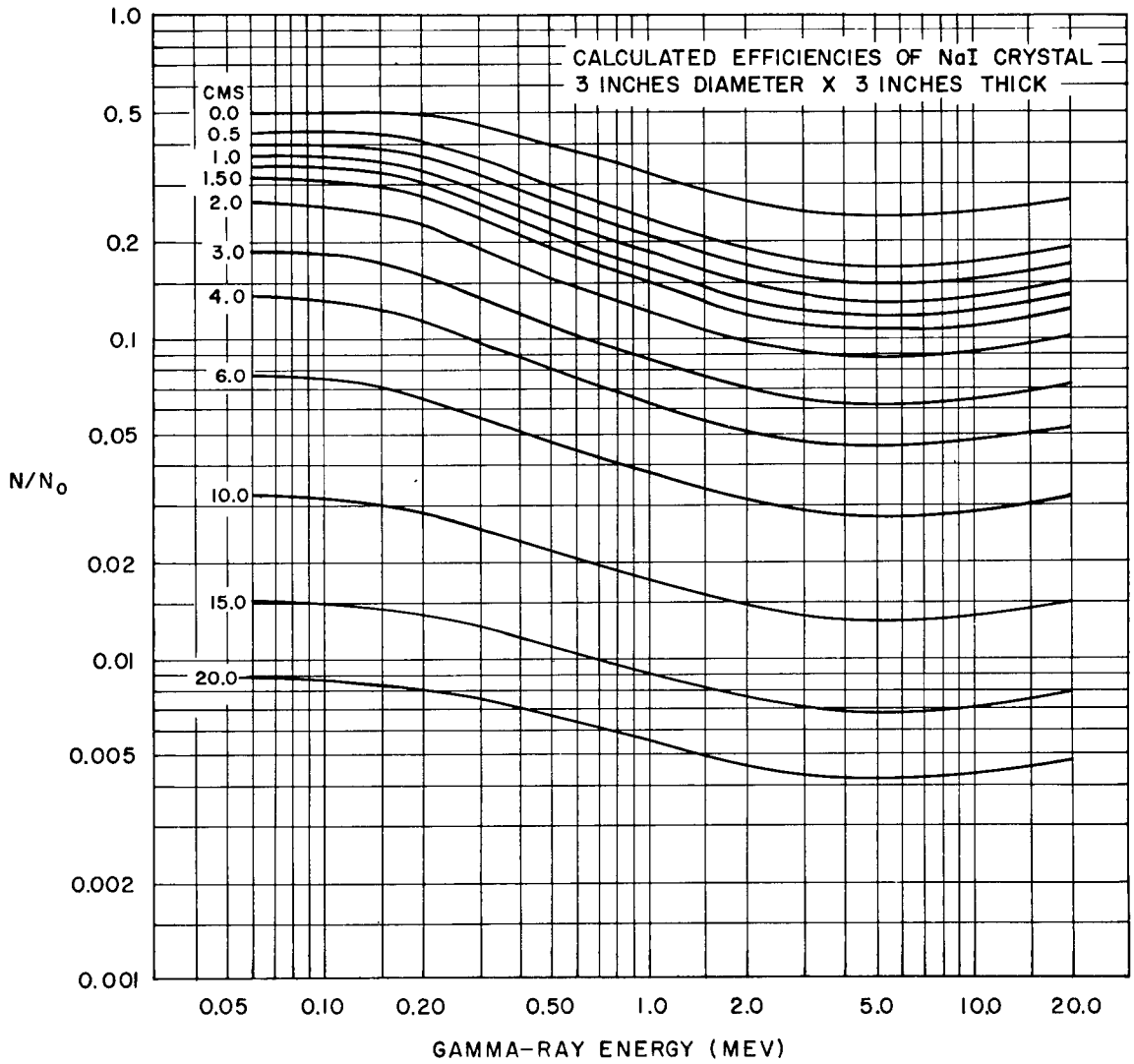

Fig. 18 - Calculated efficiencies of NaI crystal 3 inches diameter and 3 inches thick

TABLE 18
Calculated Efficiencies of NaI Crystal 3 Inches Diameter and 3 Inches Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-3}$
.06	5.00	4.48	4.35	4.03	3.72	3.43	3.15	2.66	1.89	1.37	7.72	3.25	1.53	8.81
.08	5.00	4.47	4.34	4.01	3.70	3.41	3.13	2.63	1.87	1.35	7.64	3.22	1.52	8.77
.10	5.00	4.45	4.32	3.99	3.68	3.38	3.10	2.60	1.84	1.33	7.51	3.18	1.51	8.70
.15	5.00	4.39	4.24	3.88	3.55	3.24	2.95	2.46	1.72	1.24	7.06	3.03	1.46	8.46
.20	4.97	4.23	4.07	3.69	3.34	3.03	2.74	2.27	1.58	1.14	6.53	2.86	1.39	8.17
.30	4.65	3.77	3.60	3.22	2.89	2.60	2.34	1.92	1.34	.971	5.67	2.55	1.27	7.58
.40	4.28	3.39	3.23	2.87	2.57	2.31	2.08	1.70	1.19	.866	5.11	2.34	1.18	7.09
.50	3.99	3.12	2.97	2.63	2.35	2.11	1.90	1.56	1.09	.794	4.71	2.18	1.11	6.68
.60	3.78	2.93	2.79	2.47	2.20	1.98	1.78	1.46	1.02	.747	4.45	2.07	1.06	6.39
.80	3.47	2.67	2.54	2.24	2.00	1.79	1.61	1.32	.927	.680	4.07	1.91	.979	5.95
1.0	3.25	2.48	2.36	2.08	1.86	1.66	1.50	1.23	.861	.633	3.80	1.79	.922	5.61
1.5	2.87	2.17	2.06	1.82	1.62	1.45	1.31	1.07	.754	.555	3.35	1.59	.823	5.02
2.0	2.66	2.01	1.90	1.68	1.49	1.34	1.20	.989	.696	.513	3.10	1.48	.767	4.69
3.0	2.47	1.85	1.76	1.55	1.38	1.23	1.11	.913	.643	.475	2.87	1.37	.714	4.37
4.0	2.40	1.79	1.70	1.50	1.33	1.20	1.08	.884	.623	.460	2.79	1.33	.694	4.25
5.0	2.38	1.78	1.69	1.49	1.32	1.19	1.07	.877	.618	.456	2.77	1.32	.689	4.22
6.0	2.38	1.78	1.69	1.49	1.32	1.19	1.07	.877	.618	.456	2.77	1.32	.689	4.22
8.0	2.41	1.81	1.71	1.51	1.34	1.20	1.08	.889	.626	.463	2.80	1.34	.698	4.28
10.0	2.46	1.85	1.75	1.55	1.38	1.23	1.11	.911	.641	.474	2.87	1.37	.713	4.37
15.0	2.61	1.97	1.86	1.65	1.46	1.31	1.18	.969	.682	.503	3.04	1.45	.753	4.61
20.0	2.73	2.06	1.96	1.73	1.54	1.38	1.24	1.02	.716	.528	3.19	1.51	.787	4.81

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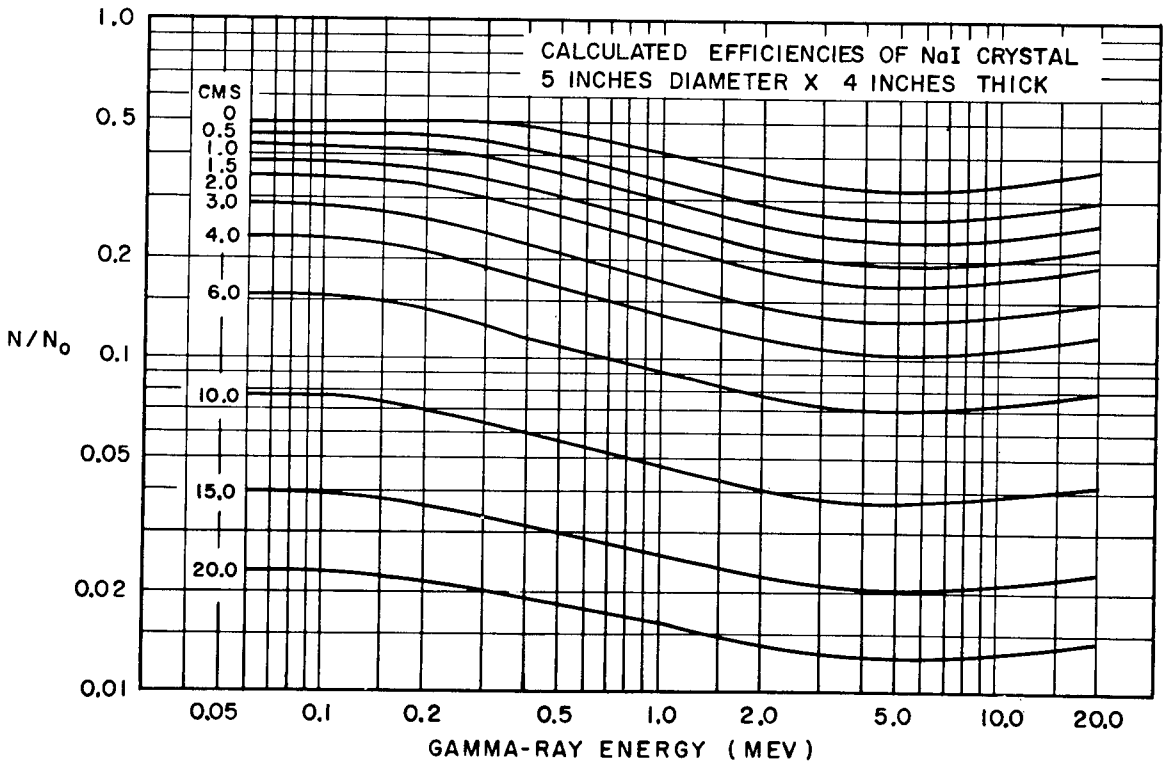

Fig. 19 - Calculated efficiencies of NaI crystal 5 inches diameter and 4 inches thick

TABLE 19
Calculated Efficiencies of NaI Crystal 5 Inches Diameter and 4 Inches Thick

γ-Ray Energies (mev)	Distance, a (centimeters)													
	.0	.4	.5	.75	1.0	1.25	1.5	2.0	3.0	4.0	6.0	10.0	15.0	20.0
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{-2}$	$\times 10^{-2}$	$\times 10^{-2}$
.06	5.00	4.68	4.61	4.41	4.22	4.03	3.85	3.49	2.85	2.32	1.56	7.74	3.94	2.33
.08	5.00	4.68	4.61	4.41	4.21	4.02	3.84	3.48	2.84	2.31	1.55	7.69	3.92	2.32
.10	5.00	4.68	4.60	4.40	4.20	4.01	3.82	3.46	2.82	2.29	1.53	7.62	3.88	2.31
.15	5.00	4.68	4.57	4.36	4.15	3.95	3.76	3.39	2.73	2.21	1.47	7.33	3.76	2.25
.20	5.00	4.62	4.52	4.29	4.07	3.86	3.65	3.27	2.62	2.10	1.39	6.97	3.62	2.17
.30	4.93	4.44	4.33	4.07	3.83	3.60	3.38	3.00	2.37	1.89	1.25	6.34	3.34	2.03
.40	4.78	4.22	4.11	3.84	3.59	3.36	3.16	2.78	2.18	1.74	1.15	5.90	3.14	1.93
.50	4.61	4.02	3.91	3.64	3.40	3.18	2.97	2.62	2.05	1.63	1.08	5.57	2.99	1.84
.60	4.47	3.88	3.76	3.50	3.26	3.04	2.85	2.50	1.95	1.56	1.03	5.34	2.88	1.78
.80	4.24	3.64	3.53	3.27	3.04	2.84	2.65	2.33	1.82	1.45	.962	5.00	2.71	1.68
1.0	4.06	3.46	3.35	3.10	2.88	2.68	2.51	2.19	1.71	1.36	.908	4.74	2.58	1.60
1.5	3.71	3.13	3.03	2.80	2.60	2.42	2.25	1.97	1.54	1.22	.817	4.28	2.34	1.46
2.0	3.50	2.94	2.85	2.62	2.43	2.26	2.11	1.84	1.44	1.14	.764	4.02	2.20	1.38
3.0	3.30	2.76	2.67	2.46	2.28	2.12	1.97	1.72	1.34	1.07	.715	3.76	2.07	1.30
4.0	3.22	2.69	2.60	2.39	2.22	2.06	1.92	1.68	1.30	1.04	.696	3.67	2.02	1.27
5.0	3.20	2.67	2.58	2.38	2.20	2.04	1.91	1.66	1.30	1.03	.691	3.64	2.00	1.26
6.0	3.20	2.67	2.58	2.38	2.20	2.04	1.91	1.66	1.30	1.03	.691	3.64	2.00	1.26
8.0	3.24	2.70	2.61	2.40	2.23	2.07	1.93	1.68	1.31	1.04	.700	3.69	2.03	1.27
10.0	3.29	2.76	2.66	2.45	2.27	2.11	1.97	1.72	1.34	1.07	.714	3.76	2.07	1.30
15.0	3.45	2.90	2.80	2.58	2.39	2.22	2.07	1.81	1.41	1.12	.752	3.95	2.17	1.36
20.0	3.58	3.01	2.91	2.69	2.49	2.32	2.16	1.89	1.47	1.17	.783	4.11	2.25	1.41

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