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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

PREPARATION AND CALIBRATION OF CO^{60} STANDARDS FOR INTEGRATED THERMAL FLUX MEASUREMENTS

by

R. VANINBROUKX in collaboration with G. GROSSE

1963

Joint Nuclear Research Center
Geel Establishment - Belgium

Central Bureau of Nuclear Measurements

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SUMMARY

At the request of the "Working group of neutron dosimetry" 3 series of Co^{60} standards for flux monitoring - 0.25, 2 and 35 mc - were prepared and standardized with high precision. The maximum error on the absolute activity is $\pm$ 1 %. The complete standardization method, including the absolute and the relative method, is described in detail, together with a discussion of the errors. The activities of the standards are expressed also in thermal flux units, and an explanation of this choice of unit is given.

I — INTRODUCTION

Euratom has established a "Working group for neutron dosimetry in research reactors" with the aim of standardizing neutron flux measurements. A "Subcommittee for Co standardization" under the chairmanship of Mr. MOTTE (C.E.N. Mol) has developed a standard method ([1]) for the measurement of integrated thermal fluxes.

This method is based on the activation of Co^{59} detectors and the measurement of these detectors by comparison with Co^{60} standards. At the request of this "Working group" the C.B.N.M. of Euratom Geel has prepared and calibrated high precision Co^{60} standards for integrated thermal flux measurements.

II — GENERAL PROPERTIES OF THE STANDARDS

The following standards have been prepared and distributed:

1. Foils 10 mm Ø, 0.1 mm thick, activity about 0,25 mc for the range 10^{16} — 10^{18} n.cm^{-2} of integrated flux. (We still have 7 standards of this type in stock.)

2. Foils 3 mm Ø, 0.1 mm thick, activity about 2 mc for the range 10^{18} — 10^{20} n.cm^{-2}. (We still have 4 standards in stock.)

3. Wires 0,5 mm Ø, 10 mm long, activity about 35 mc for the range 10^{20} — 10^{22} n.cm^{-2}. (These standards are all distributed.)

The standards 1 and 2 are prepared from specpure cobalt from Johnson and Matthey, and the standards 3 from cobalt obtained from Mackay New York. The Fe contamination, which amounts to 25 ppm and 210 ppm for Johnson-Matthey and Mackay cobalt resp., does not cause interferences for the standards.

The activity of $Fe^{55} + Fe^{59}$ is always smaller than 10^{-5} times the Co^{60} activity. The standards are packed in Trovidur (a polyvinyl chloride) or aluminium containers with a diameter of 15 mm and a thickness of 3 mm (see fig. 1).

The accuracy in the statement of the activities is generally $\pm$ 1.0 %. This «maximum error» will be treated in detail later on.

The «Working group» accepted for the Co^{60} half-life the value (5.27 $\pm$ 0.06) y [1]. To day this value and particularly the stated error are known more precisely to be (5.265 $\pm$ 0.03) y, which is the mean value from the Nuclear Data Sheets and the results of several recent measurements (also of the C.B.N.M.).

The adopted reference time is 1.1.1963 0 h. MET.

Besides the standards mentioned in 1), 2) and 3) we have also calibrated standards with other activities (see table I).

These standards can be delivered on request.

TABLE I

Supplementary Co^{60} standards prepared

Type	Diameter mm	Thickn. Length. mm	Act. on 1. 1. 63 mc	Max. Error ± %	Number availab. Standards
Foil	10	0.2	0.3 — 0.5	1.0	14
Foil	10	0.1	0.03 — 0.06	1.5	27
Foil	10	0.05	0.1 — 0.15	1.0	11
Foil	10	0.05	0.004 — 0.04	1.5	116
Foil	10	0.02	0.003 — 0.01	1.5	12
Foil	3	0.1	0.02	1.0	6
Foil	3	0.1	0.002	1.5	7
Foil	3	0.05	0.002	1.5	49
Wire	0.5	10	0.03	1.5	4
Wire	0.25	10	0.007	1.8	4
Wire	0.125	10	0.005	2.0	14

III — DETERMINATION OF THE ACTIVITY OF THE STANDARDS

A. Method

All standards were first measured in a γray-spectrometer with a reproducibility of $\pm$ 0.1 %. (Relative standardization.)

Some of these standards — called primary standards — were then dissolved. The standards which were not dissolved are called further secondary standards.

The solutions were standardized absolutely by two independent methods. The accuracy of the absolute standardization is better than $\pm$ 0.5 %. The relative and absolute standardization together determine the absolute activity of the secondary standards with an accuracy of better than $\pm$ 1.0 % (details see below).

B. Relative standardization

All primary and secondary standards were measured with a γ ray-spectrometer with a 3" × 3" NaI (Tl) crystal (see fig. 2).

For each type of standard the inner lead shield between source and crystal was chosen in such a way that the registered counting-rate did not exceed 3000 c.p.s. The determination of the relative activities of the standards was effected by a pure count in one point of the centre of the plateau (see fig. 3); because it could be shown clearly that the counting in a plateau, and thus the measurement of all effects (photo-, Compton effect and possibly bremsstrahlung), gave a much better reproducibility ($< \pm 0.1$ %) than measurements on the photopeak alone by a multi-channel-analyzer.

The overall discrimination in this measurement was approximately 10 - 15 keV. The possible errors in connection with the relative measurements can be summarized as follows:

a) Statistical error. At least 10^6 pulses were counted for each standard. Accepting 2 standard deviations as maximum error this means $\pm$ 0.2 %. b) Reproducibility of the measurements on the same source. Many measurements during 10 months have shown that reproducibility is completely statistical. This means that we have not to take into account any supplementary fluctuating error. c) Differences between source holders of the same type. This was determined experimentally by measuring different standards in several source holders. Some measurements were also performed in which the sources had been moved vertically and horizontally to detect the influence of small geometrical differences. These measurements showed that, when carefully manufactured containers were used, the fluctuations were never greater than $\pm$ 0.2 %, i.e. also completely statistical. d) Selfabsorption. This effect was determined theoretically and experimentally, and a good agreement was reached for this correction, which amounts to 0.3 % resp. 1.2 % for foils with a thickness of 0.1 mm and wires with a diameter of 0.5 mm. This effect does not introduce a noticeable error, because primary and secondary standards are of the same dimensions. e) Counting loss by dead time. The counting-rate was always chosen in such a way that this correction never exceeded 1 %. The primary and secondary sources always had about the same strength and since the total correction was known to $\pm$ 10 %, the error caused by this effect is certainly smaller than $\pm$ 0.1 %. Since no other errors appear in the relative measurements the maximum total error (arithmetical sum of the separate errors f_i) amounts to:

$$\text{Max. } Error_{rel} = \pm 0.3\ \%.$$

The statistical sum of the separate errors ($\sqrt{\Sigma f_i^2}$) is $\pm$ 0.2 %.

C. Dissolution of the primary standards

After finishing the relative measurements the primary standards were dissolved. The standards of type 1 and 2 were dissolved in 1 N. HNO_3, and those of type 3 in a mixture of 3 parts concentrated HCl and 1 part concentrated HNO_3, because the wires did not quantitatively dissolve in concentrated HNO_3 or concentrated HCl.

The completeness of the dissolution was checked in two independent ways, first by chemical analysis done by the chemistry group of the C.B.N.M. with an accuracy of $\pm$ 0.3 %, and secondly by filtering the original solutions after the standardization. The filters with possible undissolved residues were measured under well-known ($\pm$ 1 %) geometrical conditions. We never found more than 10^{-6} parts of the activity of the solution on the corresponding filter. Also loss by adsorption on glass can be ruled out completely, especially because of the big amount of carrier and the high acidity of the solutions. Moreover the used glassware was tested, after normal rinsing, with a γ monitor. We never found any significant residual activity. The maximum possible error introduced by the dissolution can thus be estimated as less than $\pm$ 0.1 %.

D. Absolute standardization of the solutions

All solutions were standardized absolutely by two independent methods: 4 Π liquid scintillation counting and $4\Pi\beta$-γ coincidence counting.

a) 4 Π *Liquid scintillation counting.* ([2])

Small aliquots of the solution, which is prepared in such a manner that it satisfies certain conditions concerning specific activity, carrier concentration, acidity etc., are mixed with suitable liquid scintillators e.g. toluene + PPO (5 g/l) + POPOP (0.5 g/l). These samples are counted in a liquid scintillation β-spectrometer. With an adequate total amplification (high voltage on the photomultiplier and external amplification) a linear extrapolation of the measured integral spectrum can be performed and the absolute counting-rate of the sample can be obtained in this way. After application of a few corrections — all smaller than 1 % — this method gives for Co^{60} a reproducibility of $\pm$ 0.3 %. The possible errors are summarized below.

	Max. Error $\pm$ %
Dead time correction	0.10
Decay correction	0.03
Background + afterpulses	0.02
Extrapolation (including statistics, reprod, stability)	0.30
Source preparation	0.10
Adsorption, sedimentation	0.05

These errors were determined by an intensive research on this standardization method, and have been verified in several international intercomparisons. The maximum total error is $\pm$ 0.6 %. The statistical sum of the errors is a factor 2 smaller.

b) 4 $\Pi\beta$-γ *coincidence counting.* ([3]) ([4])

Here well-known aliquots of the solution are normally put on thin foils and dried by evaporation. This source preparation can also be performed in different ways such as precipitation, electrodeposition, etc. These sources are counted in an apparatus which consists principally of a 4 $\Pi\beta$ counter (in most cases a proportional counter) and a NaI (Tl) crystal as γ counter, both with the necessary electronics. The method is based on the following main equations:

$$N_\beta = N_o\varepsilon_\beta;\ N_\gamma = N_o\varepsilon_\gamma;\ N_c = N_o\varepsilon_\beta\varepsilon_\gamma \text{ and } N_o = N_\beta\, N_\gamma/N_c$$

N_β and N_γ are the counting-rates, corrected for decay and background, of the β-resp. the γ channel. N_c is the number of observed coincidences between the β and the γ channel, corrected for background and accidental coincidences. N_o is the absolute disintegration-rate of the sample, while ε_β and ε_γ are the efficiencies of the β-resp. γ counter. Some small corrections have to be applied to the result for the disintegration-rate N_o.

The results for Co^{60} obtained with this method are reproducible within $\pm$ 0.2 %. The final errors can be summarized as follows:

	Max. Error $\pm$ %
Statistics	0.05
Source preparation	0.10
Stability electronics	0.15
Dead time correction and correction for accidental coincidences	0.15
Decay scheme dependent correction	0.03

The maximum error is $\pm$ 0.5 %, the stat. sum is a factor 2 smaller.

c) *Comparison of both standardization methods and control measurements.*

The mean deviation between the results obtained with 4 Π l.s. and with 4 $\Pi\beta$-γ for different solutions (20 solutions, namely 10 foils Ø 10 mm, 6 foils Ø 3 mm and 4 wires Ø 0.5 mm) was much smaller than 0.5 %. Only one solution gave a difference of 0.8 %. The results of the 4 $\Pi\beta$-γ method were always somewhat higher. As a check all solutions were measured relatively to a very precisely known Co^{60} solution. This was done with accurately weighed ampoules filled with aliquots of the standardized solutions and aliquots of the reference solution. The measurements were done with the γ ray-spectrometer in one point of the centre of the plateau. Experimentally the reproducibility of this method has been found to be $\pm$ 0.3 % with a maximum possible error of $\pm$ 0.5 %. The mean value obtained from the absolute measurements always agreed within this $\pm$ 0.5 % with the results of the relative control measurements. Thus we can take safely as extreme error for the absolute measurements :

$$\text{Max. } Error_{abs} = \pm\ 0.5\ \%.$$

E. Activity of the standard

We can derive from the absolute activity of the primary standards (D) and their relative measurements (B) a factor which is valid for the conversion of all relative results to absolute activity values. We thus can calculate the absolute activity of all secondary standards. The results of these measurements are compiled in table II.

The activity of the standards is given on the reference date 1.1.1963. The error on these results is given by :

Max. $Error_{rel}$	: $\pm$ 0.3 %
Max. $Error_{abs}$	: $\pm$ 0.5 %
Max. $Error_{decay}$	: $\pm$ 0.2 % (0.07 % per year, thus untill 1.1.66)

The maximum total error of the activity of the standards is :

$$\text{Max. } Error_{tot} = \pm\ 1.0\ \%\ \text{(stat. sum of the errors is } \pm\ 0.6\ \%)$$

The last column of table II gives the activity of the standards in units of an integrated flux I_E. The meaning of I_E will be discussed in chapter IV.

IV — ACTIVITY OF THE STANDARDS EXPRESSED IN FLUX UNITS

The planned Euratom standard method ([1]) for the measurement of the integrated thermal flux requires the indication of the activity of the standards in flux units (n. cm^{-2}). Therefore we have to define how this will be done and what the real meaning of this activity statement will be.

A. Derivation of the integrated thermal flux from the induced activity by the standard method proposed by Motte

The integrated thermal neutron flux $I = \int \varnothing\ (t)\ dt$ is obtained in the induced activity method by counting the number of activated detector atoms.

TABLE II

Activity of the standards on 1.1.1963 0 h. MET

1. Foils Ø 10 mm, thickness 0.1 mm.

Stand. N°	Cont. mater	Weight mg	dps = A_E	mc	$n.cm^{-2} = I_E$
602	Trovidur	73.739	10447 10^3	0.2824	8.753 10^{16}
604	Trovidur	72.743	10162 10^3	0.2747	8.631 10^{16}
610	Trovidur	72.967	10309 10^3	0.2786	8.729 10^{16}
621	Trovidur	74.683	10294 10^3	0.2782	8.516 10^{16}
624	Trovidur	74.132	10302 10^3	0.2784	8.586 10^{16}
625	Aluminium	73.478	11335 10^3	0.3063	9.531 10^{16}
626	Aluminium	73.839	9185 10^3	0.2482	7.686 10^{16}
627	Aluminium	73.181	8598 10^3	0.2324	7.259 10^{16}
628	Aluminium	74.517	8438 10^3	0.2281	6.996 10^{16}
629	Aluminium	71.294	7865 10^3	0.2126	6.816 10^{16}
630	Aluminium	74.304	8058 10^3	0.2178	6.700 10^{16}
631	Aluminium	74.111	7914 10^3	0.2139	6.597 10^{16}
632	Aluminium	73.860	8948 10^3	0.2418	7.486 10^{16}
633	Aluminium	73.890	7761 10^3	0.2098	6.490 10^{16}
634	Aluminium	73.779	7791 10^3	0.2106	6.524 10^{16}
635	Aluminium	74.278	7911 10^3	0.2138	6.580 10^{16}
636	Aluminium	73.434	7908 10^3	0.2137	6.653 10^{16}
637	Aluminium	74.563	8242 10^3	0.2228	6.830 10^{16}
638	Aluminium	72.532	8313 10^3	0.2247	7.081 10^{16}
639	Aluminium	73.004	7689 10^3	0.2078	6.507 10^{16}
640	Aluminium	73.371	11032 10^3	0.2982	9.290 10^{16}
641	Aluminium	74.103	11429 10^3	0.3089	9.529 10^{16}
642	Aluminium	72.946	11210 10^3	0.3030	9.495 10^{16}
643	Trovidur	74.353	10587 10^3	0.2861	8.797 10^{16}
644	Trovidur	74.137	10350 10^3	0.2797	8.626 10^{16}
645	Trovidur	73.008	10355 10^3	0.2799	8.763 10^{16}
647	Trovidur	73.463	11016 10^3	0.2977	9.265 10^{16}
648	Trovidur	72.660	9662 10^3	0.2611	8.215 10^{16}
650	Trovidur	73.254	9244 10^3	0.2499	7.797 10^{16}
652	Trovidur	71.867	9144 10^3	0.2471	7.861 10^{16}
653	Trovidur	74.504	9779 10^3	0.2643	8.109 10^{16}
654	Aluminium	73.376	11068 10^3	0.2991	9.320 10^{16}

2. Foils Ø 3 mm, thickness 0.1 mm, adopted weight 6.6 mg (see chapter IV).

St. No.	Cont mat.	Activity on 1.1.63 dps = A_E	mc	n.cm^{-2} = I_E	St. No.	Cont mat.	Activity on 1.1.63 dps = A_E	mc	n.cm^{-2} = I_E
701	Al.	7448 10^4	2.013	6.972 10^{18}	713	Al.	7330 10^4	1.981	6.861 10^{18}
702	Al.	6897 10^4	1.864	6.456 10^{18}	714	Al.	6945 10^4	1.877	6.501 10^{18}
703	Al.	6889 10^4	1.862	6.449 10^{18}	721	Tr.	7411 10^4	2.003	6.938 10^{18}
704	Al.	6860 10^4	1.854	6.422 10^{18}	722	Tr.	7896 10^4	2.134	7.391 10^{18}
705	Al.	7607 10^4	2.056	7.121 10^{18}	723	Tr.	7012 10^4	1.895	6.564 10^{18}
706	Al.	7034 10^4	1.901	6.584 10^{18}	724	Tr.	8048 10^4	2.175	7.533 10^{18}
707	Al.	7437 10^4	2.010	6.962 10^{18}	725	Tr.	7145 10^4	1.931	6.688 10^{18}
708	Al.	7037 10^4	1.902	6.588 10^{18}	726	Tr.	6830 10^4	1.846	6.394 10^{18}
709	Al.	7807 10^4	2.110	7.308 10^{18}	727	Tr.	7352 10^4	1.987	6.882 10^{18}
710	Al.	6819 10^4	1.843	6.384 10^{18}	728	Tr.	7274 10^4	1.966	6.810 10^{18}
711	Al.	7400 10^4	2.000	6.927 10^{18}	729	Tr.	7363 10^4	1.990	6.893 10^{18}
712	Al.	7023 10^4	1.898	6.574 10^{18}					

3. Wires Ø 0.5 mm, L 10 mm, adopted weight 17.9 mg (see chapter IV).

St. No.	Cont mat.	Activity on 1.1.63 dps = A_E	mc	n.cm^{-2} = I_E	St. No.	Cont mat.	Activity on 1.1.63 dps = A_E	mc	n.cm^{-2} = I_E
731	Al.	1215 10^6	32.85	4.195 10^{19}	744	Al.	1277 10^6	34.50	4.406 10^{19}
734	Al.	1253 10^6	33.87	4.326 10^{19}	745	Al.	1356 10^6	36.64	4.679 10^{19}
735	Al.	1282 10^6	34.64	4.424 10^{16}	746	Al.	1280 10^6	34.59	4.418 10^{19}
736	Al.	1268 10^6	34.28	4.378 10^{19}	747	Al.	1340 10^6	36.22	4.626 10^{19}
737	Tr.	1264 10^6	34.18	4.365 10^{19}	748	Al.	1346 10^6	36.38	4.646 10^{19}
741	Al.	1275 10^6	34.46	4.401 10^{19}	749	Al.	1368 10^6	36.96	4.720 10^{19}
742	Al.	1331 10^6	35.97	4.593 10^{19}	750	Al.	1366 10^6	36.92	4.716 10^{19}
743	Al.	1375 10^6	37.16	4.746 10^{19}	753	Al.	1276 10^6	34.50	4.406 10^{19}

Motte uses the following formula, which relates the activity A of the irradiated detector to the integrated flux I :

$$A = \frac{\lambda N \sigma_a I x}{F_{cd}} \qquad (1)$$

A = activity of the detector in d.p.s. at the end of the irradiation.

λ = decay constant of Co^{60} = (4.16764 ± 1.1 %) 10^{-9} sec $^{-1}$ (1).

N = number of Co^{59} atoms at the beginning of the irradiation.

σ_a = cross-section of Co^{59} for the activation by thermal neutrons = 38 barns $\pm$ 1.8 % [1].

x = by Motte calculated and tabulated correction factor for the $C0^{59}$ and Co^{60} consumption during the irradiation [5].

F_{cd} = correction factor for the influence of epithermal neutrons (Cd ratio).

We obtain from the formula (1) :

$$I = \frac{A\ F_{cd}}{\lambda N\ \sigma_a x}\ n.cm^{-2} \tag{2}$$

If the mass of the detector is P_D mg we get :

$$N = (1.022 \pm 0.01\ \%)\ P_D\ 10^{19}\ \text{atoms.}$$

Substituting the numerical values of λ, N and σ_a in (2) gives :

$$I = 0.61784\ \frac{A\ F_{cd}}{P_D\ x}\ 10^{12}\ n.cm^{-2}\ (\pm\ 2.2\ \%) \tag{3}$$

The error given between brackets is the statistical sum of the separate errors. Since the activity of the standards (table II) is given on the reference date 1.1.63, and since we determine the activity of the detector by measuring the ratio of the activities of the detector and the standard (see further the factor y) we obtain also the activity of the detector on the reference date. If we call the activity of the detector on 1.1.63 A' then the following relation exists between A' and A :

$A = A'\ e^{-\lambda t} = A'\ F_t$ (t = time elapsed between 1.1.63 and the end of the irradiation).

In this way formula (3) becomes :

$$I = 0.61784\ \frac{A'\ F_{cd} F_t}{P_D\ x}\ 10^{12}\ n.cm^{-2}\ (\pm\ 2.2\ \%) \tag{4}$$

We still have to determine the factor x from formula (4). If we adopt from Motte the notation $I^* = I\ x$ we obtain :

$$I^* = I\ x = 0.61784\ \frac{A'\ F_{cd}\ F_t}{P_D}\ 10^{12}\ n.cm^{-2}\ (\pm\ 2.2\ \%) \tag{5}$$

The activity of the detector will be determined by measuring the ratio of the activities of the detector and the standard :

$$y = \frac{\text{act. det. } F_{t'}}{\text{act. stand.}}$$

$F_{t'}$ is here the decay correction for the time t' elapsed between the measurements of detector and standard. Normally $F_{t'}$ equals 1.

From more measurements of y we obtain, like Motte, $\bar{y}$. Than we have

$A' = \bar{y}\, A_E$, where

A' = activity of the detector in d.p.s. on 1.1.63.

A_E = activity of the standard in d.p.s. on 1.1.63 ($\pm$ 1 %).

Substituting A' in formula (5) gives :

$$I^* = 0.61784 \frac{\bar{y} A_E F_{cd} F_t}{P_D} 10^{12} \text{ n.cm}^{-2} (\pm \text{ a } \%) \tag{6}$$

The error a is determined as follows : $a^2 = 2{,}2^2 + 1^2 + f^2_{F_{cd}} + f^2_{F_t} + f^2\bar{y}$ where $f_{F_{cd}}$, f_{F_t} and $f\bar{y}$ are the errors on the corresponding factors.

Starting from I*, and knowing the total time of irradiation, we obtain from the tables of Motte ([5]) the factor x and finally the value I.

$$I = 0.61784 \frac{\bar{y}\, A_E F_{cd} F_t}{P_D\, x} 10^{12} \text{ n.cm}^{-2} (\pm \text{ b } \%) \tag{7}$$

The resulting error b is determined by : $b^2 = a^2 + f^2_x$.

B. Activity expressed in thermal flux units

In formula (7) we can express the activity A_E of the standard as the specific activity a_E times the mass P_E : $A_E = a_E\, P_E$.

The formula (7) then contains the following dimensionless factors $\bar{y}$, F_{cd}, F_t, x and P_E/P_D. The remaining factors together which contain the activity of the standard have the dimension of a flux, and can thus be represented by a fictive flux of the standard I_E :

$$I_E = 0.61784\, a_E\, 10^{12} \text{ n.cm}^{-2} = 0.61784 \frac{A_E}{P_E} 10^{12} \text{ n.cm}^2 \tag{8}$$

We can write the formula (7) according to Motte as :

$$I^* = \bar{y}\, I_E \frac{P_E}{P_D} F_{cd} F_t \tag{9}$$

But we must not forget that I_E does not possess any real meaning. The only characteristic property of the standard is its activity. This follows clearly from the following simple considerations : First, there is no meaning in speaking of an integrated flux at a reference time. Further, I_E is not the real integrated flux for the irradiation of the standard.

If we now consider formula (9) we see that the factor P_E appears in the numerator, while I_E contains this same value P_E in the denominator. Thus we can give any arbitrary value to P_E without affecting the result I*.

For that reason we accurately weighed only the standards of type 1 before and after irradiation. For the other standards we accepted mean values ($\pm$ 2 %) for P_E, since it was difficult to weigh these standards after the irradiation, as they possessed a high activity. The values I_E, obtained from formula (8), give the activities of the standards in flux units (n. cm^{-2}). These values are compiled in table II too.

V. REMARKS

When using the standards one should remember that the flux I as determined here is not exactly the physical flux. It is calculated with omission of some smaller corrections, which should be applied to the norm if the real integrated flux is needed.

These corrections are : flux perturbation by the detector, loss of CO^{60} from the detector by recoil, especially at high temperatures, effects related with neutron energy- and angular distribution, etc. These problems are all too complicated to be treated in this report. The rather high effect of flux perturbation, in particular, has been treated extensively in published papers. A short treatment and a literature survey have been given in an earlier report ([6]), from which the fig. 4 and 5 are taken. More details and more precise results will be published in a later Euratom report.

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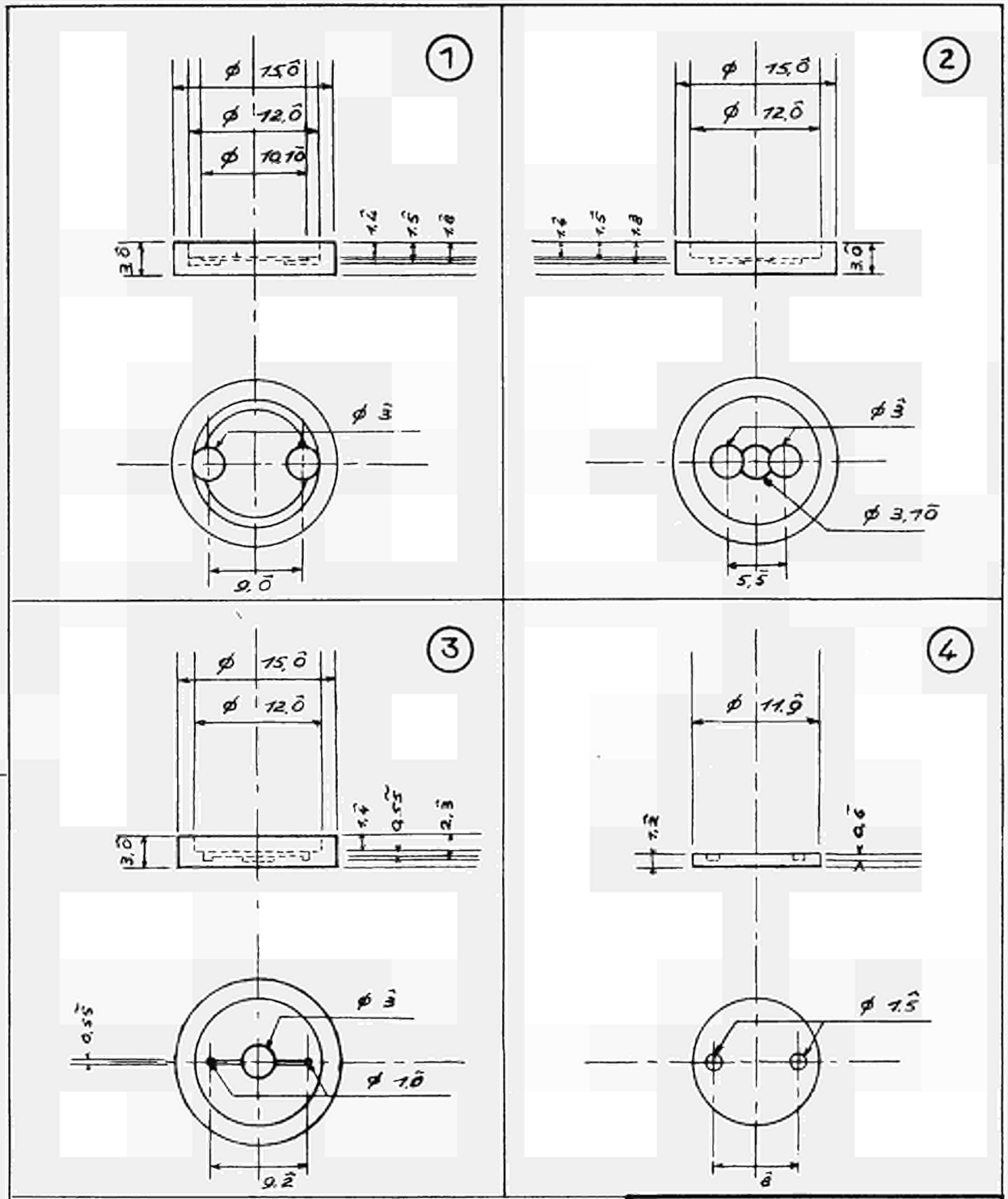


$3\tilde{2} = \pm 2$	$32{,}\tilde{0} = \pm 0{,}2$	$32{,}0\tilde{0} = \pm 0{,}02$
$3\bar{2} = \pm 1$	$32{,}\bar{0} = \pm 0{,}1$	$32{,}0\bar{0} = \pm 0{,}01$
$3\hat{2} = \pm 0{,}5$	$32{,}\hat{0} = \pm 0{,}05$	$32{,}0\hat{0} = \pm 0{,}005$

AFDELING

EURATOM
C.B.K.M. GEEL

MATER. Trovidur of Aluminium | BEHAND. Bronhouders

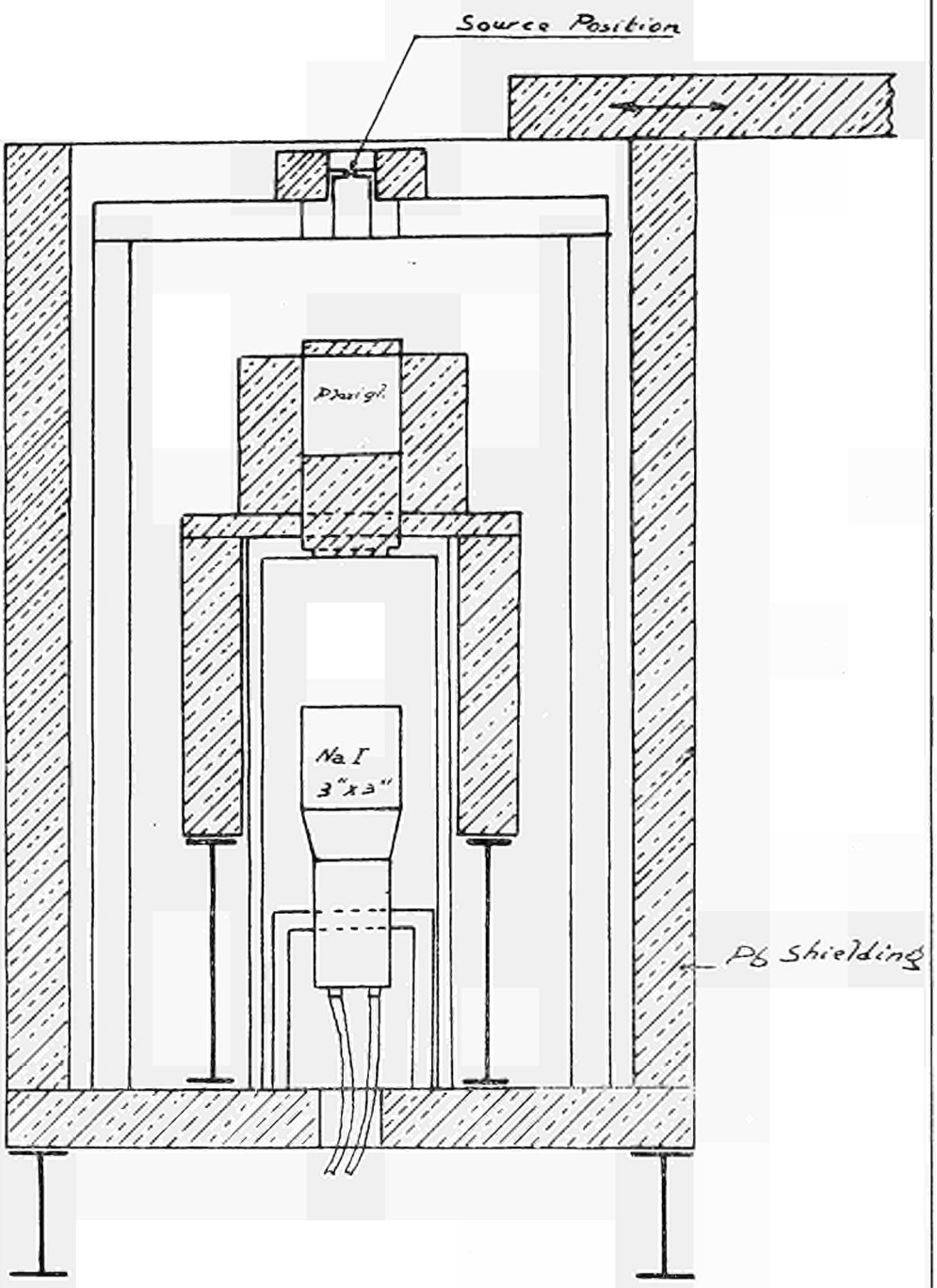
AANVRAGER
1. Voor folies met ø 10
2. " " " " 3
3. Voor draden L = 10 d = 0,5

DIENSTHOOFD
4. Deksel voor 1, 2 en 3

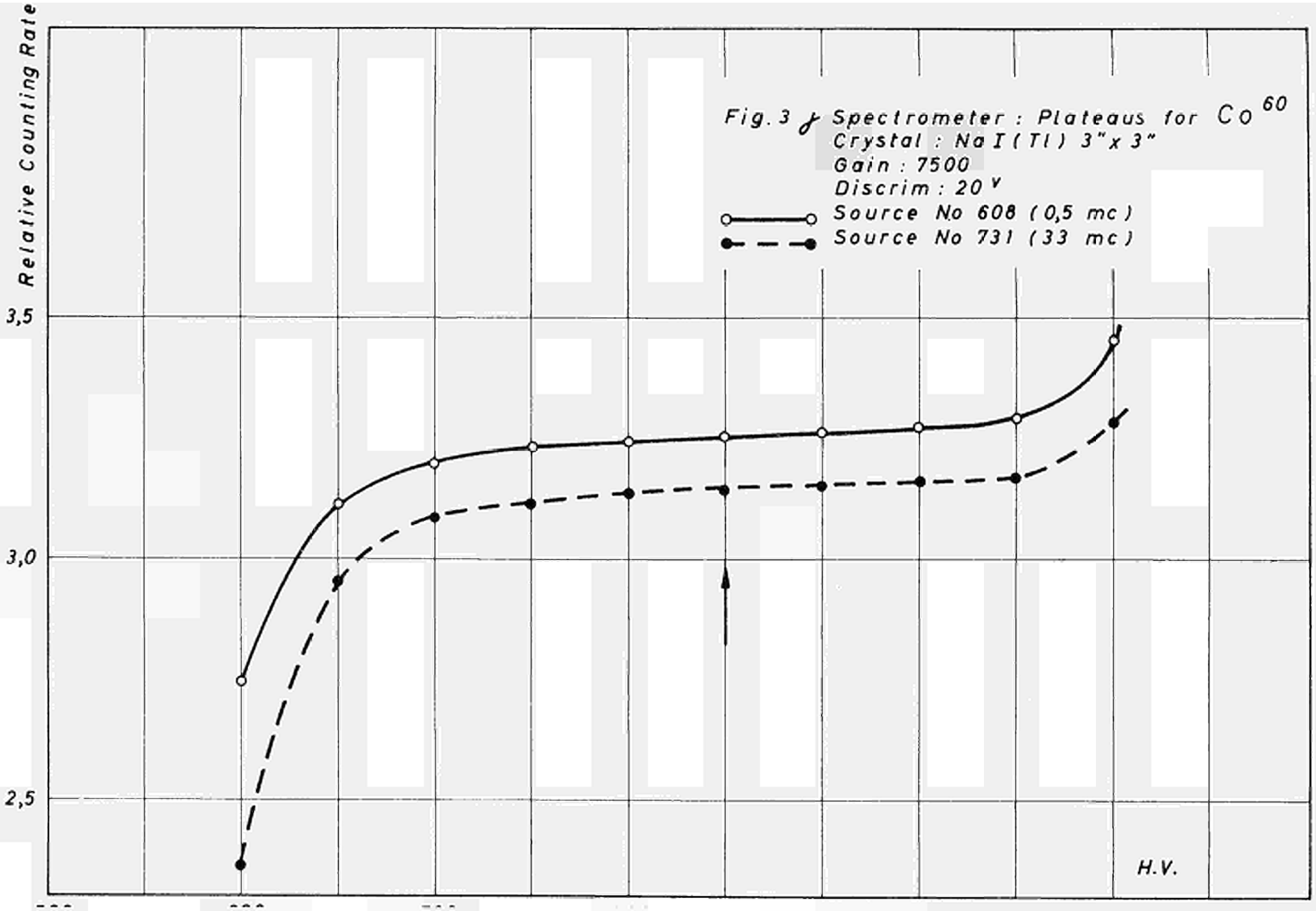
Fig. 1

AANT. BL. | SCHAAL
BLAD Nr | 2/1

GET. | DAT. | VERV.



$3\tilde{2} = \pm 2$ $32{,}\tilde{0} = \pm 0{,}2$ $32{,}0\tilde{0} = \pm 0{,}02$ $3\bar{2} = \pm 1$ $32{,}\bar{0} = \pm 0{,}1$ $32{,}0\bar{0} = \pm 0{,}01$ $3\hat{2} = \pm 0{,}5$ $32{,}\hat{0} = \pm 0{,}05$ $32{,}0\hat{0} = \pm 0{,}005$	AFDELING	EURATOM C.B.K.M. GEEL
MATER.	BEHAND.	
AANVRAGER	γ Spectrometer	Fig. 2
DIENSTHOOFD		AANT. BL. / SCHAAL BLAD Nr / 1/5
GET. / DAT. / VERV.		DIT DOCUMENT IS EIGENDOM VAN EURATOM. VERMENIGVULDIGING OF MEDEDELING AAN DERDEN VEREIST VOORAFGAANDELIJKE TOESTEMMING


Relative Counting Rate
3,5
3,0
2,5
H.V.
Fig. 3 γ Spectrometer : Plateaus for Co 60
Crystal : Na I (Tl) 3" x 3"
Gain : 7500
Discrim : 20 V
Source No 608 (0,5 mc)
Source No 731 (33 mc)

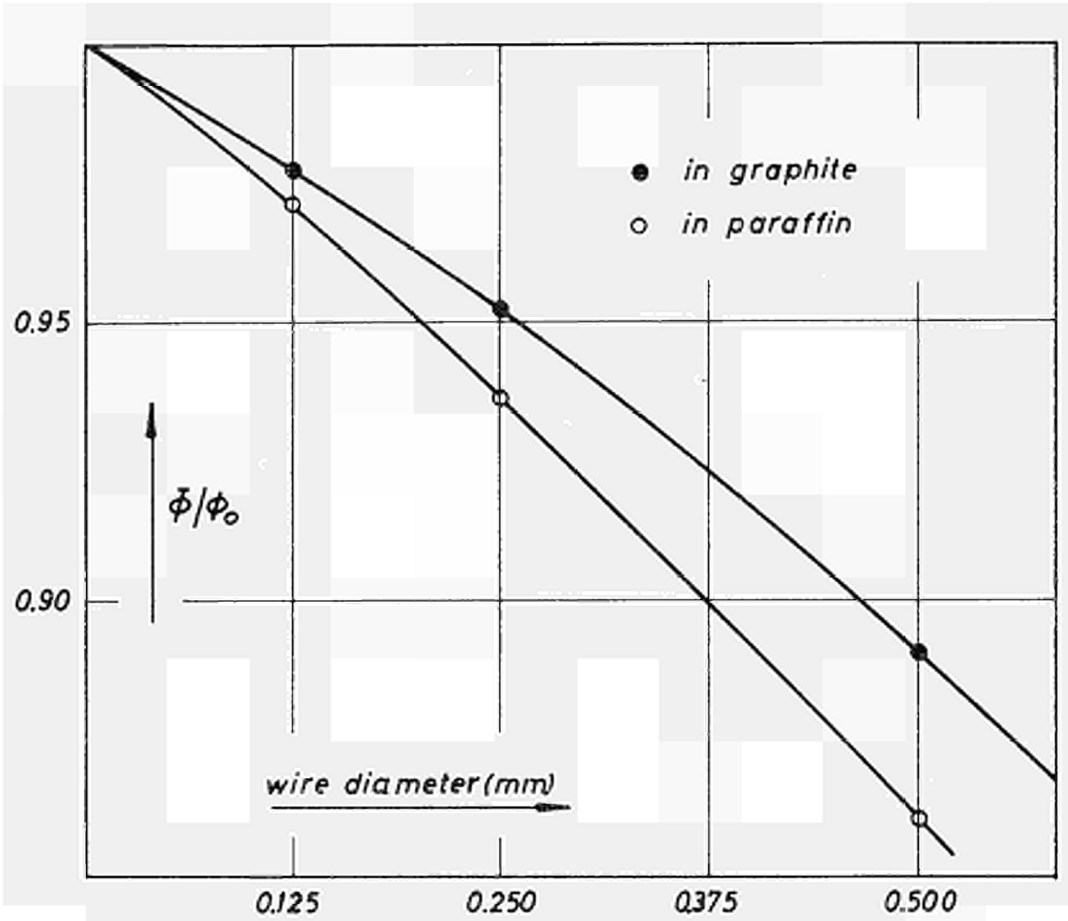


Fig. 4 Flux perturbation in cobalt wires

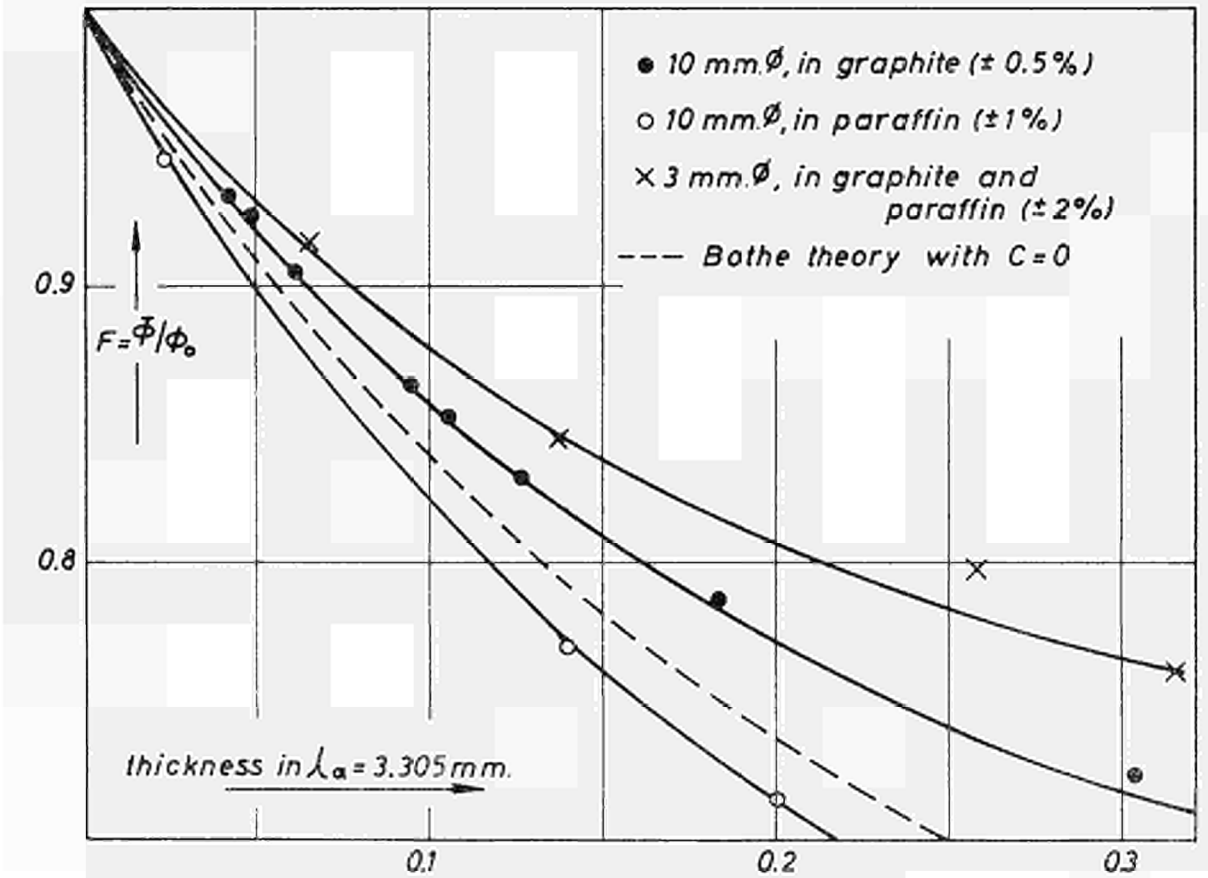


Fig. 5 Flux perturbation in cobalt foils