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CALCULATIONS OF THE EPITHERMAL NEUTRON SPECTRA IN THE LENA (TRIGA MARK II) REACTOR AND DETERMINATION OF THE COBALT RESONANCE CAPTURE INTEGRAL

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operating at Pavia University, have been performed utilizing the DTK neutron transport code and the GAZE neutron diffusion code. The calculations have shown the presence of a neutron spectrum closely approximating $\frac{1}{E}$ in the 0.68 eV - 2.05 KeV energy region, in some positions of the water and graphite reflectors. In these positions a value of 71.9 $\pm$ 3.5 barns has been measured for the cobalt resonance capture integral by activation techniques.

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ABSTRACT

Calculations of epithermal neutron spectra in a Triga Mark II reactor, operating at Pavia University, have been performed utilizing the DTK neutron transport code and the GAZE neutron diffusion code. The calculations have shown the presence of a neutron spectrum closely approximating $\frac{1}{E}$ in the 0.68 eV - 2.05 KeV energy region, in some positions of the water and graphite reflectors. In these positions a value of 71.9 $\pm$ 3.5 barns has been measured for the cobalt resonance capture integral by activation techniques.

KEYWORDS

CALCULATIONS OF THE EPITHERMAL NEUTRON SPECTRA IN THE LENA (TRIGA MARK II) REACTOR AND DETERMINATION OF THE COBALT RESONANCE CAPTURE INTEGRAL[*]

1. INTRODUCTION

The calculations of epithermal neutron spectra by nuclear codes and the determination of the cobalt resonance capture integral have been performed as a part of a program of measurements of resonance capture integrals for a set of detectors. These detectors will be utilized in measurements of epithermal neutron spectra in connection with neutron damage experiments to be performed at the CCR Euratom - Ispra. In order to measure resonance capture integrals it is necessary to irradiate in an epithermal neutron spectrum very close in shape to a $\frac{1}{E}$ spectrum. J.B. Sampson [1] and M.K. Drake and J.R. Brown [2] report the presence of a $\frac{1}{E}$ spectrum, determined by nuclear code calculations, in the water reflector of a Triga Mark F reactor. Details of these calculations are reported by G.B. West and J.E. Larsen [3]. Following these indications we have performed calculations of epithermal neutron spectra by multigroup nuclear codes, based on the neutron transport and diffusion theories, for several positions of a Triga Mark II reactor (Lena reactor) operating at Pavia University. A high number of energy groups has been utilized in the region of our interest between about 1 and 2000 eV. As a check of the calculations a new determination of the cobalt resonance capture integral has been performed by activation techniques.

2. CALCULATIONS OF THE EPITHERMAL NEUTRON SPECTRA IN A TRIGA MARK II REACTOR

2.1 Physical model of the LENA reactor

The LENA is a Triga Mark II reactor. A sketch of the reactor is shown in Fig. 1. The fuel elements are made of 20% enriched uranium and zirconium hydride. A detailed description of this reactor, the region composition and the material volume fractions are reported by G.B. West and J.E. Larsen [3]. In the calculations the reactor has been assumed as formed by the core, by a reflector ring and by a graphite reflector.

a) Core

In the calculations it has been assumed that all the regions are homogeneous. The actual etherogeneity has been accounted for by means of a preliminary evaluation, both of the self-shielding factors and Dancoff correction, as will be specified in Section 2.2. The one-dimensional calculation that we have carried out does not allow us to consider separately the reflectors placed above and below the core, consisting of graphite and water. They have been accounted for by means of a saving

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term. The height of the reactor calculated in this way is 67 cm. The
four fuel elements of the external ring have not been considered. The
radius of the equivalent cylindrical core is 17.77 cm. The cold-clean
condition with no control rods and Sm_2O_3 burnable-poison disks has also
been considered.

b) Reflector ring

For the calculation of the neutron spectra in the F positions (see Fig. 1)
an external core ring filled with water has been assumed. For the calcu-
lation of the neutron spectra in the other positions of the graphite
reflector the external core ring has been assumed to consist of graphite
dummy elements and water. The external radius of the ring is 22.0 cm.

c) Graphite reflector

In the graphite reflector the irradiation positions are placed in a
rotating facility.
In the calculations this facility, consisting of an air-filled region
hollowed out in the graphite block, has not been considered.
Also the water of the swimming-pool surrounding the reflector has been
ignored.
The external radius of the reflector is 54.2 cm.

2.2 Cross-section Libraries

Two cross-section libraries have been used:
a) Los Alamos library: [4]
   18 groups (17 epithermal and fast + 1 thermal groups) with 5 down -
   scattering terms in each group.

b) General Atomic library:
   26 groups (25 epithermal and fast + 1 thermal groups) with 25 down-
   scattering terms in each group.
   In Table 1 the group energy boundaries, and the energy and lethargy widths
   are listed.
   The first was used only for comparison with the library prepared from
   G.A. data.
   The second has been prepared by means of the GAMICO [5] code (which is
   an APWRC code).
   This code, as the original GAM [6] code computes the slowing-down spectrum
   in either the P-1 or B-1 approximation, using 68 fine groups.

The broad group cross-sections evaluated with this method have been corrected by self-shielding factors. These have been obtained by CELCOR [7] (APWRC code) as well as DTF [8], an S_n code.

The Dancoff-Ginsburg correction for fuel rod shadowing has also been evaluated by the SHOCK-II [9] code.

This correction is required by the presence of a large quantity of U^{238} in the fuel which is enriched in U^{235} only to 20%.

Resonance absorption in U^{238} is accounted for by one or more of the following approximations, depending on the resonance energy and separation:

a) Narrow Resonances (NR)

b) Narrow Resonances Infinite Mass Approximation (NRIA) for wide resonances

c) Unresolved Resonances

2.3 Nuclear Codes for spectra evaluation

The following two codes have been used for multigroup space dependent neutron spectra calculation:

a) GAZE [10]:

A one-dimensional multigroup neutron diffusion code, which allows full scattering matrices and a large number of spatial meshes.

b) DTK:

Solves multigroup neutron transport equation in one-dimensional space using discrete S_n method.

All the results reported in this work have been obtained by means of the DTK code.

Some calculations were also performed by the GAZE code for comparison purpose. No significant differences were noted in the shape of neutron spectrum in the thermal and epithermal region over all spatial points. We observed, instead, that for fast neutron spectrum near the outer boundary of the reflector the GAZE gives overstimated solutions.

This is a feature of the diffusion theory whose limitations near the boundaries of diffusing medium are known. This reason, along with the consideration of the small dimensions of the reactor, lead us to prefer the more sophisticated transport theory.

Results obtained by DTK using the generated cross-sections have been checked against those given by the same code when using Los Alamos cross-sections. S4 approximation was employed for transport calculation, along with 30 to 60 mesh points. Diffusion calculation was performed with 40 mesh points.

Table 1 - Group energy boundaries and energy and lethargy widths

Group N°	Upper energy		ΔE		Δu
1	0.683	eV	0.683	eV	
2	1.125		0.442		0.5
3	1.855		0.730		0.5
4	3.059		1.204		0.5
5	5.043		1.984		0.5
6	8.315		3.272		0.5
7	13.71		5.395		0.5
8	22.60		8.890		0.5
9	37.27		14.67		0.5
10	61.44		24.17		0.5
11	101.3		39.86		0.5
12	167.0		65.70		0.5
13	275.4		108.4		0.5
14	454.0		178.6		0.5
15	748.5		294.5		0.5
16	1.234	KeV	485.5		0.5
17	2.034		800.0		0.5
18	5.531		3.497	KeV	1.0
19	15.03		9.503		1.0
20	40.87		25.84		1.0
21	111.1		70.23		1.0
22	302.0		190.9		1.0
23	820.8		518.8		1.0
24	2.231	MeV	1.410	MeV	1.0
25	6.065		3.834		1.0
26	10.00		3.935		0.5

2.4 Results

a) Neutron spectra

Multigroup one-dimensional calculations have given details of the energy
distribution of the neutron flux between 0.683 eV and 2.05 KeV.
In Fig. 2, epithermal and fast neutron spectra are shown for several
positions in the reactor.
Values of the calculated fluxes in the points near the irradiation
positions are also listed in Table 2, for energies ranging from 0.683 eV
to 2.05 KeV. The irradiation positions (see Fig. 1) are placed in the
light water reflector at radial distances of 18.8, 19.8 and 20.8 cm and
in the graphite reflector at a radial distance of 33.3 cm from the core
axis. In Table 2 are also represented the relative deviations of the
actual spectra from a spectrum of $\frac{1}{E}$ shape, for each energy group, normalized
as follows:

$$\int_{0.683 \text{ eV}}^{2.05 \text{ KeV}} \Phi(E)dE = K \int_{0.683 \text{ eV}}^{2.05 \text{ KeV}} \frac{1}{E} dE$$

In Fig. 3 these relative deviations are shown. The above results and
graphics show that the calculated epithermal neutron spectrum in the
region 0.683 eV - 2.05 KeV for the irradiation positions does not differ
significantly from a $\frac{1}{E}$ spectrum. The most serious discrepancies are in RF
position but they do not exceed a few percents.
The curves 1 and 2 in Fig. 2 show typical neutron flux depressions due
to the U238 absorption resonances. The effects of these resonances are
evanishing at increasing distances from the core boundary and is negli-
gible in the points near the irradiation positions (curves 3, 4 and 5
of Fig. 2 and curves of Fig. 3). The calculated spectra are in good
agreement to the spectra reported by G.B. West and J.E. Larsen [3]. We
have to point out that a larger number of energy groups has been used
in our calculations for the region below 2.05 KeV. The use of a small
number of groups for the energy region above 2.05 KeV introduces a lower
accuracy in the shape of the calculated spectra.

Additional calculations were performed to investigate the neutron spectra
in a light water reflector. For this purpose the graphite reflector of
LENA reactor has been replaced by water in the calculations.

Table 2 - Calculated neutron fluxes and relative deviations from a $\frac{1}{E}$ spectrum for different radial distances. Energy range 0.683 eV - 2.05 KeV

Group N°	Upper energy (eV)	Radial distances (cm)							
		18.85		19.60		20.40		29.50	
		Φ (arbitrary units)	$e = \dfrac{\Phi-\Phi_{1/E}}{\Phi_{1/E}}$ (%)	Φ (arbitrary units)	$e = \dfrac{\Phi-\Phi_{1/E}}{\Phi_{1/E}}$ (%)	Φ (arbitrary units)	$e = \dfrac{\Phi-\Phi_{1/E}}{\Phi_{1/E}}$ (%)	Φ (arbitrary units)	$e = \dfrac{\Phi-\Phi_{1/E}}{\Phi_{1/E}}$ (%)
1	0.683	-	-	-	-	-	-	-	-
2	1.125	1.6055	- 2.815	1.4742	- 0.981	1.3523	0.207	0.85841	- 3.477
3	1.855	1.6323	- 1.192	1.4962	0.497	1.3706	1.563	0.86328	- 3.929
4	3.059	1.6427	- 0.563	1.5033	0.974	1.3753	1.912	0.86733	- 2.468
5	5.043	1.6500	- 0.121	1.5077	1.269	1.3774	2.067	0.87129	- 2.051
6	8.315	1.6561	0.248	1.5109	1.484	1.3787	2.164	0.87433	- 1.687
7	13.709	1.6651	0.793	1.5130	1.625	1.3775	2.075	0.87791	- 1.284
8	22.603	1.6747	1.374	1.5180	1.961	1.3800	2.260	0.88112	- 0.923
9	37.266	1.6750	1.392	1.5120	1.558	1.3717	1.645	0.88491	- 0.497
10	61.442	1.6751	1.398	1.5068	1.209	1.3641	1.082	0.88938	0.006
11	101.30	1.6699	1.083	1.4986	0.658	1.3547	0.385	0.89490	0.626
12	167.00	1.6642	0.738	1.4985	0.047	1.3444	- 0.378	0.90138	1.355
13	275.4	1.6583	0.381	1.4804	- 0.564	1.3340	- 1.149	0.90885	2.195
14	454.0	1.6512	- 0.048	1.4703	- 1.243	1.3229	- 1.971	0.91822	3.248
15	748.5	1.6449	- 0.430	1.4588	- 2.015	1.3097	- 2.949	0.92975	4.546
16	1234.1	1.6375	- 0.871	1.4472	- 2.794	1.2967	- 3.912	0.94472	6.228
17	2034.7	1.6294	- 1.368	1.4340	- 3.681	1.2818	- 5.017	0.94472	8.343

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In Fig. 4 the relative deviations from a $\frac{1}{E}$ spectrum are shown for several distances from the core axis. At increasing distances from the core boundary up to about 15 cm the relative deviations are increasing. For larger distances the deviations decrease.

b) **Ratios of the Co^{59} and Au^{197} Epithermal Activations in the Calculated Spectra**

In the adopted multigroup formalism, the epithermal activation rate is given by the expression:

$$R = \sum_{i=i_c}^{n} \sigma_{a,i} \bar{\Phi}_i$$

where: $\sigma_{a,i}$ = absorption cross-section for the ith group

$\bar{\Phi}_i$ = mean flux for the ith group

i_c = first epithermal group (lower energy = Cadmium cut-off energy)

n = total number of groups

In a 1/E spectrum R corresponds to the absorption resonance integral. In these calculations the multigroup absorption cross sections of Au^{197} have been obtained by reducing the original 68-groups data of General Atomic library (GAM library) [6] to average values over 16 broad groups between 0.683 eV and 2.05 KeV. A 1/E spectrum was used as weighting flux in the reduction process.

General Atomic data for Co^{59}, instead, gave a very low value for the absorption resonance integral. So we preferred to prepare a code which computes the absorption cross section, by means of the one-level Breit-Wigner formula, including the $\frac{1}{v}$ contribution in more than 1000 energy points and gives multigroup $\frac{1}{E}$ flux weighted cross sections. Resonance parameters used in calculation were kept from A.P. Jain et al. [11]. The values of resonance integral so obtained, 67 barns, is in good agreement with the literature results. The quantity $A = \frac{R_{Au}}{R_{Co}}$ has been evaluated using a $\frac{1}{E}$ spectrum and the fluxes listed in Table 2.

In Table 3 these quantities normalized to the $\frac{1}{E}$ flux value are reported. It is possible to see that $A_{norm.}$ assumes increasing values from the F 1 to the F 3 position and that the values are very close to unity.

Table 3 - Ratios of Au^{197} and Co^{59} calculated epithermal activations at
different radial distances. The values are normalized to the
ratio in a $\frac{1}{E}$ spectrum assumed equal to 1

1/E flux	r = 18.85	r = 19.60	r = 20.40	r = 29.50
1	1.00	1.01	1.02	0.98

3. MEASUREMENT OF THE COBALT RESONANCE CAPTURE INTEGRAL

Several data are reported in the literature for the cobalt resonance capture

integral defined as $\Sigma = \int_{E_{Cd}}^{\infty} \frac{\sigma(E)}{E} \, dE$. Most of the cobalt resonance capture

occurs at the 132 eV resonance. All the data of the literature have been de-
termined by comparison with a detector (normally gold) in which most of the
resonance capture occurs at lower energies. This comparison is correct only
if the epithermal neutron spectrum has a $\frac{1}{E}$ dependence with energy. Therefore
we have limited our analysis to the literature data obtained by experimenters
who have considered in some detail the problem of the epithermal neutron
spectrum.

R. Dahlberg et al. [12] made their measurements at the Swedish heavy water,
natural uranium reactor, A 1, in Stockholm. The cadmium ratios of the cobalt
and of a $\frac{1}{v}$ absorber (a thin BF_3 counter) were measured in a neutron beam. The
neutron spectrum in the beam was accurately known from measurements with a
fast chopper, as described by E. Johansson et al. [13]. Corrections could
thus be made for the deviation of the flux from 1/E dependence. A Σ_{Co} value
of 72.3 ± 5 barns has been measured relative to a value of 38.0 ± 0.7 barns
for the 2200 m/sec cross section $\sigma_{o,Co}$. The energy of the cadmium cutoff was
0.49 eV.

T.A. Eastwood and R.D. Werner [14] made their measurements in the zero energy
reactor ZED-2 and in an empty fuel position in the NRX reactor at Chalk River.

The slowing - down spectra in the ZED-2 reactor have been studied by
C.B. Bigham and R.M. Pearce [15]. This investigation indicates that the
epithermal spectrum with a 24 cm lattice pitch has a $\frac{1}{E}$ dependence within the
limitations of the calculation.

The neutron spectrum in the empty fuel position of the NRX reactor was found
to be the same as that in the ZED-2 with the 24-cm lattice. The resonance
integral of cobalt has been measured by comparison of the cadmium ratios for
cobalt and gold. A Σ_{Co} value of 69.9 $\pm$ 3.5 barns is reported relative to a
$\sigma_{o,Co}$ value of 37.5 $\pm$ 1.0 barns, to a $\sigma_{o,Au}$ value of 98.8 $\pm$ 0.5 barns and
to a Σ_{Au} value of 1535 $\pm$ 40 barns. The energy of the cadmium cutoff was 0.5 eV.

R.Vidal and E. Cardoso - Martinho [16] determined Σ_{Co} by a pile oscillation
method in the centre of the Minerve reactor at Fontenay-aux-Roses. The
calculation of the epithermal neutron spectrum in this position has been
performed by J. Bouchard [17] and has shown that the spectrum has a $\frac{1}{E}$ depen-
dence with energy. A Σ_{Co} value of 67.4 $\pm$ 4 barns is reported relative to a
$\sigma_{o,Co}$ value of 37.6 $\pm$ 0.3 barns, to a $\sigma_{o,Au}$ value of 98.9 $\pm$ 0.2 barns and
to a Σ_{Au} value of 1585 $\pm$ 30 barns. The lower limit of the integral was 0.5 eV.

In the present work the Σ_{Co} has been determined by comparison of the activa-
tions of cobalt and gold utilizing three different techniques:

1) Cobalt and gold have been irradiated under cadmium in the F positions
   (see Figure 1) and the activation rates, R_{Co} and R_{Au}, have been determined
   by absolute activity measurements. The following formula has been utilized:

$$\Sigma_{Co} = \Sigma_{Au} \frac{R_{Co}}{R_{Au}} \qquad (1)$$

2) Cobalt and gold have been irradiated under cadmium in the F positions
   and in the rotating irradiation facility (see Figure 1) and without
   cadmium in the thermal column where the activation is totally produced
   by thermal neutrons (measured value of gold cadmium ratio higher than
   500).

   The ratios of the epithermal activation rate to the thermal activation
   rate for cobalt and gold, R'_{Co} and R'_{Au}, have been determined by relative
   measurements. The following formula has been utilized:

$$\Sigma_{Co} = \Sigma_{Au} \frac{\sigma_{o,Co}}{g \, \sigma_{o,Au}} \frac{R'_{Co}}{R'_{Au}} \qquad (2)$$

For the assumed neutron temperature of 20°C in the thermal column
$g = 1.005$ [18].

3) The cadmium ratios of cobalt and gold, $R_{Cd,Co}$ and $R_{Cd,Au}$, have been determined in the rotating irradiation facility. The following formula has been utilized:

$$\Sigma_{Co} = \Sigma_{Au} \frac{(R_{Cd,Au}-1)}{(R_{Cd,Co}-1)} \frac{\sigma_{o,Co}}{g\ \sigma_{o,Au}} \qquad (3)$$

For the assumed neutron temperature of 20°C in the graphite reflector
$g = 1.005$ [18].

3.1 Experimental

In order to minimize self shielding corrections, cobalt and gold were irradiated in the form of disks (8 mm in diameter and 2/10 mm thick) of dilute alloys with aluminium (cobalt content = 0.950 ± 0.015 %, gold content = 0.101 ± 0.001% by weight). The uniformity of the cobalt and gold contents in the alloys had been previously checked.

For the irradiations in the F positions (see Figure 1) the detectors were placed inside cylindrical cadmium capsules with 1 mm thick walls, 8.5 mm internal diameter and 19 mm internal length. Three pairs of cobalt-alloy and gold-alloy monitors, separated by suitable spacers, were irradiated in each capsule. The cadmium capsule was placed in a dummy element and positioned radially at the midplane of the core.
In the rotating facility of the graphite reflector (see Figure 1) cobalt and gold monitors, with 1 mm cadmium shielding, and unshielded, were irradiated at the same time. The cadmium shielded detectors were positioned 20 cm from the unshielded detectors. The irradiation position of the thermal column was located at about 150 cm from the core boundary.

After a suitable cooling time to allow the decay of short half-life radioactive impurities, the activities of Co 60 (5.27 y. half-life) and Au 198 (2.7 d. half-life) were determined by γ-spectrometry utilizing a 3in. x 3in. NaI(Tl) crystal connected with a multichannel pulse height analyzer. The Au198 activity was measured evaluating the 412 KeV γ-photopeak area. The

Co60 activity was measured evaluating the 1.17 and 1.33 MeV γ-photopeak area. The γ-spectrometer had been calibrated in efficiency by Co60 and Au198 sources of known absolute activity determined by $4\pi\beta^--\gamma$ coincidence technique. To check the absence of radioactive impurities the Co60 activity measurements were repeated over a period of a few months and the decay of the Au198 activity was followed over a period of about two weeks.

3.2 Results

The resonance neutron self shielding has been found [19] [20] [21] to be very small (about 0.5 %) and similar for both the cobalt and gold alloys and therefore no correction has been introduced. The thermal neutron self shielding is negligible.

In Table 4 the Σ_{Co} measured values are reported, relative to a $\sigma_{o,Co}$ values of 37.4 ± 0.3 barns [22], to a $\sigma_{o,Au}$ value of 98.8 ± 0.2 barns [22] [23] and to a Σ_{Au} value of 1535 ± 40 barns [23]. The energy of the cadmium cutoff in these experiments was assumed as 0.55 eV.

Table 4 - Cobalt resonance capture integral (barns)

Position	Distance from the core centre (cm)	Irradiations			
		1 [eq 1]	2 [eq 2]	3 [eq 2]	4 [eq 3]
F1	18.8	74.5	70.1	73.8	
F2	19.8	75.1	70.3	71.7	
F3	20.8	71.8	68.4	71.7	
RF	33.3			71.8	69.9 72.9 72.7

The average value of the cobalt resonance capture integral is 71.9 barns. The standard deviation is ± 1.9 barns. If the errors in the thermal cross sections of cobalt and gold, and in the resonance integral of gold, and the errors due to the deviation of the neutron spectrum from the $\frac{1}{E}$ shape (1.5 barns) and to the uncertainty in the knowledge of the cadmium cutoff energy

(1.5 barns) are included, the overall error amounts to about $\pm$ 3.5 barns.

In order to perform a comparison with our value of 71.9 $\pm$ 3.5 barns, the values reported in the literature have been modified on the basis of the nuclear data and the cadmium cutoff energy utilized in the present experiment. The value of R. Dahlberg et al. [12] is modified to 70.2 $\pm$ 5 barns, the value of T.A. Eastwood and R.D. Werner [14] to 68.7 $\pm$ 3.5 barns and the value of R. Vidal and E. Cardoso-Martinho [16] to 66.4 $\pm$ 4 barns.

4. CONCLUSIONS

The nuclear code calculations have shown that the deviations from the $\frac{1}{E}$ spectrum in the energy region between 0.683 eV and 2.05 KeV are not significant in the points of the water and graphite reflectors which correspond to the irradiation positions. Therefore we may conclude that it is correct to measure in these positions resonance capture integrals for materials which have most of the epithermal activation in this energy region. The determination of the resonance capture integrals is normally performed by comparison of cadmium ratios or epithermal activations with gold as the reference. In Table 3 the ratios for the epithermal activations of gold and cobalt in the actual spectra, are given normalized to the ratio in a $\frac{1}{E}$ spectrum assumed equal to 1.

The maximum deviation of these ratios from 1 is 2%. This deviation corresponds to the error introduced in the determination of the resonance capture integrals of cobalt when the gold is taken as the reference material.

We have to point out that the resonance energies of gold (4.9 eV) and cobalt (132 eV) are quite different. The difference between the resonance energy of gold and the resonance energies of the other detectors of interest (In 115, Tm 169, Sb 121, Sb 123, La 139, Mn 55) is normally smaller. Only Mn 55 has resonance energies higher than Co 59. Therefore the error in the determination of the resonance capture integrals, due to the deviation of the neutron spectrum from a $\frac{1}{E}$ shape, would be smaller than 2% for most of the detectors. The experimental value of the resonance capture integral for cobalt - 71.9 $\pm$ 3.5 barns - is in good agreement with the experimental results reported by Authors [12] [14] [16] who have utilized a neutron spectrum close to $\frac{1}{E}$.

In Table 4 the value of the experimental capture integral shows a small decrease from position F 1 to position F 3. This is in agreement with the theoretical results reported in Table 3. On the basis of the theoretical results a higher value of the resonance capture integral would be expected for

the RF position.

The disagreement with the experimental values can be explained with the assumptions made in the physical model: the four fuel elements in the external ring have not been accounted for in the calculations and the rotating facility was supposed filled by graphite. From the above considerations the reliability of both experimental and theoretical results can be deduced.

These calculations will be utilized for the neutron spectra determination in the Ispra I reactor in order to complete the information obtained by resonance and threshold detectors in neutron damage experiments.

ACKNOWLEDGEMENTS

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Fig. 1 – SKETCH OF THE LENA REACTOR WITH THE IRRADIATION POSITIONS.

GRAPHITE REFLECTOR

ROTATING IRRADIATION

FACILITY   RF POSITION

GRAPHITE REFLECTOR

ALUMINIUM

POSITION F1 F2 F3

LIGHT WATER

10 cm
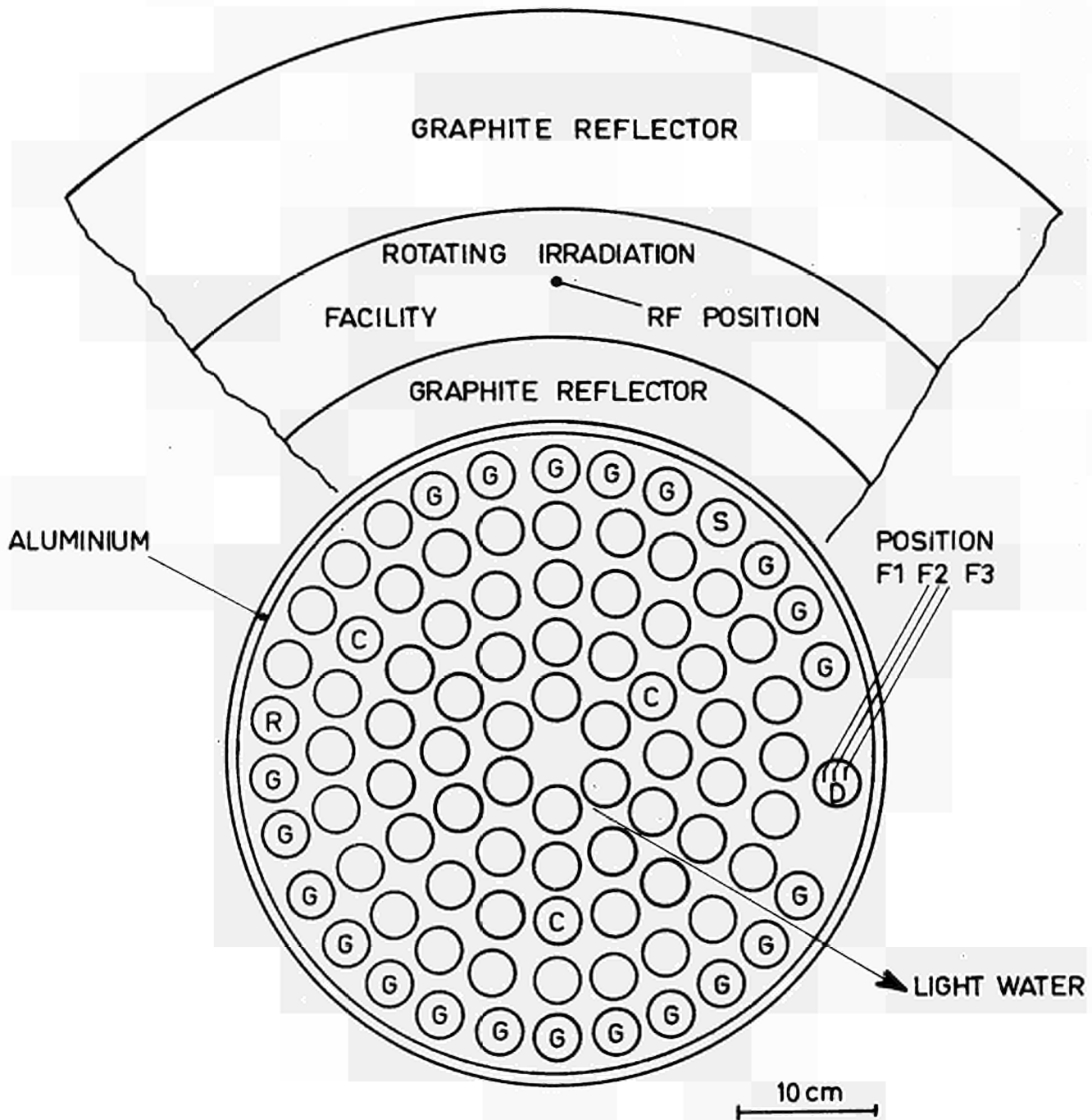
- ◯ FUEL ELEMENT
- Ⓒ CONTROL ROD
- Ⓖ GRAPHITE ELEMENT
- Ⓡ RABBIT
- Ⓢ NEUTRON SOURCE
- Ⓓ DUMMY ELEMENT

Fig. 2 - CALCULATED EPITHERMAL AND FAST NEUTRON SPECTRA.
r = RADIAL   DISTANCE (cm) FROM CORE AXIS.
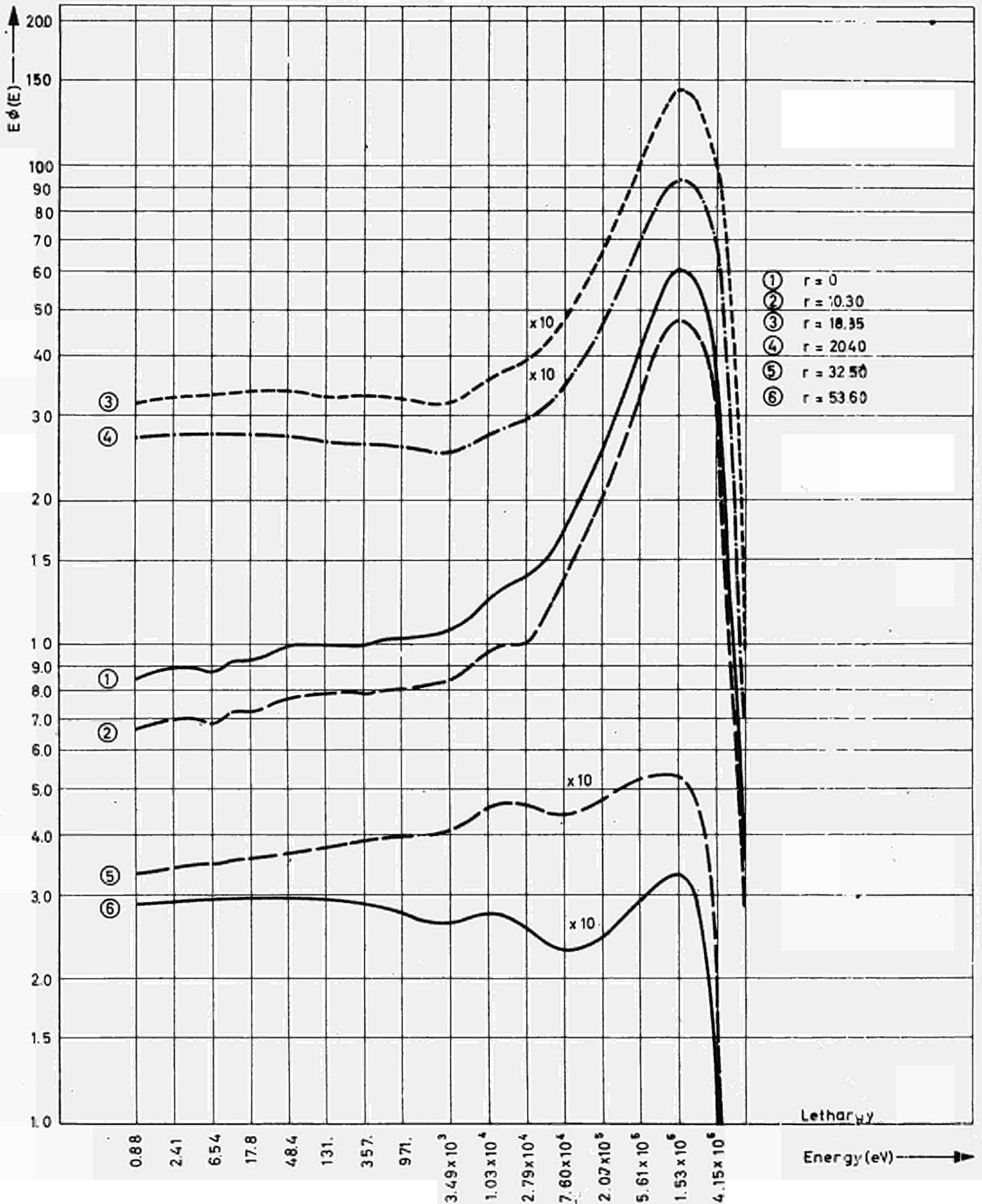
Fig. 3 - RELATIVE DEVIATIONS FROM A 1/E SPECTRUM CALCULATED FOR THE IRRADIATION POSITIONS. r = RADIAL DISTANCE (cm) FROM CORE AXIS.
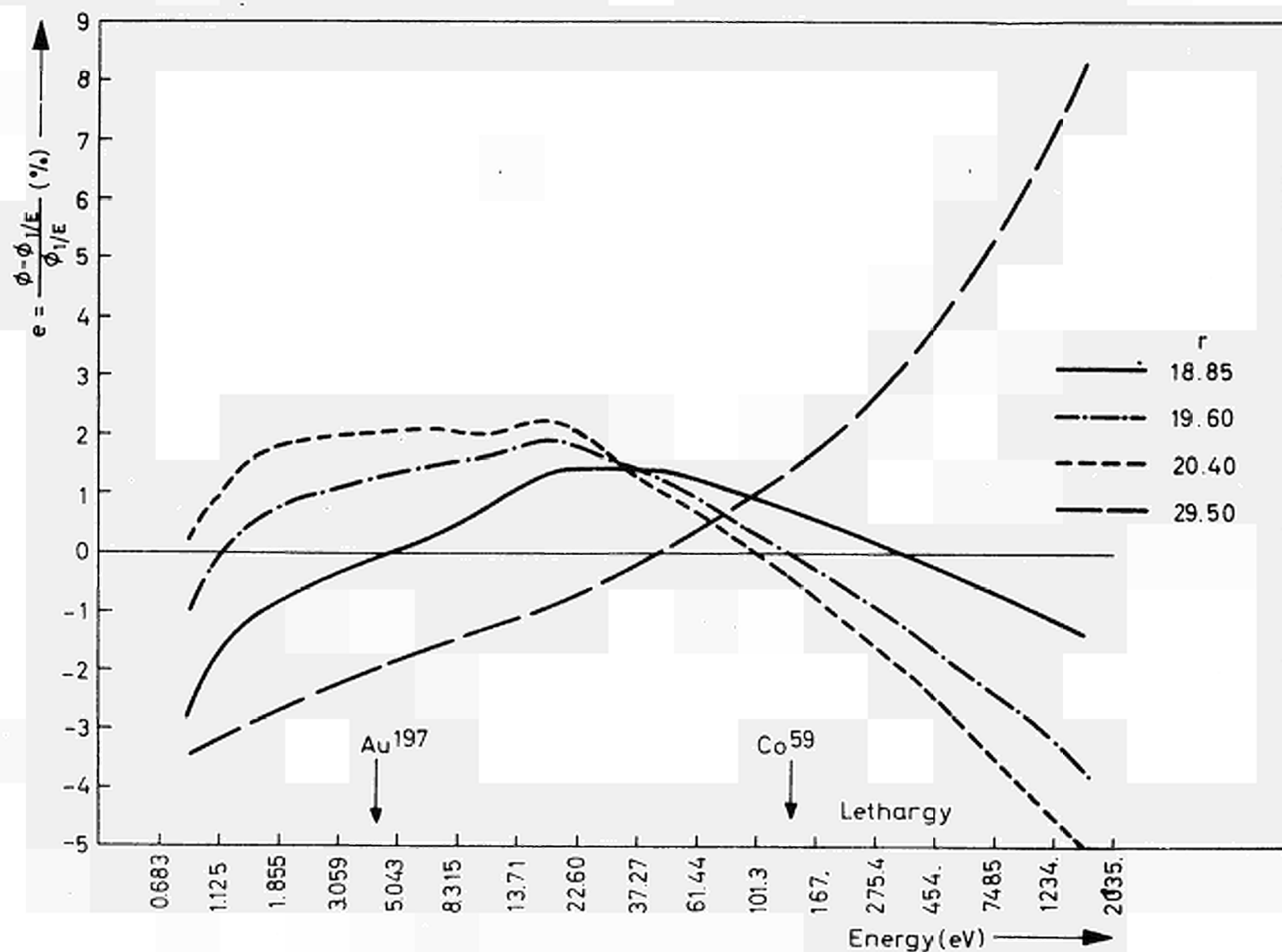
Fig. 4 – RELATIVE DEVIATIONS FROM A 1/E SPECTRUM CALCULATED FOR A LIGHT WATER REFLECTOR.
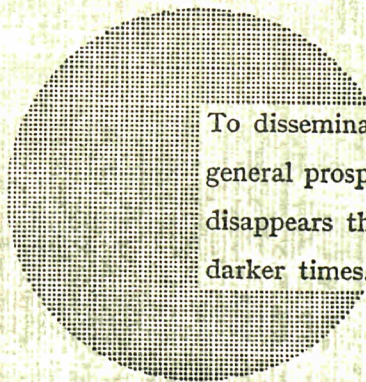r = RADIAL DISTANCE (cm) FROM CORE AXIS
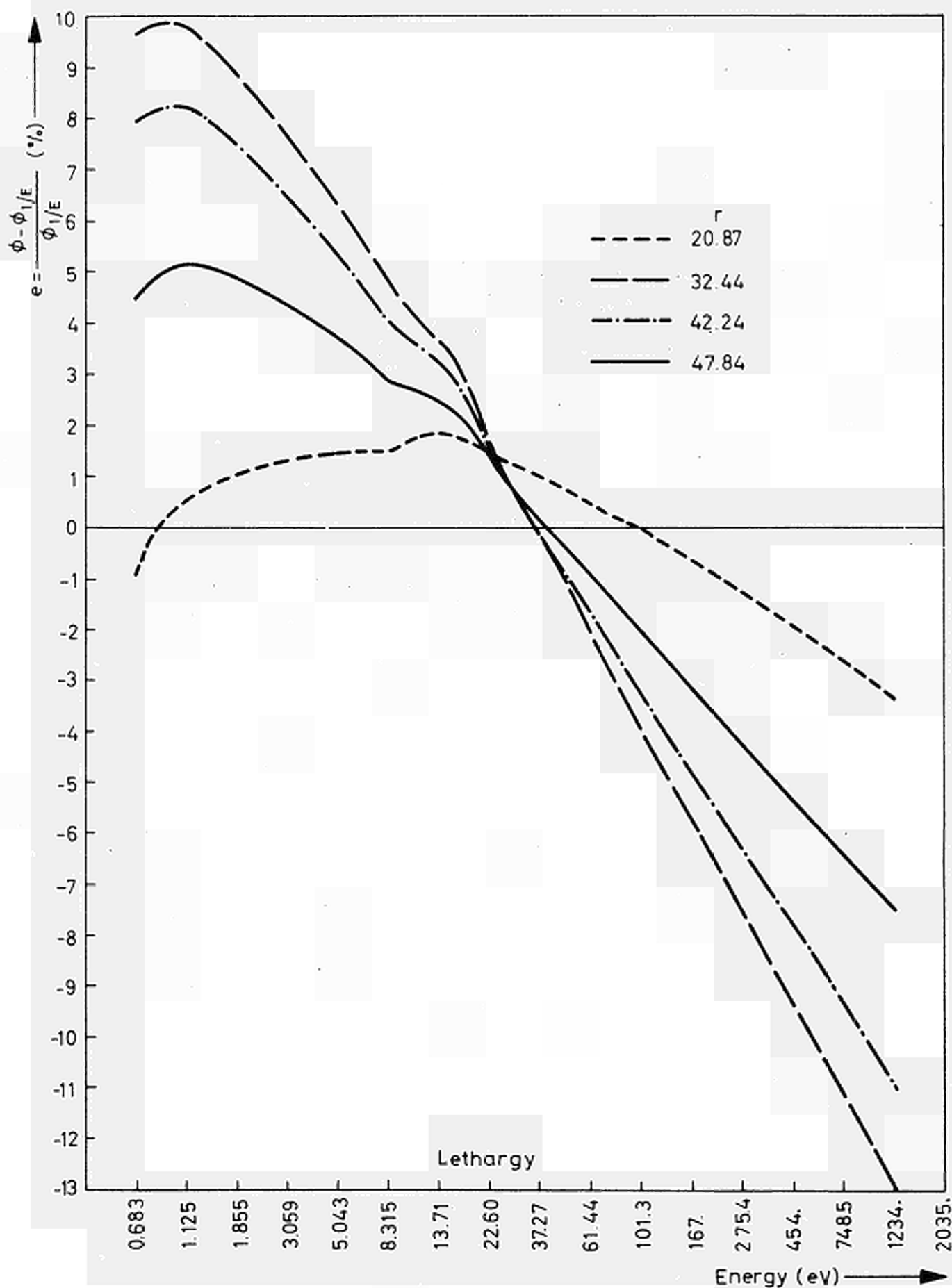
To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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