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A SURVEY OF COUNTING EFFICIENCIES FOR A 1 1/2-INCH DIAMETER BY 1-INCH HIGH SODIUM IODIDE (THALLIUM ACTIVATED) CRYSTAL

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October 20, 1954

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A Survey of Counting Efficiencies for a 1 1/2-Inch Diameter by 1-Inch High Sodium Iodide (Thallium Activated) Crystal

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ABSTRACT

This report presents a short survey of the published gamma ray photopeak counting efficiencies for sodium iodide crystals, and also a determination of these efficiencies using the Berkeley 50-channel gamma analyzers. Curves are presented which summarize these efficiencies as a function of gamma ray energy and also of source-to-crystal distance.

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INTRODUCTION

The determination of absolute gamma-ray abundances in nuclear spectroscopy often involves the use of calibrated sodium iodide scintillation spectrometers. Several studies[1-5] of the detection efficiency of sodium iodide (thallium activated) crystals, an important part of this calibration, have been published which have been very helpful to users of scintillation instruments.

Several 50-channel scintillation spectrometers are in present use by the Berkeley Chemistry Group; however, the interpretation of data taken on these instruments has been somewhat uncertain because of the lack of agreement among available efficiency data. In particular, a recent report by Maguire and O'Kelley[1] lists crystal efficiencies which are at some gamma ray energies quite at variance with other determinations.

Because of these discrepancies, we have undertaken to measure the gamma ray counting efficiencies on the Berkeley 50-channel analyzers using several well-known standards, and to compare our results at several gamma ray energies with the more complete studies made by others.

This report was prepared primarily for the users of the Berkeley 50-channel analyzers, and constitutes mainly a tabulation of the published gamma ray counting efficiencies which we feel are applicable for use with these instruments.

EXPERIMENTAL ARRANGEMENT AND RESULTS

A 1 1/2-inch diameter by 1-inch thick thallium activated sodium iodide crystal was used in conjunction with the 50-channel differential analyzer designed by Ghiorso and Larsh.[6] A diffuse reflector of MgO surrounded the crystal, and a thin beryllium window separated it from the sample. The crystal was bonded to a thin quartz disk which in turn was optically coupled to a Dumont 6292 photomultiplier tube by a layer of mineral oil. An aluminum-lined lead shield housed the detector assembly, and samples were mounted in a standard GM tube five-position shelf holder. Most of our measurements were made with the sample on shelf 2, at a distance of approximately 1 1/2 inches from the crystal. This represented a geometry factor of 0.051 (as determined with the 60-kev gamma ray of a standardized Am^{241} sample).

We have measured the counting efficiencies of gamma rays at 412 kev (Au^{198}), 511 kev (Na^{24}), 661 kev (Cs^{137}), 1.28 Mev (Na^{22}), and 1.33 Mev (Co^{60}) using a 4π counter to determine the absolute disintegration rates of the standard samples. The results obtained were:

412 kev	0.26
511 kev	0.17
661 kev	0.11
1.28 Mev	0.049
1.33 Mev	0.045

RESULTS OF OTHER INVESTIGATIONS

Gamma-ray absorption coefficients in sodium iodide have been measured by Bell et al.[3] Making use of these data and the calculated values of the total absorption efficiencies as a function of absorption coefficient, they derive a family of curves for the calculated total counting efficiency as a function of energy at various source-to-crystal distances. Their curves for a 1 1/2-inch diameter by 1-inch high crystal are reproduced in Figs. 1 and 2. Heath et al.[4] and McGowan[5] have determined the ratio of the integrated photopeak to the total counts produced in a 1 1/2-inch diameter by 1-inch high crystal for various energies. Their values are plotted in Fig. 3 with a smooth curve drawn through the points for the purpose of interpolation. The variation between their points, for different distances between source and crystal, are of a random nature and are all within about 10 percent of each other. The product of the total counting efficiency times the ratio of photopeak to total count is the photopeak counting efficiency. Curves for the photopeak counting efficiency as a function of energy obtained in this way by multiplying Figs. 1 and 2 by Fig. 3, are shown in Figs. 4 and 5.

Kahn and Lyon[2] measured the photoelectric efficiencies of 23 gamma rays up to a maximum energy of 2.76 Mev. They also present a curve for total absorption which they calculated from the absorption coefficients given by White,[7] for a distance of 2.45 cm. Their calculated curve agrees with the values obtained from Fig. 2. Their experimental curve has roughly the same shape as those in Figs. 4 and 5, but with values up to 20 percent lower above 300 kev.

Maguire and O'Kelley[1] have measured the photoelectric counting efficiency for Am^{241} (60 kev), Na^{22} (511 kev, 1.28 Mev), Cs^{137} (661 kev), Pb^{212} (238 kev), and Np^{238} (1.0 Mev, determined relative to Na^{22}) at a source-to-crystal distance of 1.9 inches. Their values below 1 Mev are considerably higher than those of Fig. 5, and in addition their value for the ratio of efficiencies of the two gamma rays of Na^{22} is quite different from the ratio obtained by the other investigations[2-5] and also by our measurements.

CONCLUSIONS

Examination of our data shows good agreement with the values of the Oak Ridge photopeak counting efficiencies[3-5] shown in Fig. 5. We therefore feel that these curves are the most applicable for use with the Berkeley analyzers under the present experimental setup. The Oak Ridge curves are also very convenient to use in that they are tabulated for a wide range of sample-to-crystal distances.

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

APPENDIX

Geometry.--In the process of calculating the total absorption efficiencies, the geometry factor as a function of sample-to-crystal distance has also been calculated.[3] The curve obtained for a 1 1/2-inch diameter crystal is shown in Fig. 6.

Compton Scattering.--Backscattered radiation is a prominent feature of most gamma-ray spectra where there are gamma rays of greater than approximately 200 kev energy. We have therefore included curves for the maximum Compton electron energy and for the energy of the 180° backscattered gamma ray as a function of the initial gamma-ray energy. These are given in Fig. 7.

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3. P. R. Bell, R. C. Davis, D. S. Hughes, W. H. Jordan, and C. A. Randall, Oak Ridge National Laboratory Physics Department Quarterly Report ORNL-1415 (1952).
4. R. L. Heath, P. R. Bell, and R. C. Davis, Oak Ridge National Laboratory Physics Department Quarterly Report ORNL-1415 (1952).
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6. A. Ghiorso and A. E. Larsh, University of California Radiation Laboratory Report UCRL-2647 (1954); to be published.
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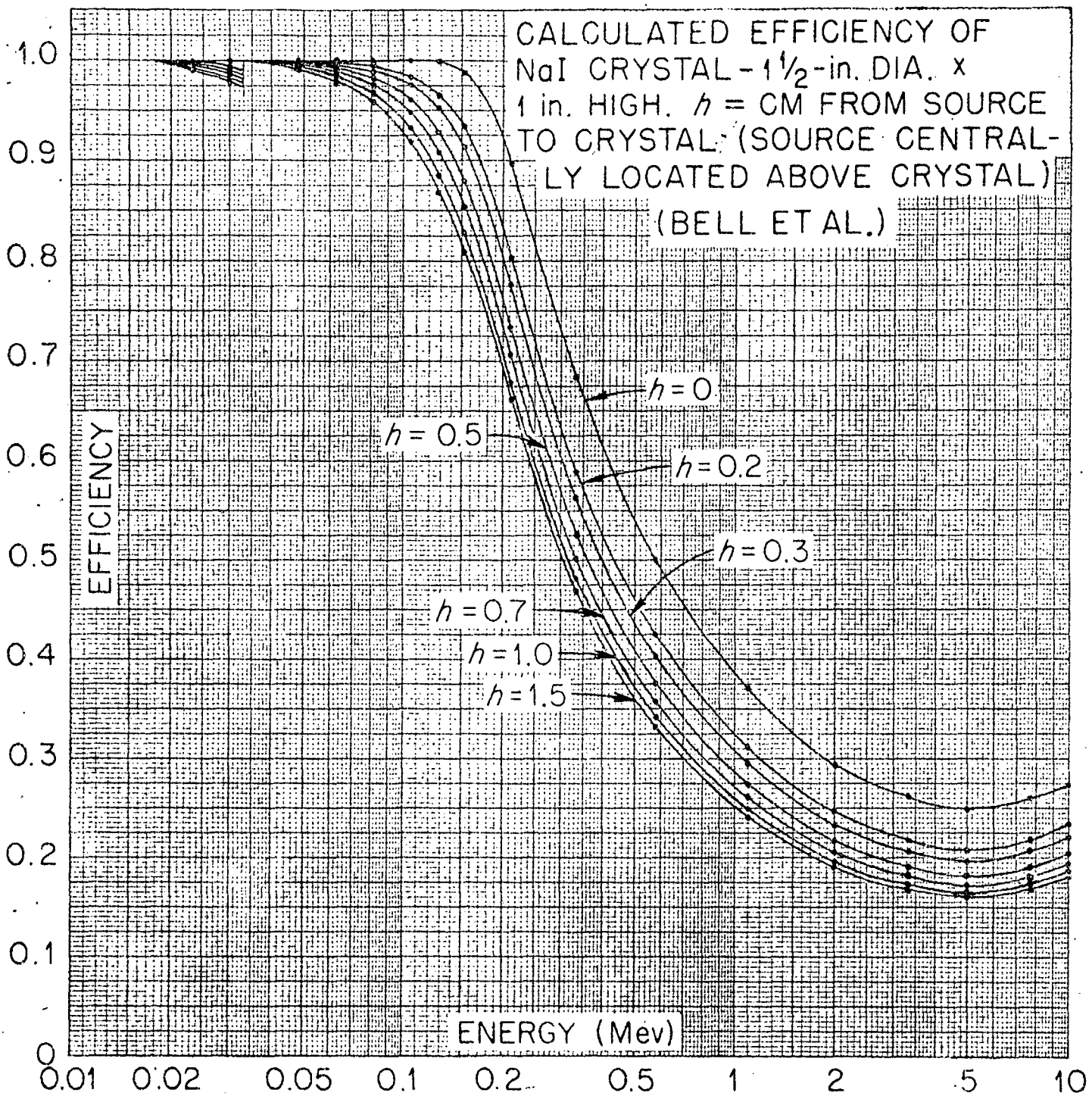
CALCULATED EFFICIENCY OF
NaI CRYSTAL - 1½-in. DIA. x
1 in. HIGH. h = CM FROM SOURCE
TO CRYSTAL (SOURCE CENTRAL-
LY LOCATED ABOVE CRYSTAL)
(BELL ET AL.)
h = 0
h = 0.5
h = 0.2
h = 0.3
h = 0.7
h = 1.0
h = 1.5
EFFICIENCY
ENERGY (Mev)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10

FIG. 1

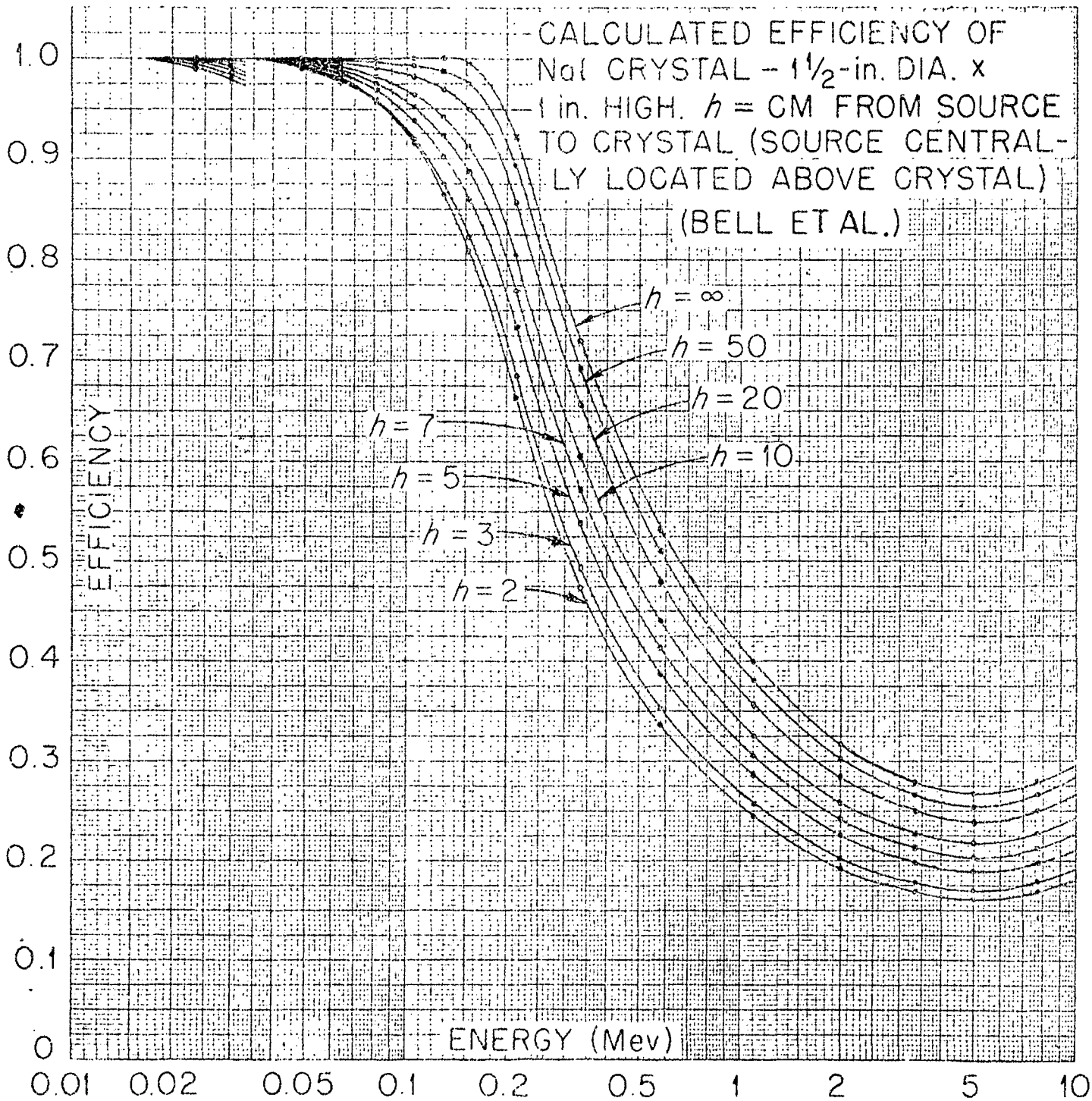
CALCULATED EFFICIENCY OF
NaI CRYSTAL – 1½-in. DIA. x
1 in. HIGH. h = CM FROM SOURCE
TO CRYSTAL (SOURCE CENTRAL-
LY LOCATED ABOVE CRYSTAL)
(BELL ET AL.)
h = ∞
h = 50
h = 20
h = 10
h = 7
h = 5
h = 3
h = 2
EFFICIENCY
ENERGY (Mev)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10

FIG. 2

FIG. 3

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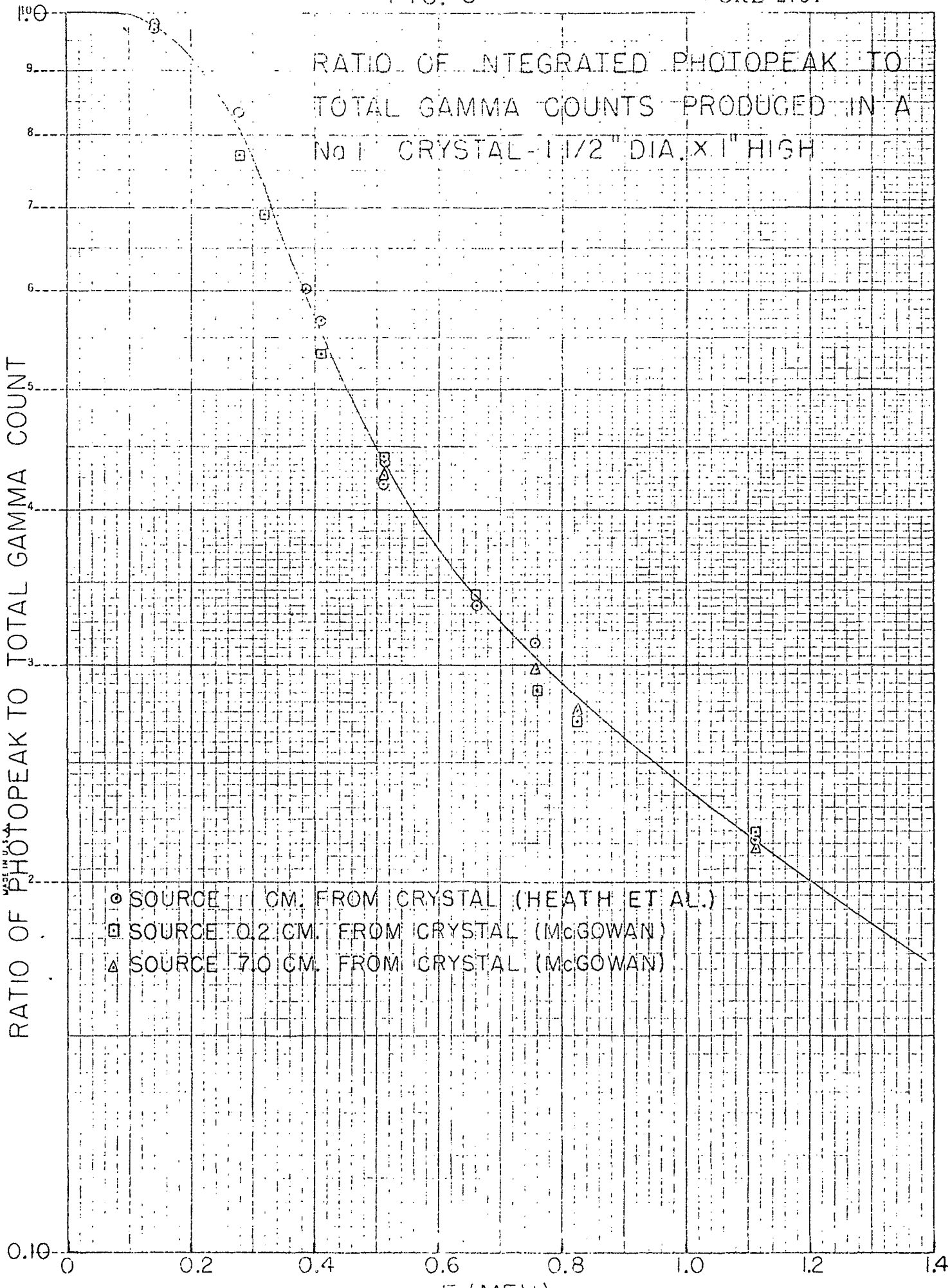


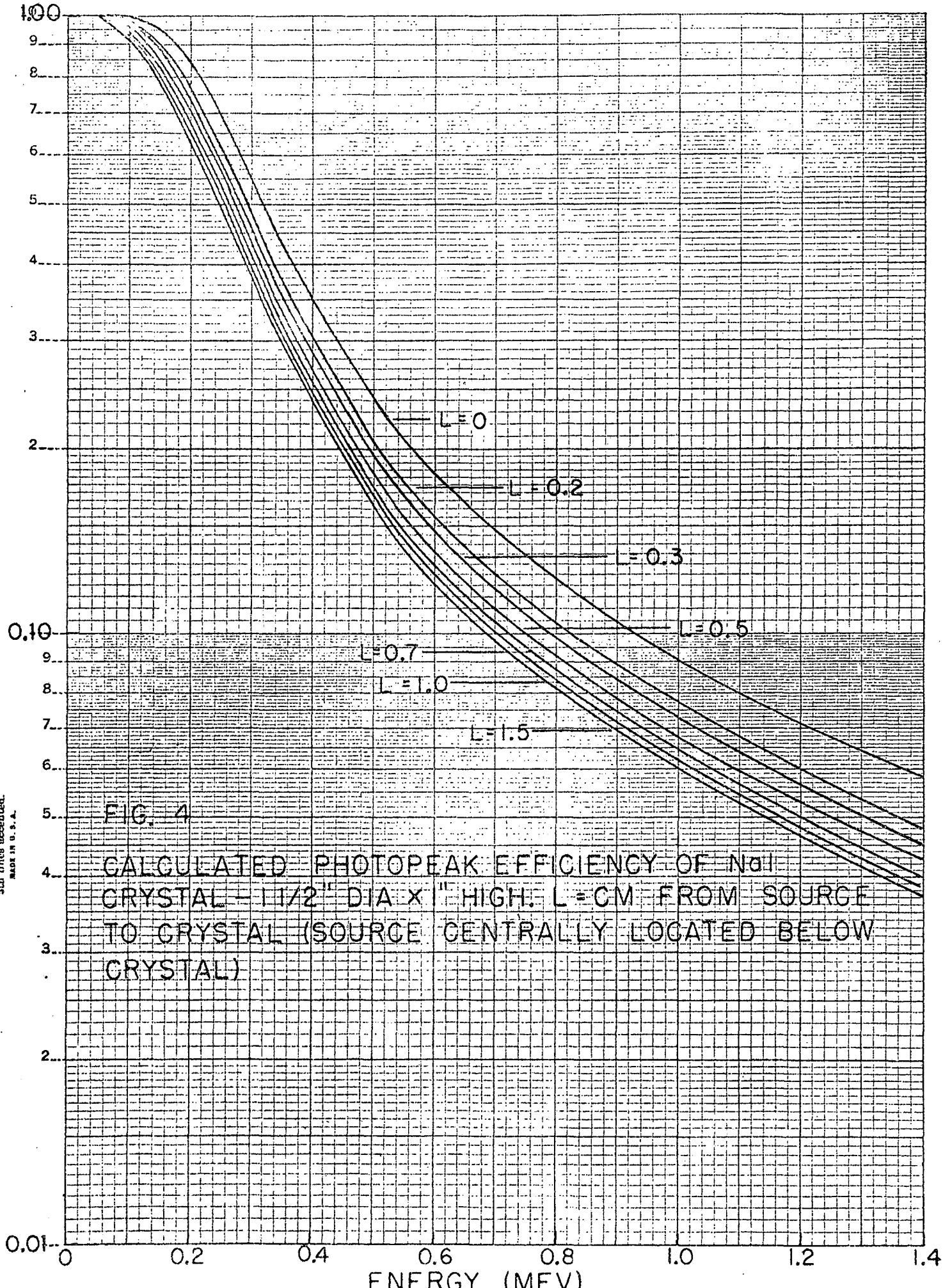


FIG. 4

CALCULATED PHOTOPEAK EFFICIENCY OF NaI CRYSTAL – 1 1/2" DIA X 1" HIGH. L = CM FROM SOURCE TO CRYSTAL (SOURCE CENTRALLY LOCATED BELOW CRYSTAL)

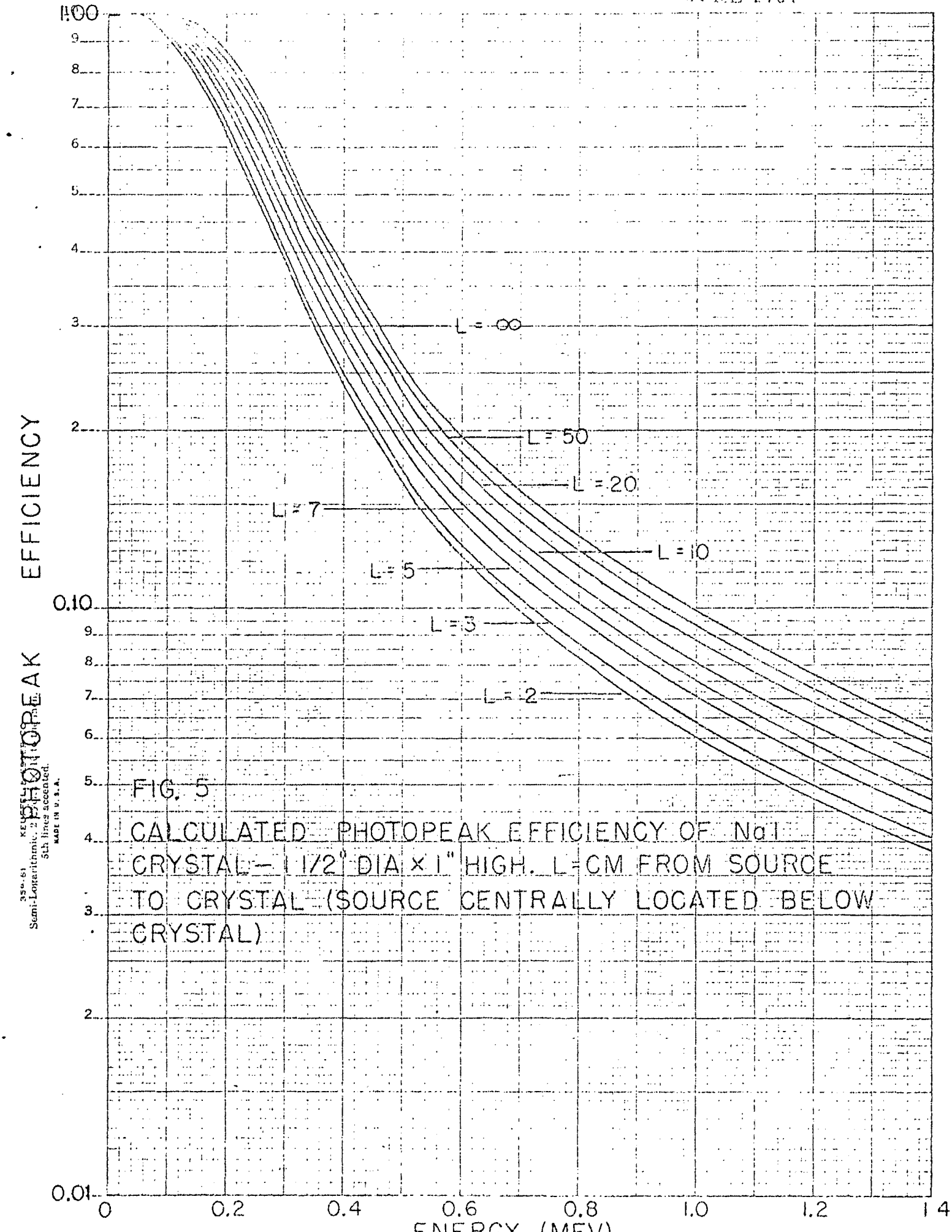


FIG. 5

CALCULATED PHOTOPEAK EFFICIENCY OF NaI CRYSTAL — 1 1/2" DIA × 1" HIGH. L = CM FROM SOURCE TO CRYSTAL (SOURCE CENTRALLY LOCATED BELOW CRYSTAL)

KEUFFEL & ESSER CO.
Semi-Logarithmic, 2 Cycles
5th lines accented.
MADE IN U.S.A.

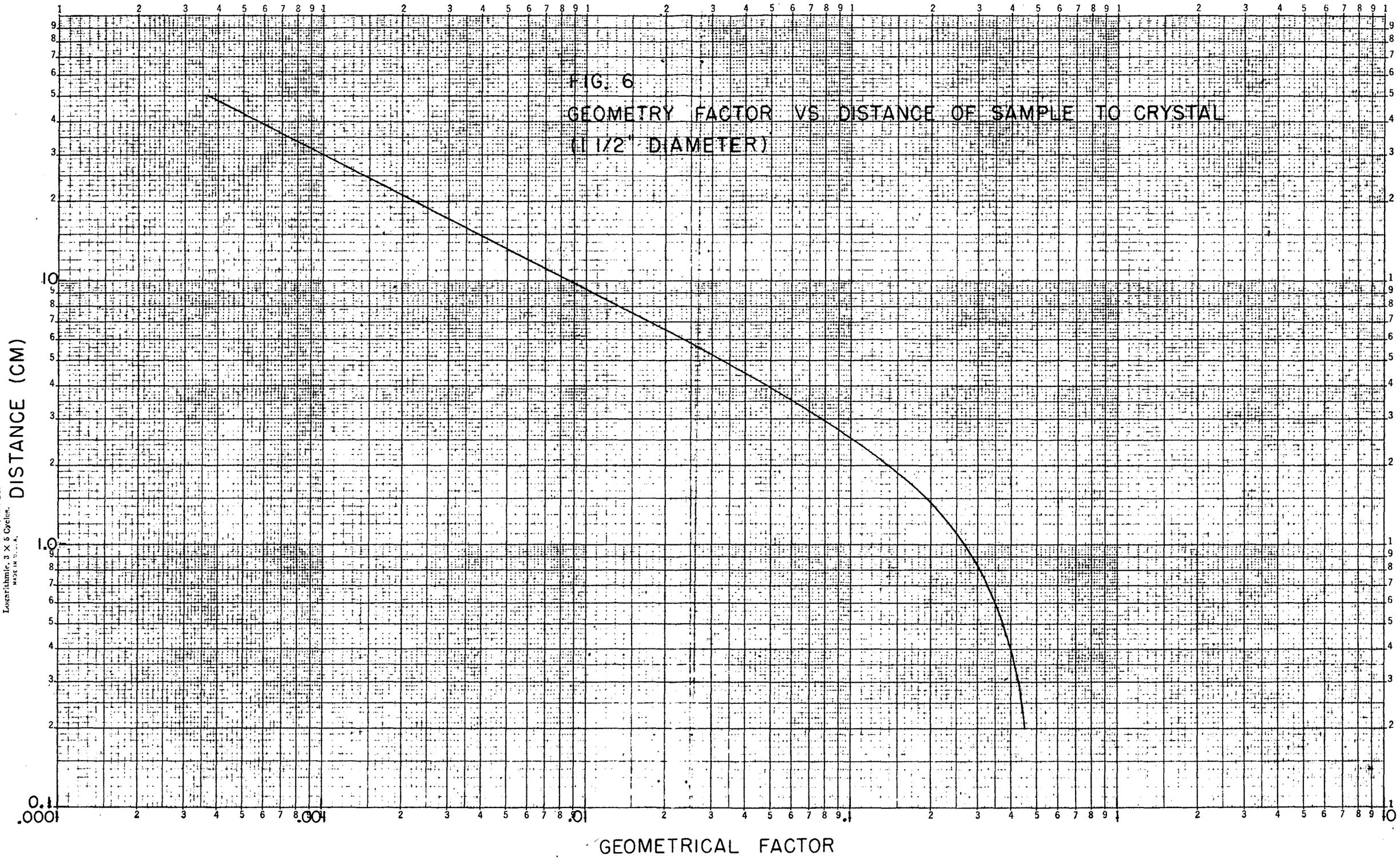
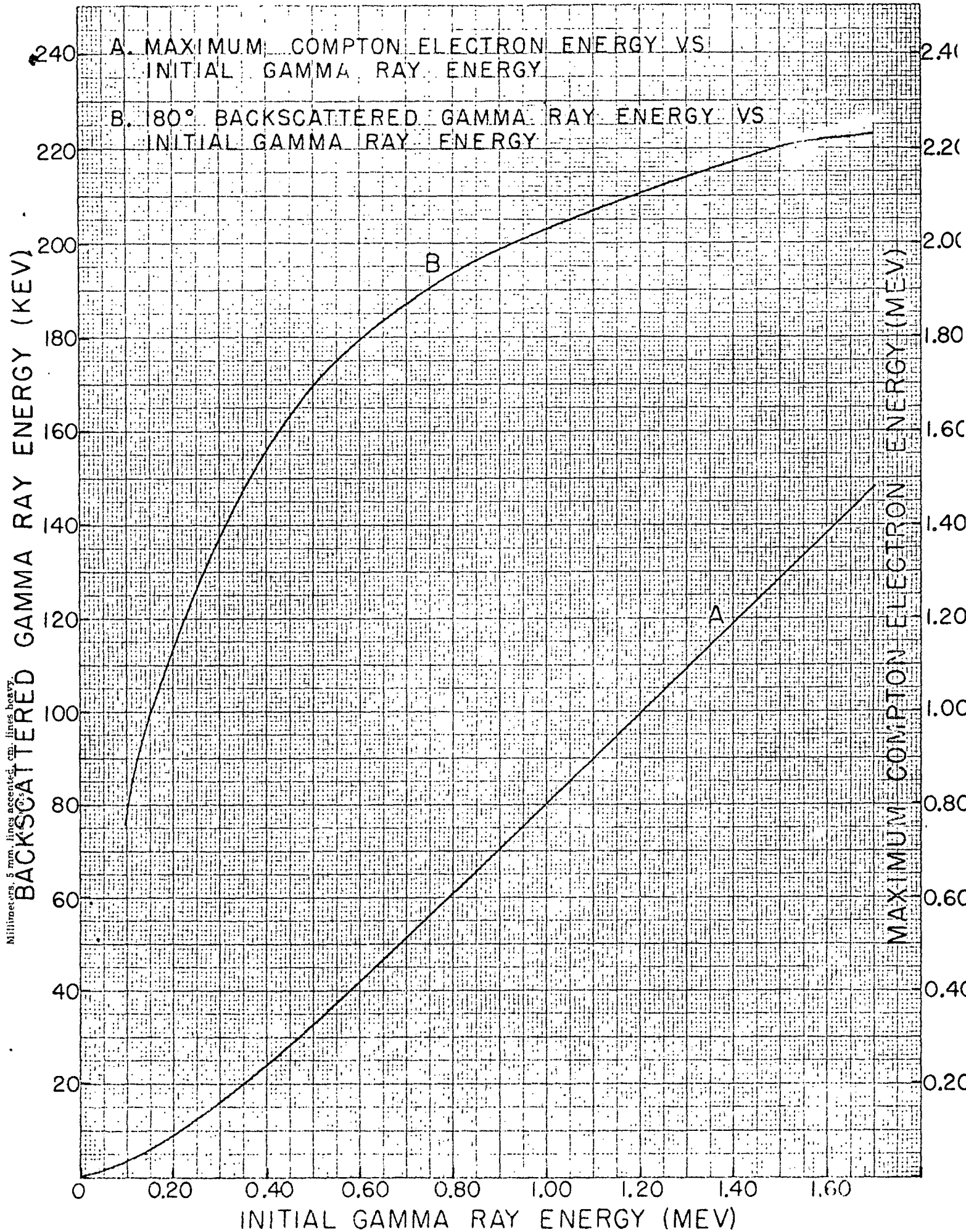


FIG. 6
GEOMETRY FACTOR VS DISTANCE OF SAMPLE TO CRYSTAL
(1 1/2" DIAMETER)
DISTANCE (CM)
GEOMETRICAL FACTOR
10
1.0
0.1
.001
.01
.1
1
10
KEUFFEL & ESSER CO.
359-125L
Logarithmic, 3 X 5 Cycles.

FIG. 7


A. MAXIMUM COMPTON ELECTRON ENERGY VS INITIAL GAMMA RAY ENERGY
B. 180° BACKSCATTERED GAMMA RAY ENERGY VS INITIAL GAMMA RAY ENERGY
A
B
BACKSCATTERED GAMMA RAY ENERGY (KEV)
MAXIMUM COMPTON ELECTRON ENERGY (MEV)
INITIAL GAMMA RAY ENERGY (MEV)
240
220
200
180
160
140
120
100
80
60
40
20
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Millimeters, 5 mm. lines accented, cm. lines heavy.