CHAPTER IV

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Determination of Epithermal Index $r(T/T_o)^{1/2}$ and β at the Position of 3.5 cm. and 2.5 cm. from a Neutron Source in Water.

4.1.1 Epithermal Index at the Position of 3.5 cm.

Results of cadmium ratio of various thickness of indium foil at 3.5 cm. from source are shown in table 4.1.1 and 4.1.2. The foil's area is 1x1 cm^2. and 7.069 cm^2. respectively.

Table 4.1.1

Bare Indium		Cadmium-covered foil		CdR
mg/cm^2	C_o(cpm)	mg/cm^2	C_o(cpm)	
10.4	335.5	10.4	65.0	5.17
25.4	593.5	25.3	85.2	6.94
51.7	899.0	52.0	105.5	8.58
69.9	993.0	70.0	109.0	9.11
72.5	967.5	72.8	106.3	9.14
99.2	1001.0	99.2	107.9	9.37

N.B. C_o is the saturated count rate.

Table 4.1.2

mg/cm^2	Bare (C_o)	Cadmium-covered (C_c)	CdR
99.5	691	76.2	9.07
197.2	656	81.6	8.025
283.8	610	73.7	8.28
384.5	587	73.5	7.99

Results of different analyses of the cad mium ratio of indium at the position of 3.5 cm. are shown in table 4.1.3.

Table 4.1.3

Epithermal index at the position of 3.5 cm. from source with various analysis.

mg/cm^2.	CdR	$r(T/T_o)^{1/2}$ (eqn.2.3.14)	CdR_o	$r(T/T_o)^{1/2}$ (eqn.2.3.15)	CdR_o	$r(T/T_o)^{1/2}$ (eqn.2.3.15)
10.4	5.17	.02715	3.18	.02795	3.22	.0274
25.4	6.94	.02592	3.315	.02625	3.20	.0278
51.7	8.58	.02675	3.19	.02780	3.19	.0279
69.9	9.11	.02755	3.095	.02910	3.23	.0273
72.5	9.14	.02775	3.035	.030	3.23	.0273
99.2	9.37	.02990	2.92	.03190	3.22	.0274
					$\bar{a}$ 3.22	$\bar{a}$ .0275

Column 3 was obtained by substituting CdR from column 2 into equation 2.3.14. In the same way column 5 and 7 are epithermal indices which were calculated by substituting CdR_o from column 4 and 6 into equation 2.3.15. CdR_o in column 4 was calculated by using the following relation:

$$CdR_o - 1 = (G_r/G_{th})(CdR - 1) \quad (4.1.1)$$

Equation 4.1.1 was obtained from (5). CdR_o in column 6 is given in Annex III.

For indium,

S_o = 18.8

W = .335

g = 1.021

F = 0.92

K = 2.21 for cadmium thickness = 0.0779 cm.

G_r and G_{th} at various thickness of indium were shown in Annex I.

4.1.2 Epithermal Index at The Position of 2.5 cm.

The position of 2.5 cm. from source was used to measure the epithermal index in order to check the accuracy of various methods of analyses as can be seen in table 4.1.4.

Table 4.1.4

mg/cm^2	CdR	$r(T/T_o)^{1/2}$ (eqn.2.3.14)	CdR_o	$r(T/T_o)^{1/2}$ (eqn.2.3.15)	CdR_o	$r(T/T_o)^{1/2}$ (eqn.2.3.15)
10.4	4.78	.030	2.98	.0309	3.01	.0304
25.4	6.5	.0281	3.09	.0292	3.03	.0301
51.7	8.12	.0289	3.035	.0301	3.055	.0297
69.9	8.46	.02965	2.95	.0313	3.06	.0298
99.0	8.8	.032	2.89	.0322	3.07	.0295
					$\bar{a}$ = 3.045	$\bar{a}$=.0299

By using a pair of gold foil at position of 2.5 cm., the cadmium ratio is 5.82. The activity of the bare foil (41.6 mg/cm^2.) is 7175 count per 30 minute and that of the cadmium-covered foil (42.2 mg/cm^2.) is 1252 count per 30 minute. The value of $r(T/T_o)^{1/2}$ = .0302 is obtained from equation 2.3.24.

For gold of thickness 41.6 mg/cm^2.

S_o = 17.3

W = 0.09

g = 1.005

F = 0.99 see (4)

K = 2.21

G_{th} = .965

G_r = .365

4.1.3 Ratio of Epithermal Flux per Unit Lethargy to True Thermal Flux (β) at Positions of 2.5 cm. and 3.5 cm. From Source.

From the cadmium ratio, it is possible to utilize equation 2.2.15 to obtain β. The modification of equation 2.2.15 is need--ed in order to be applied to thick foils.

For indium at position of 3.5 cm. from source, 150 and 2500 barn are used as σ_o and σ_r respectively. Then B can be calculated as follows:

$$\beta = \frac{150 \times 1.021}{1.128 \times 2500(.92\times3.22 - 1)}$$

$$= 0.0277$$

At position of 2.5 cm. from source, for indium β can be calculated as

$$\beta = \frac{150 \times 1.021}{1.128 \times 2500(.92\times3.045 - 1)}$$

$$= 0.03015$$

For gold at the same position, if 98.8/1.128 and 1558 barns are used as $\hat{\sigma}$ and σ_r respectively together with the CdR_o of 2.83, β can be calculated as follows:

$$B = \frac{98.8}{1.128 \times 1558(.99\times2.83 - 1)}$$

$$= 0.0312$$

Table 4.1.5

Summary of the result of $r(T/T_o)^{1/2}$ and β at the position of 2.5 cm. and 3.5 cm.

	x(cm.)	indium (eqn. 2.3.15) CdR_o(Annex III)	gole (eqn. 2.3.14)
$r(T/T_o)^{1/2}$	2.5	0.0299	0.0302
β	2.5	0.03015	0.0312
$r(T/T_o)^{1/2}$	3.5	0.0275	—
β	3.5	0.0277	—

Discussion

From the results of different analyses of the cadmium ratio of indium, epithermal index was calculated as shown in table 4.1.3 and 4.1.4 at the positions of 3.5 cm. and 2.5 cm. respectively. In case of 2.5 cm. position, epithermal index in column 3 which was calculated by using equation 2.3.14 has large variation. The difference from the average value at zero thickness could easily be identified especially in case of thick foil. Besides, the cadmium ratios at zero thickness in column 4 are not very consistent. It is felt that G_r and G_{th} of indium foils obtained directly from Baumann's report (2) may not be correct. Consider the epithermal index in column 7, the results show small variation and the error of calculation is $\pm$ 0.000354 and the average.

epithermal index is 0.0299 ± .000354. In table 4.1.5 the result for gold foil agrees with the average value of indium. Therefore the epithermal index which was calculated by using equation 4.3.15 with the cadmium ratios at the zero thickness of indium foil from Annex III gives the accurate results. The cadmium ratio at zero thickness of indium foil of this method has high accuracy value. The advantage of this method is that G_r and G_{th} self-shielding factors are not necessary. The factor $Q_{th}(x)/Q_{epi}(x)$ depends only on foil properties and does not depend on the flux ratio or the detector. This includes the effects of self-shielding for neutrons as well as the self-absorption, self-scattering and back-scattering of beta particle.

For the position of 3.5 cm. from source, poor results were obtained by using eqn. 2.3.14. These come from the incorrected values of G_r and may be G_{th} of indium. The accurate result of $r(T/T_o)^{1/2}$ was calculated by means of CdR_o in Annex III and the result with error correction is 0.0275 ± .000265. Besides, G_r/G_{th} ratios in table 4.1.6 of column 2 are greater than those in column 3. This means that G_r obtained directly from Baumann's (2) may not be corrected for the total epithermal self-shielding in case of indium. The better method to be used in the determination of $r(T/T_o)^{1/2}$ is to use equation 3.3.15 with CdR_o from Annex III. However, if foils are not very thick when G_r is closed to unity, equation 2.3.14 and 2.3.15 give almost identical results.

Table 4.1.6

G_r/G_{th} of indium calculated from Annex I and III as the function of the the function of the thickness.

mg/cm^2	G_r/G_{th} (Annex I)	G_r/G_{th} (Annex III)
10.4	.523	.533
25.4	.381	.371
51.7	.286	.289
69.9	.258	.275
72.5	.256	.274
99.5	.229	.265

It should be noted that the calculation of β is not as rigorous as that of $r(T/T_o)^{1/2}$, since the factor W and also the variation due to cadmium cut-off are neglected. However, in case of gold and indium, these corrections are small.

4.2 Epithermal Indices at Various Positions in a Water Tank.

A pair of indium foil of 1.5 cm. diameter were used. The weight were 661.2 and 661.4 milligram for bare and cadmium-covered foils respectively. Results of epithermal indices were shown in table 4.2.1.

Table 4.2.1

Position (x) cm.	CdR	CdR_o (Annex III)	$r(T/T_o)^{½}$ (eqn. 2.3.15)
2.5	8.5	3.01	.0304
3.5	9.15	3.19	.0279
5.5	10.8	3.61	.0232
7.5	12.4	4.03	.01988
9.5	13.9	4.41	.01760
11.5	15.45	4.82	.01565
13.5	15.59	4.86	.01555
15.5	16.37	5.05	.01475
17.5	15.58	4.86	.01555
19.5	14.64	4.61	.0166

CdR_o was calculated by using the application of Annex III where, $.92xCdR_o - 1 = (.92FCdR - 1)x.26$. Column 4 was obtained by using CdR_o in column 3 but deleting G_{th} and G_r. For indium, at the thickness of 93.6 mg/cm^2, G_r and G_{th} were .2 and .86 respectively (see Annex I).

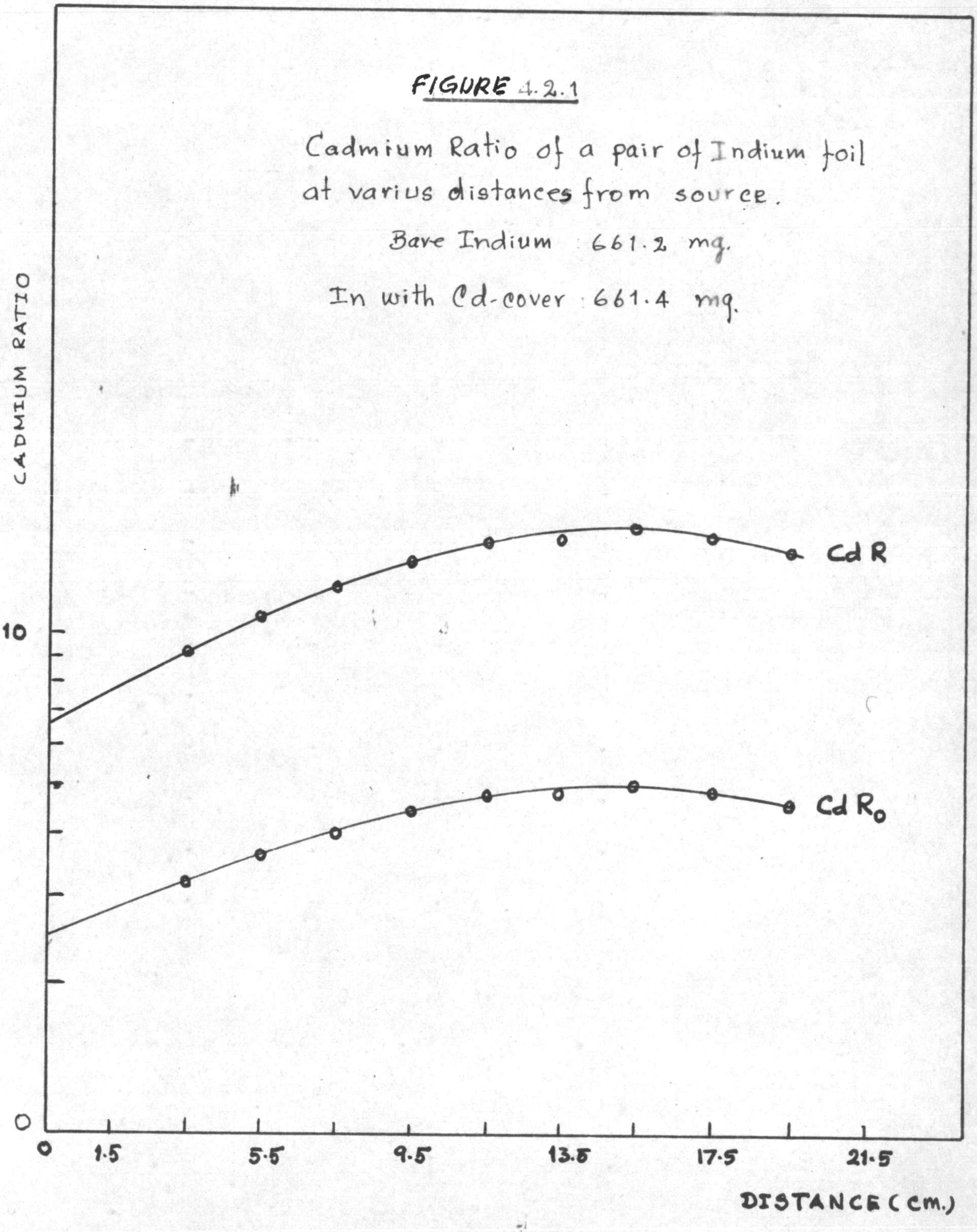


FIGURE 4.2.1
Cadmium Ratio of a pair of Indium foil at varius distances from source.
Bare Indium : 661.2 mg.
In with Cd-cover : 661.4 mg.
CADMIUM RATIO
10
0
Cd R
Cd R0
0
1.5
5.5
9.5
13.5
17.5
21.5
DISTANCE (cm.)

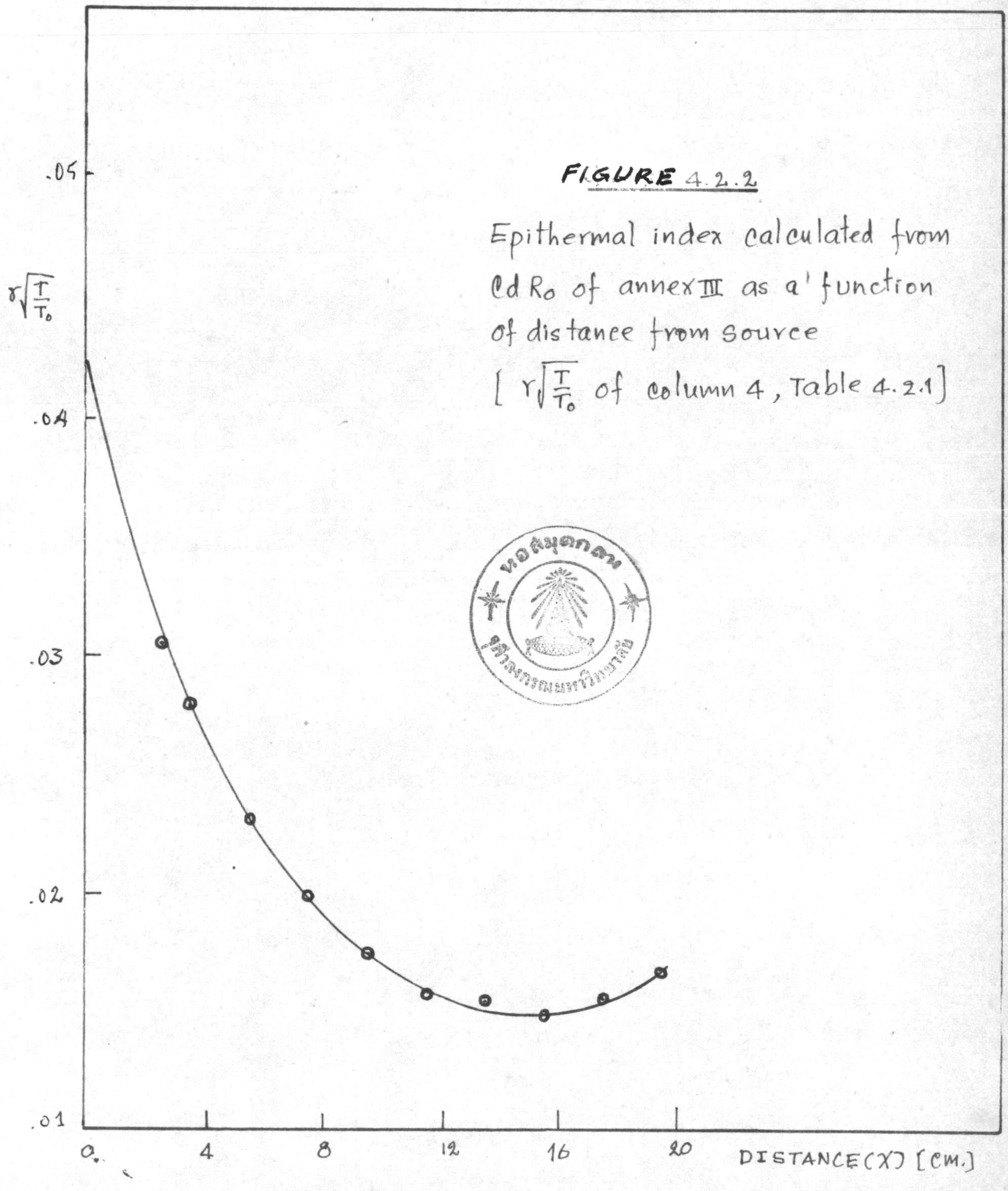


FIGURE 4.2.2

Epithermal index calculated from Cd R_0 of annex III as a function of distance from source [$r\sqrt{\frac{T}{T_0}}$ of column 4, Table 4.2.1]

From figure 4.2.2 the epithermal index is .042 at the origin of neutron source.

The minimum of epithermal index is at a position of 15.5 cm. from source. This can be explained that the degree of thermalization is maximum at a distance of 15.5 cm. from source.

4.3 The Conventional Thermal Neutron Fluxes in The Water Tank.

A pair of gold foil were used to measure the conventional thermal neutron flux (Φ_{th}) at the distance of 2.5 cm. from source as shown in table 4.3.1. The counter efficiency was 7.29%.

Table 4.3.1

Thermal neutron flux (Φ_{th}) of gold (Au^{197}) at the distance of 2.5 cm. from source.

Bare (c/m.gm)	Cadmium-covered (c/m.gm)	Thermal (C_{th}) (c/m.gm)	Φ_{th} (n/cm^2. sec)
5770	994	4776	6.2×10^3

Neutron flux can be calculated from the relation between disintegration rate and reaction rate. Some useful parameters in neutron flux calculation are the following :-

For gold (Au^{198})

Bare foil thickness = 41.6 $mg/cm.^2$

Cadmium-covered foil = 42.2 "

t = 94.3 hour.

t_1 = 10 minute

t_2 = 30 "

half-life of Au^{198} = 64.8 hour

G_r and G_{th} are .365 and .965 respectively. By using the conventional thermal neutron flux of table 4.3.1 as the reference flux at the position of 2.5 cm. from source, one can determine the values of conventional thermal neutron fluxes at various distances from source.

Table 4.3.2 showed the value of Φ_{th} at various distance from source. Indium foils of thickness 661.2 mg. and 661.4 mg. were used as bare and cadmium-covered foils respectively.

Table 4.3.2

distance (cm.)	Bare foil (c/30 min.)	Cadmium-covered foil (c/30 min.)	Thermal (c/30 min.)	$\Phi_{th} \times 10^3$ n/cm^2.sec.
2.5	100000	11770	88220	6.2
3.5	91702	10016	81686	5.74
5.5	76000	7035	68965	4.85
7.5	58974	4762	54212	3.81
9.5	42020	3020	39000	2.74
11.5	29036	1880	27156	1.91
13.5	18045	1159	16886	1.186
15.5	12699	776	11923	.838
17.5	8458	543	7915	.556
19.5	5998	410	5588	.393

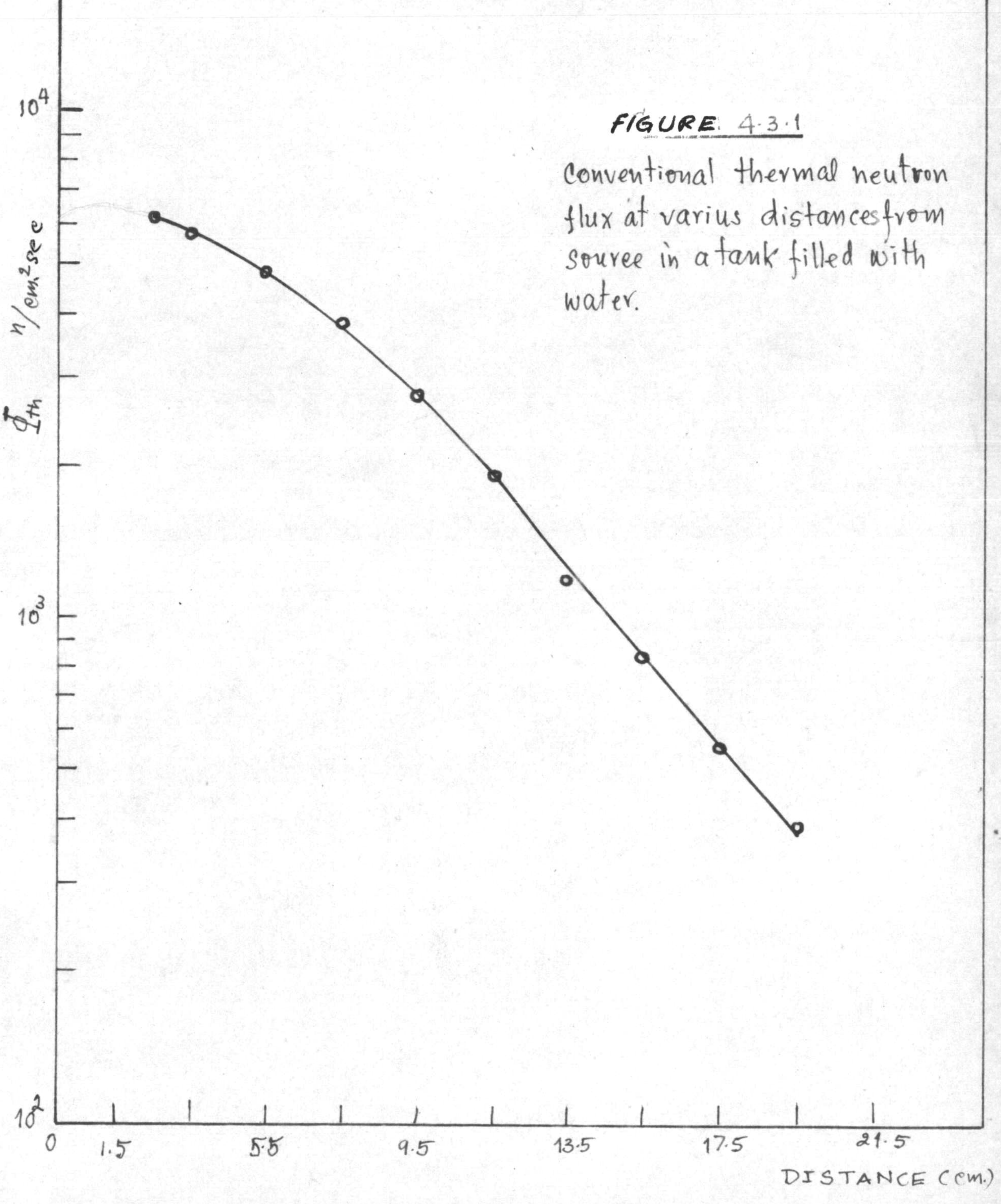


FIGURE 4.3.1

Conventional thermal neutron flux at varius distances from source in a tank filled with water.

The results of conventional thermal neutron flux at various distance was plotted in Fig. 4.3.1

4.4 <u>Neutrons Radial Distribution</u>.

It is of interest to examine the trend in the radial distribution of fluxes from a point source in water.

From the same data of table 4.3.2, table 4.4.1 can be constructed. The products of the square of the distance with count rates of thermal neutron were plotted as a function of distance from source in figure 4.4.1.

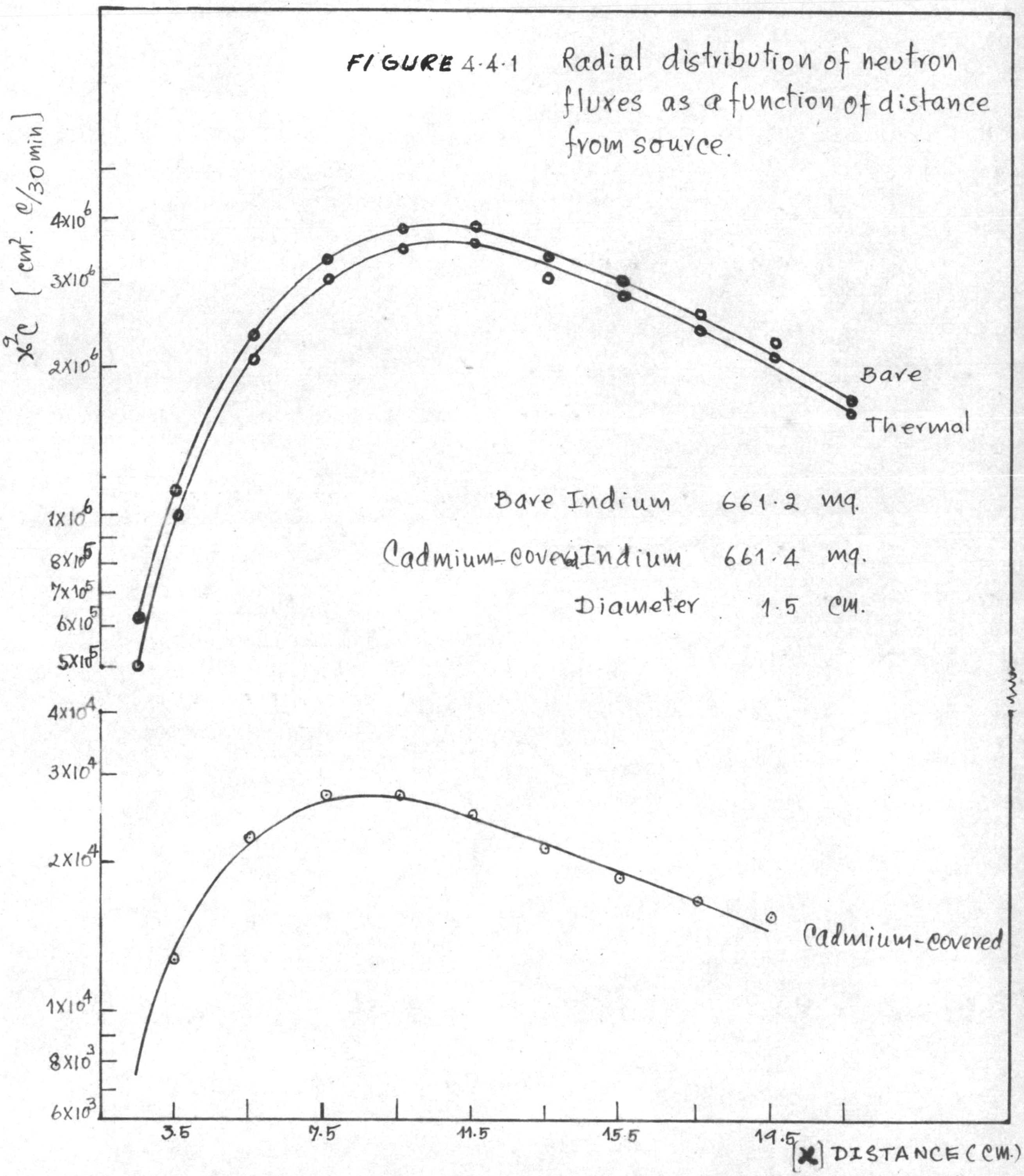


FIGURE 4.4.1 Radial distribution of neutron fluxes as a function of distance from source.

Table 4.4.1

Radial distribution of thermal neutron flux as a function of distance from source.

distance x (cm.)	$x^2 \times C_{th} \times 10^5$
2.5	5.51
3.5	10.0
5.5	20.84
7.5	30.4
9.5	35.0
11.5	35.91
13.5	30.79
15.5	28.64
17.5	24.24
19.5	21.24

From grapth 4.4.1 the thermal neutron distribution apparently goes through a maximum in water rather close to the source. It was 10 cm. from source.

4.5 Efficiency Of The Detecting Foil.

Efficiency of G.M. counter can be calculated as the function of indium foil thickness. From the data of table 4.1.1 and thermal neutron flux (6.2×10^3 neutron/cm.^{2} sec) one can calculate the efficiency (Eff) as in the table 4.5.1. G_{th} from annex I were used.

Table 4.5.1

area (cm^2)	thickness mg/cm^2.	saturated thermal count rate (c/m.gm.)	E_{ff}%
1	10.4	22900	8.41
	25.4	19800	7.5
	51.7	15350	6.40
	69.9	12950	5.23
	99	9810	4.13

The efficiency of the detector at zero thickness of indium foil is 9.1%

A G.M. tube model D-34 and a scaler of model 161 A Nuclear Chicago were used. The operating voltage was 900 volts and the distance between the window of the counter and the activated foil sample was about 1 centimeter apart. The efficiency of the counter was determined by gold foil of 41.6 thick with area 1 x 1 cm.^{2} The result of an average efficiency was 7.09%. From graph the efficiency is 6.6% at 41.7 mg/cm^2 of indium. Hence the gold foil gave higher efficiency than indium because of less thermal self-shielding.

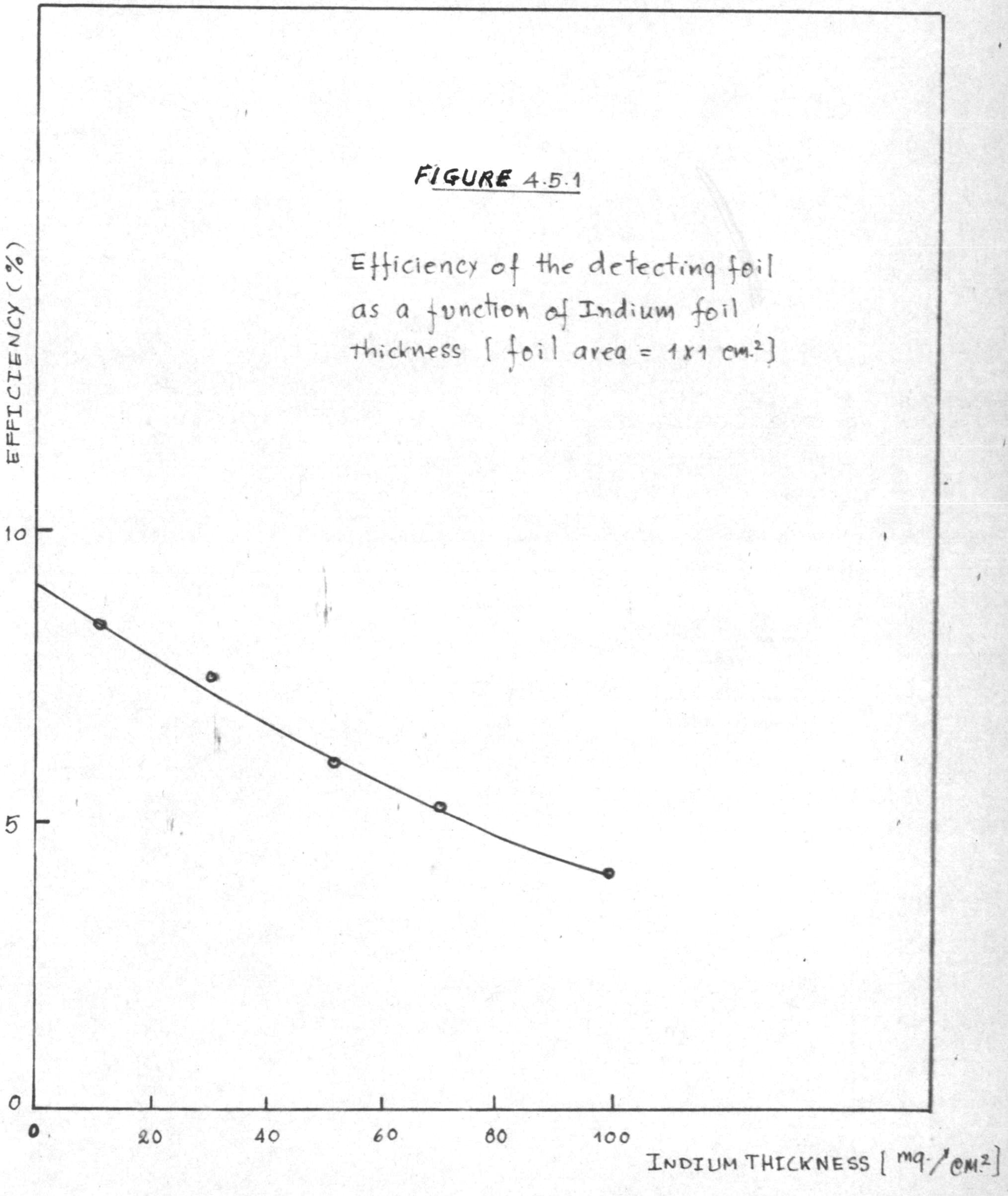


FIGURE 4.5.1

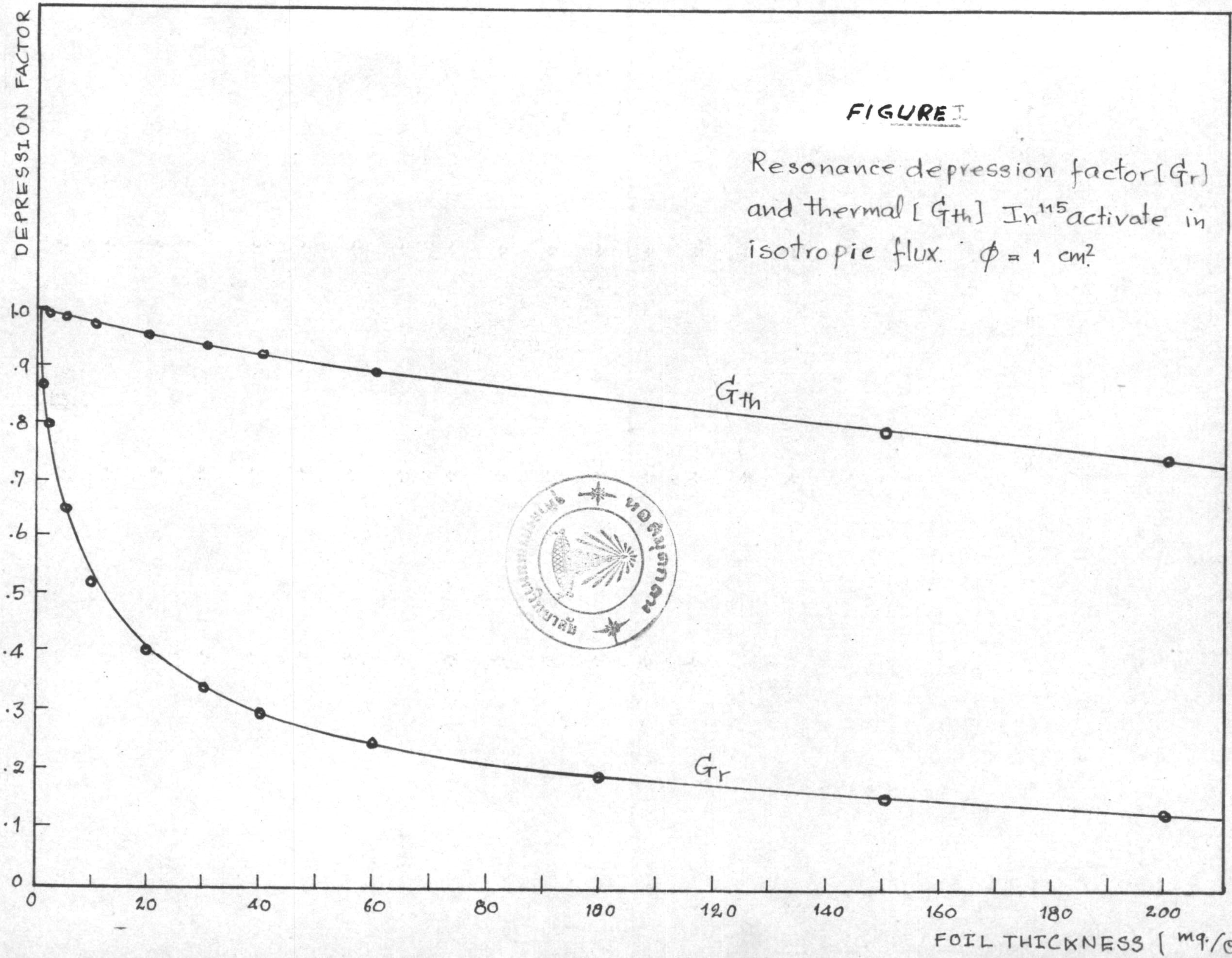
Efficiency of the detecting foil as a function of Indium foil thickness [foil area = 1x1 cm.²]

ANNEX I

G_r and G_{th} of Indium-115

[Resonance Depression Factors for In^{115} activated in isotopic flux was given by N.P. Baumann, AEC Research and Development (2).]

mg./cm^2	G_r	G_{th}
0.05	0.988	1
0.1	0.977	1
0.2	0.959	0.999
0.5	0.920	0.998
1.0	0.868	0.997
2.0	0.796	0.993
5.0	0.649	0.987
10.0	0.519	0.976
20.0	0.4	0.956
30.0	0.334	0.939
40.0	0.294	0.924
60.0	0.243	0.897
100.0	0.192	0.850
150.0	0.156	0.80
200.0	0.134	0.759
250.0	0.120	0.720



DEPRESSION FACTOR
FIGURE I
Resonance depression factor [Gr] and thermal [Gth] In115 activate in isotropie flux. φ = 1 cm²
Gth
Gr
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
20
40
60
80
100
120
140
160
180
200
FOIL THICKNESS [mg./cm²]

45

ANNEX II

G_r and G_{th} of gold-197.

[In all cases, G_{th} were calculated as the pure self-shielding correction. G_r and G_{th} were obtained directly from M.Sc. Thesis by Sudhiravuthe N. (9).]

mg./cm^2	G_{th}	G_r
11.0	.99	.62
16.7	.98	.53
33.8	.97	.40
47.9	.962	.34
53.7	.96	.325
70.5	.95	.29
113.7	.92	.24

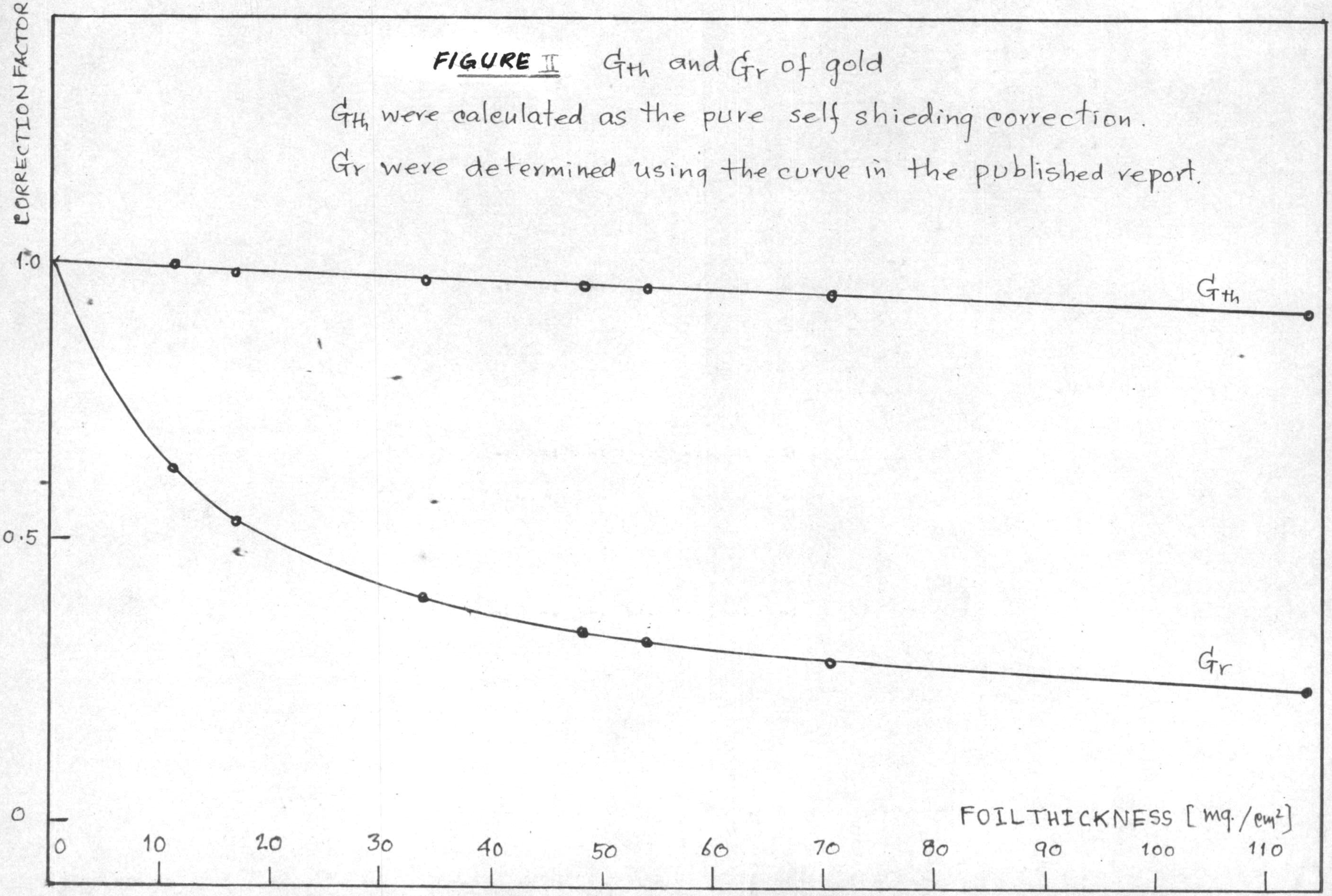


FIGURE II G_{th} and G_r of gold

G_{th} were calculated as the pure self shieding correction.

G_r were determined using the curve in the published report.

ANNEX III

Determination of CdR_o of indium

The ratio of thermal to epithermal activities per milligram of the activated indium foil at zero thickness can be determined by the method given by reports (3) and (4). The important equation is

$$\frac{A_{th}(o)}{A_{epi}(o)} = \frac{Q_{th}(x)}{Q_{epi}(x)} \cdot \frac{A_{th}(x)}{A_{epi}(x)}$$

where $A_{th}(x)$ and $A_{th}(o)$ are the thermal activity of indium foils at thickness x and zero mg/cm^2 respectively. $A_{epi}(x)$, $A_{epi}(o)$ are the epithermal activity of indium foils at thickness x and zero mg/cm^2 respectively.

$$\frac{Q_{th}(x)}{Q_{epi}(x)} = \frac{A_{th}(o)}{A_{th}(x)} \Big/ \frac{A_{epi}(o)}{A_{epi}(x)}$$

$Q_{th}(x)$ and $Q_{epi}(x)$ depend only on properties of indium and cadmium and the detector. This includes the effects of self-shielding for neutrons as well as the self-absorption, self-scattering, and back-scattering of beta particles.

$$\frac{A_{th}(x)}{A_{epi}(x)} = \frac{F\ CdR(x) - 1}{1 - X\ CdR(x)}$$

where X = fraction of thermal neutrons transmitted by the cadmium and $\frac{1}{F}$ is the fraction of epithermal neutrons absorbed by the cadmium. These fractions are independent of thickness of indium. For the 0.0779 cm. cadmium used in this experiment where F = 0.92 and X $\approx$ 0 and the values of $Q_{th}(x)/Q_{epi}(x)$ as a function of thickness in (3), one can determine the value of CdR_o from CdR(x) of any thick foils. The position of foil is 3.5 cm.

thickness (x) (mg/cm.^{2})	CdR(x)	$\frac{Q_{th}(x)}{Q_{epi}(x)}$	$\frac{A_{th}(o)}{A_{epi}(o)}$	CdR_o
10.4	5.17	0.523	1.96	3.22
25.4	6.94	0.36	1.937	3.20
51.7	8.58	0.28	1.929	3.19
69.9	9.11	0.268	1.975	3.23
72.5	9.14	0.267	1.975	3.23
99.2	9.37	0.257	1.958	3.22

N.B. $Q_{th}(x)/Q_{epi}(x)$ is independent on the position of foils from neutron source.

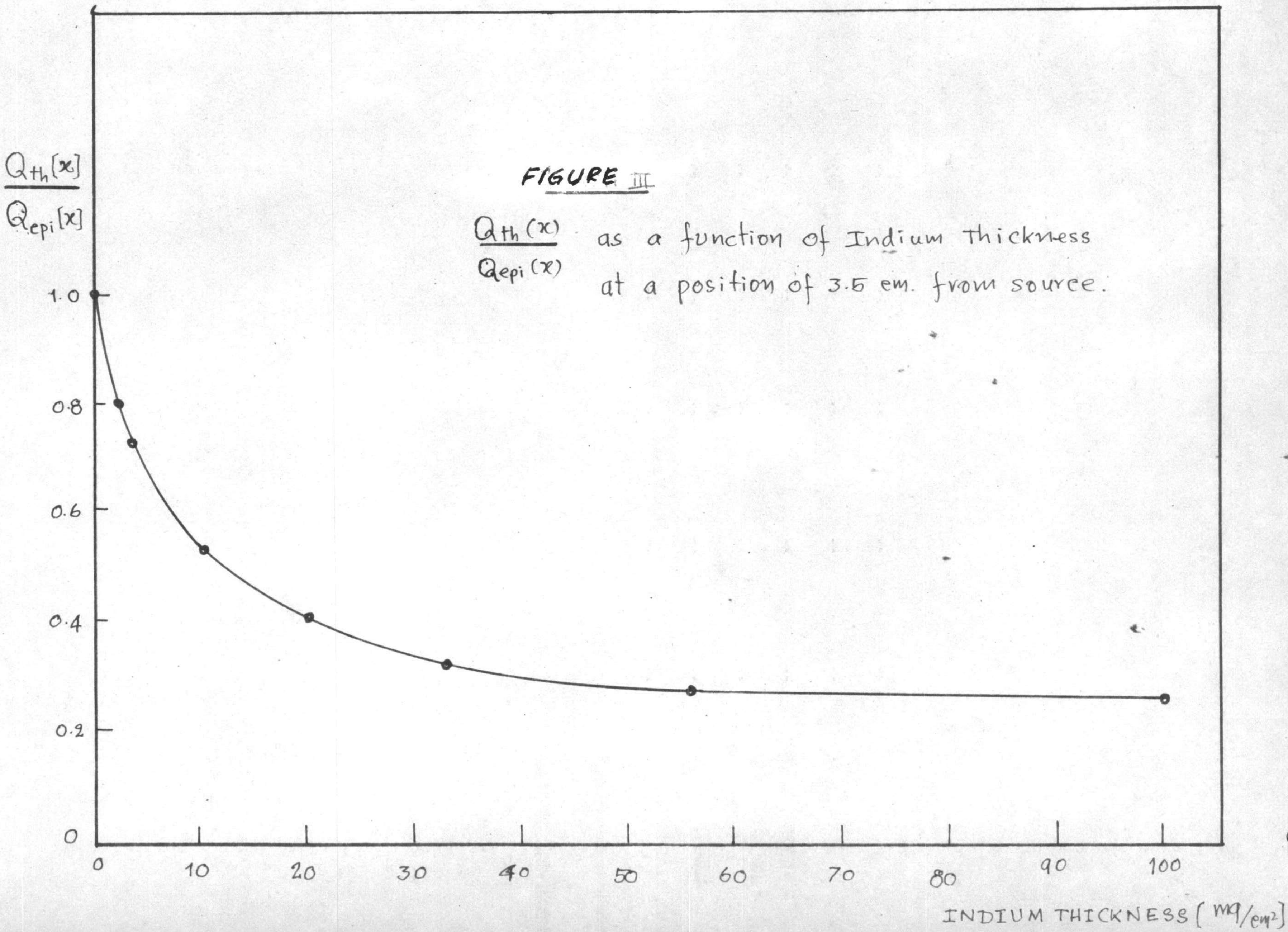


FIGURE III

$\frac{Q_{th}(x)}{Q_{epi}(x)}$ as a function of Indium thickness at a position of 3.5 cm. from source.

ANNEX IV

Error Calculation

The error is defined as follows:

$$\text{error} = \sqrt{\frac{(a_n - \bar{a})^2}{n - 1}}$$

Where n is the number of observations. For the results of experiment in table 4.1.4 at the position of 2.5 cm., n = 5

$a_n = r(T/T_o)^{1/2}$ x 10^{-2}	$a_n - \bar{a}$ x 10^{-2}	$(a_n - \bar{a})^2$ x 10^{-2}
3.04	0.05	0.0025
3.01	0.02	0.0004
2.97	0.02	0.0004
2.98	0.01	0.0001
2.95	0.04	0.0016
$\bar{a}$ = 2.99 x 10^{-2}		= 0.0050

$$\text{error} = \sqrt{\frac{.005 \times 10^{-4}}{5 - 1}}$$

$$= \pm .000354$$

In the same way the error of the results in table 4.1.3 at the position of 3.5 cm., n = 6, is ± .0002645.