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Instrumentation

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SRP SCINTILLATION COUNTERS

by

C. A. Prohaska
Instrument Development Division

March 1955

E. I. du Pont de Nemours & Co.
Explosives Department — Atomic Energy Division
Technical Division — Savannah River Laboratory

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ABSTRACT

The operating characteristics of the SRP Standard Gamma Scintillation Counter and the SRP Special Alpha Scintillation Counter were investigated. Results on both counters are essentially the same. Plateaus are over 200 volts long, with a slope of approximately one per cent per hundred volts. Reproducibility is satisfactory, but the background is high. The coincidence correction is less than one per cent per 10^5 counts per minute.

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TABLE OF CONTENTS

LIST OF FIGURES

SRP SCINTILLATION COUNTERS

INTRODUCTION

This investigation was part of a program to study the various types of counting equipment procured for use at the Savannah River Plant. The purpose was to determine the characteristics and limitations of the Special Alpha Scintillation Counter, in which the phosphor is three inches in diameter, and of the Standard Gamma Scintillation Counter with a one and one-half-inch phosphor.

The plateau, background, reproducibility, and coincidence correction were investigated. Similar studies of the SRP standard windowless flow counter(1) and the SRP standard Geiger-Mueller Counter(2) were made previously. This investigation concludes the program to study the various types of counting equipment, and no further work is planned.

SUMMARY AND CONCLUSIONS

The Scintillation Counters were found satisfactory for general use at the Savannah River Plant for counting rates up to 2×10^5 counts per minute. Neither counter is recommended for counting very low level activities.

Plateaus For both alpha and gamma counters, the plateau is at least 200 volts long. The location of the center of the plateau is 950 ± 50 volts for all counters tested. The slope at this point is about one per cent per hundred volts.

Backgrounds The background of the Gamma Scintillation Counter, inside the standard three-inch iron shield, is high. The lowest background observed was 335 counts per minute and the highest background observed was 523 counts per minute.

The lowest background observed with the Alpha Scintillation Counter was 1.2 counts per minute, and the highest was 18 counts per minute. This relatively high background makes the Alpha Counter unsuitable for counting very low levels of alpha activity (i.e., one to two counts per minute).

Reproducibility With a single scintillation counter, either alpha or gamma, the variation of replicate counts was about that to be expected from statistics. However, one alpha counter, tested over a long period of time, showed a definite drift of counting rate with time. This drift was slow enough so that the reproducibility of duplicate or triplicate counts was not affected.

The variation in the counting rate of an alpha source, counted on six counters, was less than five per cent. The variation in the counting rate of a gamma source, counted on six counters, was less than twenty per cent.

Coincidence Correction The coincidence correction for either the alpha or gamma scintillation counter can be calculated from the following equation:

$$N = R + 6.335(10^{-8})R^2 + 5.553(10^{-14})R^3$$

where N = corrected counting rate

R = observed counting rate

For $R \leq 2 \times 10^5$ counts per minute, the expected error in N is less than one per cent. A table of coincidence corrections for counting rates up to 5×10^5 counts per minute is included in the Appendix to this report.

EXPERIMENTAL WORK

GENERAL

The SRP Special Alpha Scintillation Counter is composed of the following major components:

(1) Scaler (Tracerlab Type CC-10)

(1) Scintillation Probe (General Electric Co. Type 122C255G1)

(1) Three-inch Alpha Phosphor (Nuclear Research and Development, Inc.)

(1) Scintillation Planchet Counter (Nuclear Research and Development, Inc.)

Figure 1 is a photograph of the complete Alpha Scintillation Counter.

The SRP Standard Gamma Scintillation Counter is composed of the following major components:

(1) Scaler (Tracerlab Type CC-10)

(1) Scintillation Probe (General Electric Co. Type 122C255G1)

(1) NaI(Tl) Crystal (Harshaw Chemical Co., Type X6L2)

(1) Scintillation Planchet Counter and Donut Shield (Standard Engineering and Machine Co.)

Figure 2 is a photograph of the complete Gamma Scintillation Counter.

A photograph of the phosphor used in each type of scintillation counter is shown in Figure 3. On the left is the alpha-sensitive zinc sulfide screen, formed on the large end of a conical lucite light pipe. The small end of the light pipe is machined to fit the end of an RCA 5819 photomultiplier tube. The sides of the cone are painted white, to reduce the light losses. On the right is the sodium iodide (thallium activated) crystal with the small lucite light pipe that couples it to the 5819 photomultiplier tube.

Dow Corning "200" fluid having a viscosity of 10^6 centistokes provides optical coupling between the phosphor, light pipe, and photomultiplier tube.

Six different counters of each type were employed in each phase of this investigation. A different scaler and probe were used in each counter, but the same six scalers and probes were used for both the alpha and gamma counters. The same phosphor was used for all six counters of each type, and the effect of using different phosphors was determined in a separate experiment.

PLATEAUS

Plateaus were determined for the six different alpha scintillation counters and the six different gamma scintillation counters. No significant difference was observed between the two types of counters. Plateaus for two counters of each type are plotted in Figure 4. Curves for the other four counters of each type lie between the two curves that are plotted. All plateaus were at least 200 volts long with a slope of approximately one per cent per hundred volts over this range. A potential of 950 volts lies on the plateau of all counters tested.

BACKGROUND

Backgrounds were relatively high for all twelve counters. These backgrounds were measured at the normal operating voltage, determined by running a plateau. No specific attempt was made to measure either the reproducibility of the background, or the variation of background with photomultiplier anode voltage. What data were obtained, however, indicate that the reproducibility is poor, and that the background varies considerably with anode voltage. The observed backgrounds for the six counters of each type are tabulated below.

OBSERVED BACKGROUND FOR TWELVE SCINTILLATION COUNTERS

Alpha Counters: Counter Number	Alpha Counters: Counts per Minute	Gamma Counters: Counter Number	Gamma Counters: Counts per Minute
1	18	7	512
2	1.2	8	459
3	15	9	523
4	3.7	10	335
5	12	11	429
6	12	12	424

REPRODUCIBILITY

The coincidence correction was determined by making 324 ten-minute counts. Nine Co^{60} gamma sources and nine Pu^{239} alpha sources were each counted three times on six different counters. These data were analyzed to see if their variations were statistical, by using a variance ratio (F) test, in the following manner.

For each of the 108 sets of three counts, the three deviates were calculated:

$$t_i = \sqrt{\frac{N}{N-1}} \times \frac{M_i - \overline{M}}{\sqrt{M}} \qquad i = 1,2,3$$

where

$$\overline{M} = \frac{\sum_{i=1}^{3} M_i}{3}$$

M_i = ith count in the set

N = number of counts in each set (in this case N = 3).

From these deviates, the variance was calculated:

$$S^2 = F = \frac{\sum_{i=1}^{324} t_i^{\,2}}{324}$$

For these data, F = 1.17, which is to be compared with the value of 1.21 listed in a standard F table[3][4] for the one-per cent confidence limit. The low value of F indicates that the observed variations could be statistical in nature.

In another test of the same data, the relation [3],

$$\sigma = \sqrt{\frac{N}{N-1}} \times \frac{1.645}{\sqrt{M}}$$

was used to calculate the expected deviation from the average at the 90-per cent confidence level. $\overline{M}$ is the average number of counts per observation, and N is the number of observations. Of the 324 counts that were included in this series, 317 (98%) were within the deviation, σ .

In another series of counts a single Co^{60} source was counted ninety-four times on the same counter. Included were one 1000-minute count, three 100-minute counts, thirty 10-minute counts, thirty 3-minute counts, and thirty 1-minute counts. These data were statistically analyzed with the χ^2 test[5]. The results of this analysis are listed in the following table:

VALUES OF χ^2 CALCULATED FROM THIRTY OBSERVATIONS

Length of Count (minutes)	χ^2
1	42.8
3	22.0
10	22.8

For a purely statistical variation, χ^2 should be less than 39.1 for thirty observations(5) with a confidence limit of 0.9. Hence the variation of replicate one-minute counts is greater than would be expected from statistics. The variation of replicate three-minute and ten-minute counts is within that to be expected from statistics.

The decrease in the observed counting rate with increasing time of count, noted elsewhere(1)(2), is shown by this series of counts to a much lesser degree. Timing errors, characteristic of the first Tracerlab CC-10 scalers, have been corrected in later models. One of these later models was used in collecting these data.

In a similar series of counts, a Pu^{239} alpha source was counted ninety-three times. Included were one 1000-minute count, two 100-minute counts, thirty 10-minute counts, thirty 3-minute counts, and thirty 1-minute counts. The data from the one-minute and three-minute counts were statistically analyzed by the χ^2 test, with the following results:

VALUES OF χ^2 CALCULATED FROM THIRTY OBSERVATIONS

Length of Count (minutes)	χ^2
1	33.4
3	30.4

The variation of replicate one-minute and three-minute counts is, therefore, within that to be expected from statistics. The data from the ten-minute counts were not statistically analyzed. Visual inspection of the data indicated that the counter was not working properly. The counting rate of the source decreased with time. This effect was not due to radioactive decay or loss of activity, and must be attributed to the counter.

To investigate this decrease in counting rate with time more thoroughly, a long series of counts was made. Included were one 5400-minute count, six 1000-minute counts, six 100-minute counts, and one hundred twenty 10-minute counts. Results are summarized in Figure 5. The counting rate decreased at the beginning of the series, but appeared to increase again at the end of the series. During this series, the counter was running almost continuously for eleven days. The 5400-minute count was taken over a week end and the 1000-minute counts were overnight counts.

Two values in this series were rejected. Their deviation from the average exceeded Chauvenet's criteria for the rejection of suspected observations[5].

These data were statistically analyzed in two ways. First a value of $\chi^2 = 285$ was calculated for the 118 ten-minute counts. For purely statistical variations, χ^2 should be less than 140 for 118 observations[5] with a confidence limit of 0.9. The high value of χ^2 merely re-emphasized the drift in counting rate apparent from Figure 5. These data were then broken up into ten groups of ten 10-minute counts and two groups of nine 10-minute counts, the latter corresponding to the two rejected counts. A variance ratio (F) test was applied to these twelve sets of data, and a value F = 1.23 calculated. This is to be compared with the value F = 1.38 listed in a standard F table for the one-per cent confidence limit[4][5]. The low value of F indicates that the drift in counting rate is slow enough that the statistics of a group of ten replicate ten-minute counts are not greatly affected.

The data collected to calculate the coincidence correction were also used to determine the agreement among various counters. Nine Pu^{239} alpha sources and nine Co^{60} gamma sources were each counted on six counters. The correct counting rate was taken as the average of three ten-minute counts.

The maximum variation in counting rate among the six alpha counters for any single source was 2.3 per cent. In a separate experiment, six different phosphors were used with the same counter and alpha source. The counting rate among the six phosphors differed by a maximum of 2.2 per cent. Therefore, the counting rate of a source measured with one alpha scintillation counter may differ as much as five per cent from the counting rate measured with another alpha scintillation counter.

The maximum variation in the counting rate among the six gamma counters for any single source was six per cent. In another separate experiment, nine different phosphors were used with the same counter and gamma source. The counting rate among the nine phosphors differed by as much as ten per cent. In general, therefore, agreement of better than five per cent among counters can not be expected, and differences of more than fifteen per cent are possible.

COINCIDENCE CORRECTION

The method of paired sources[6] was used to determine the coincidence correction. A relationship between the observed counting rate "R" and the true counting rate "N" is:

$$N = R + \tau R^2 + \nu R^3$$

Three "paired" sources were counted, and the values of τ and ν which best fit the experimental data were determined by a method of least squares.

The values appropriate for each counter are summarized below:

ALPHA COUNTERS

Counter Number	$\tau \times 10^8$	$\nu \times 10^{14}$
7	10.504	0.525
8	5.585	8.738
9	10.515	4.290
10	9.626	2.982
11	6.396	5.300
12	6.062	8.280
Average of six alpha counters	8.115	5.019

GAMMA COUNTERS

Counter Number	$\tau \times 10^8$	$\nu \times 10^{14}$
1	1.046	13.073
2	1.467	10.443
3	6.467	9.245
4	5.528	2.781
5	7.086	0.243
6	5.372	0.733
Average of six gamma counters	4.554	6.086
Average of twelve counters	6.335	5.553

A comparison was then made between each of the twelve specific equations calculated for the twelve counters, and the general equation calculated from the average of the data from the twelve counters. It was assumed that the "true" counting rate was the observed counting rate corrected by the specific equation for the particular counter. Calculations were then made to determine the error introduced in the "true" counting rate, for each of the twelve counters, when the observed counting rate was corrected by using the general equation. Figure 6 is a plot of this error versus counting rate. At counting rates up to 2 x 10^5 counts per minute, the maximum error introduced by using the general equation is less than one per cent.

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Instrument Development Division

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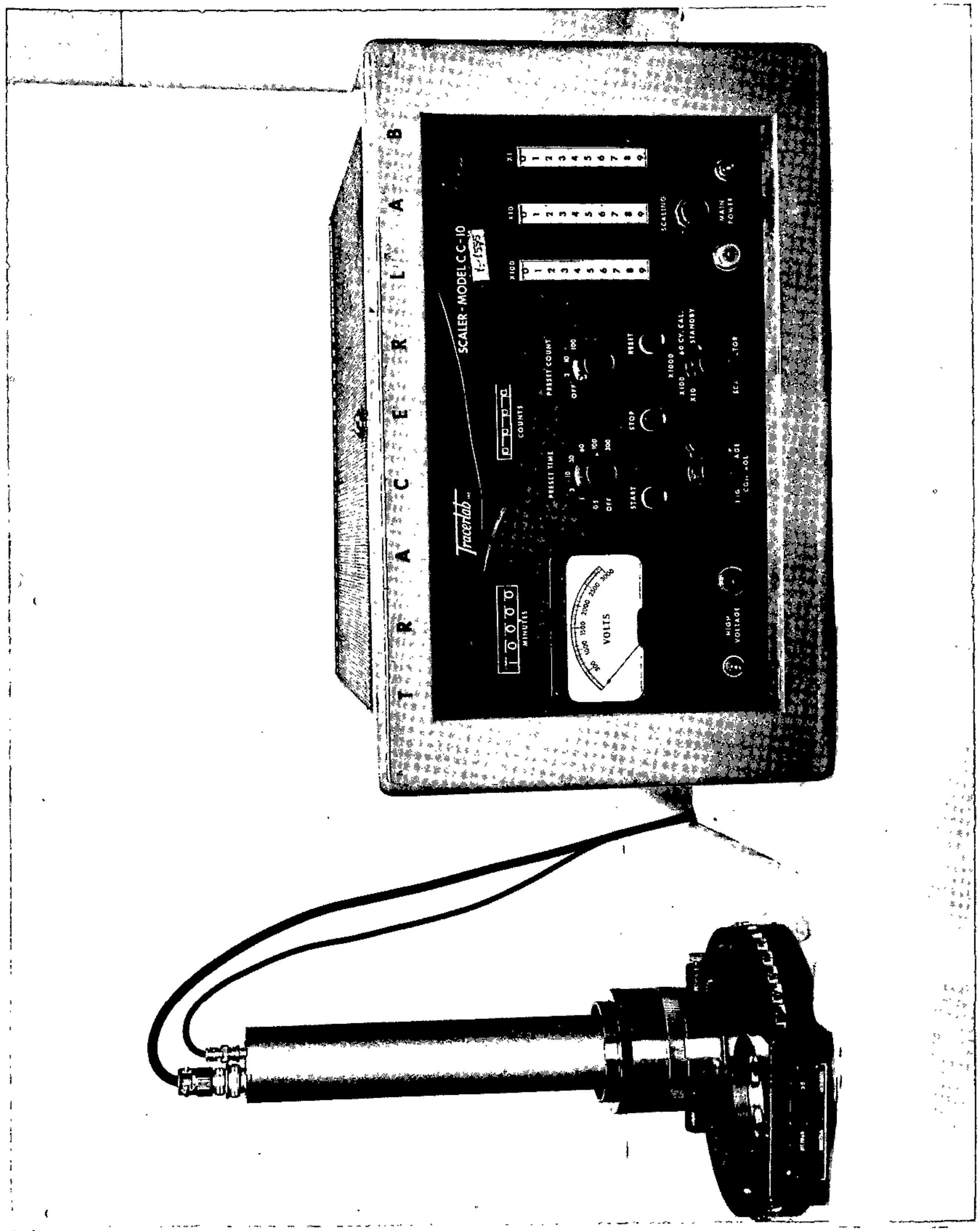
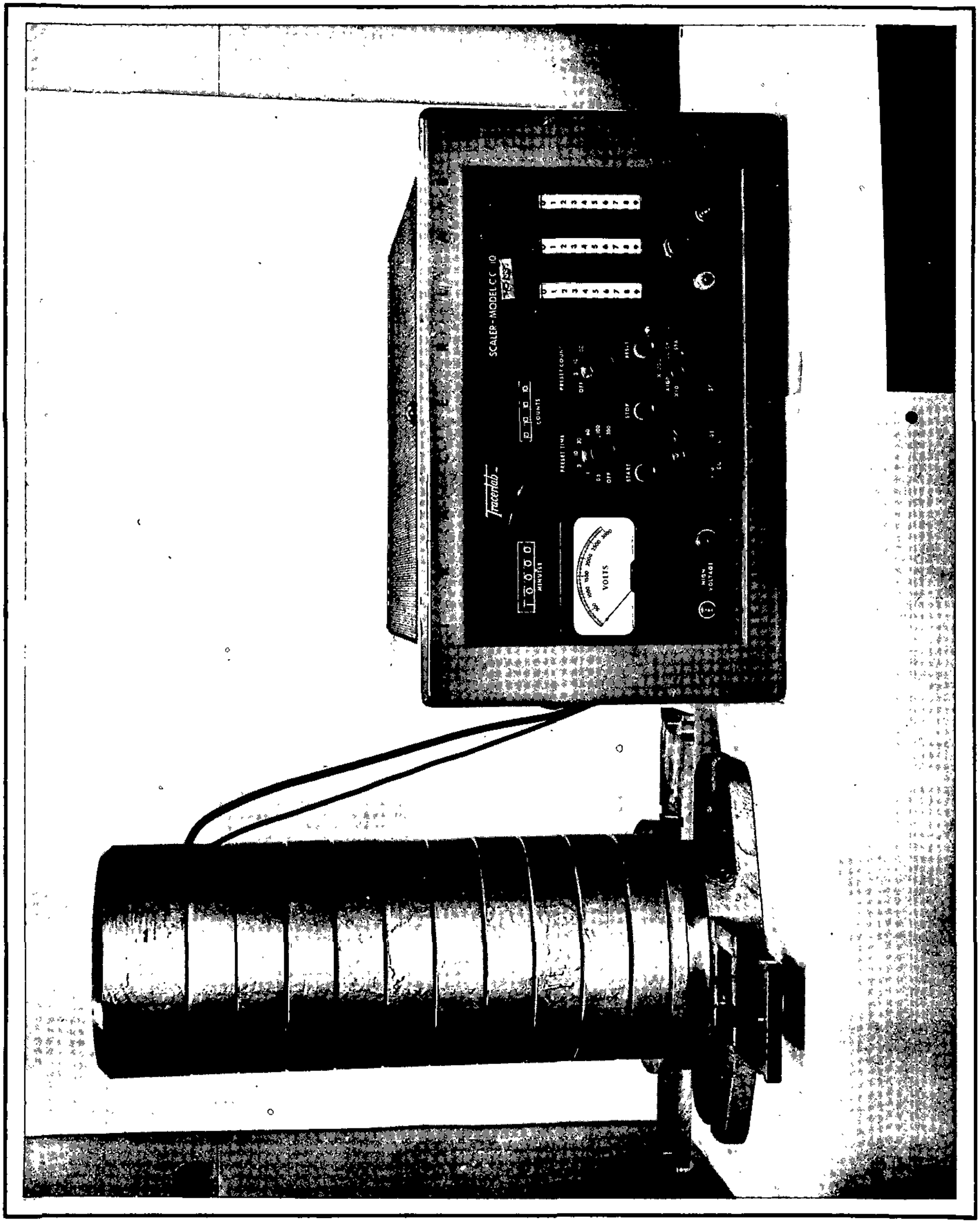
FIGURE 1



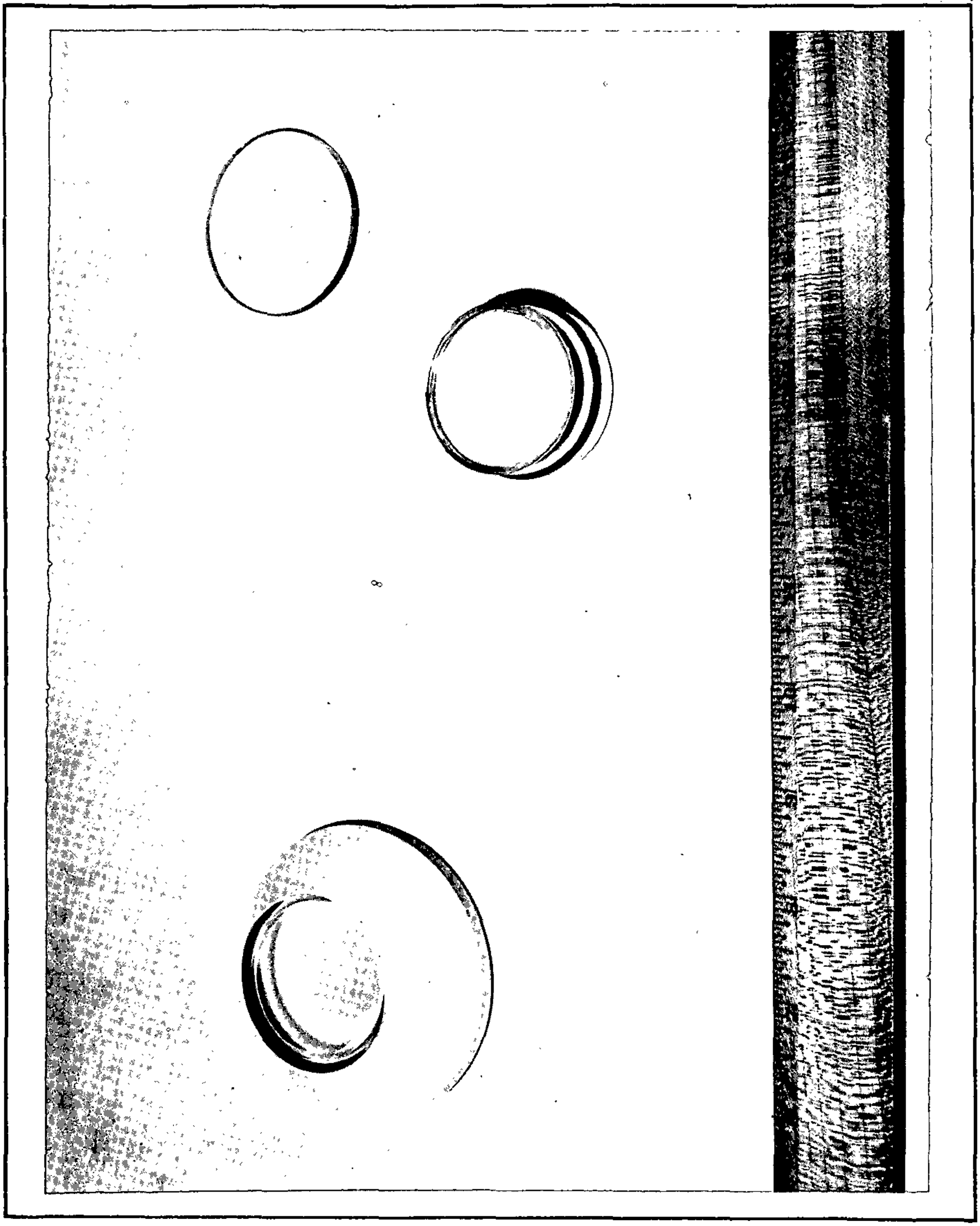
PHOTOGRAPH OF THE ALPHA SCINTILLATION COUNTER

FIGURE 2



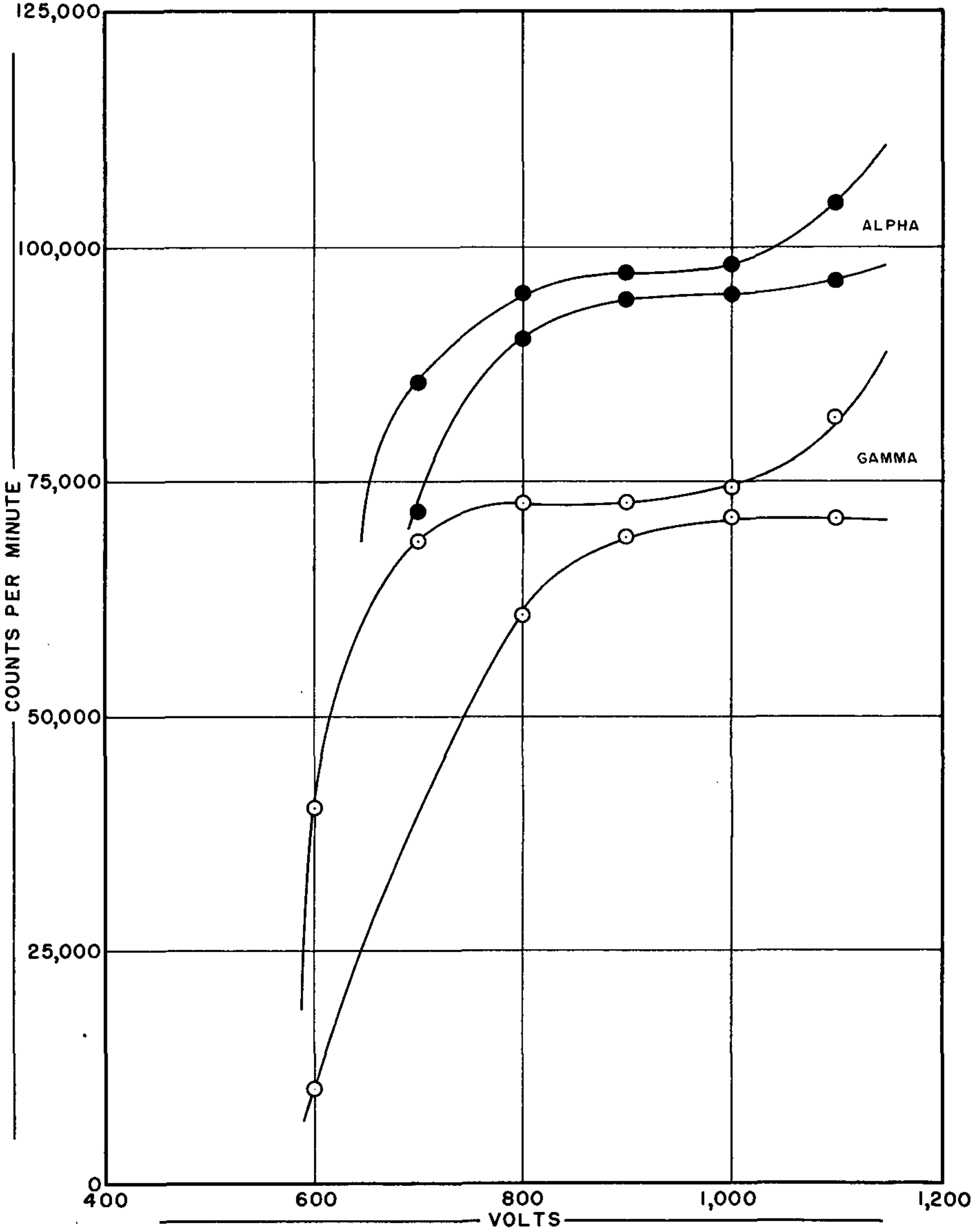
PHOTOGRAPH OF THE GAMMA SCINTILLATION COUNTER

FIGURE 3



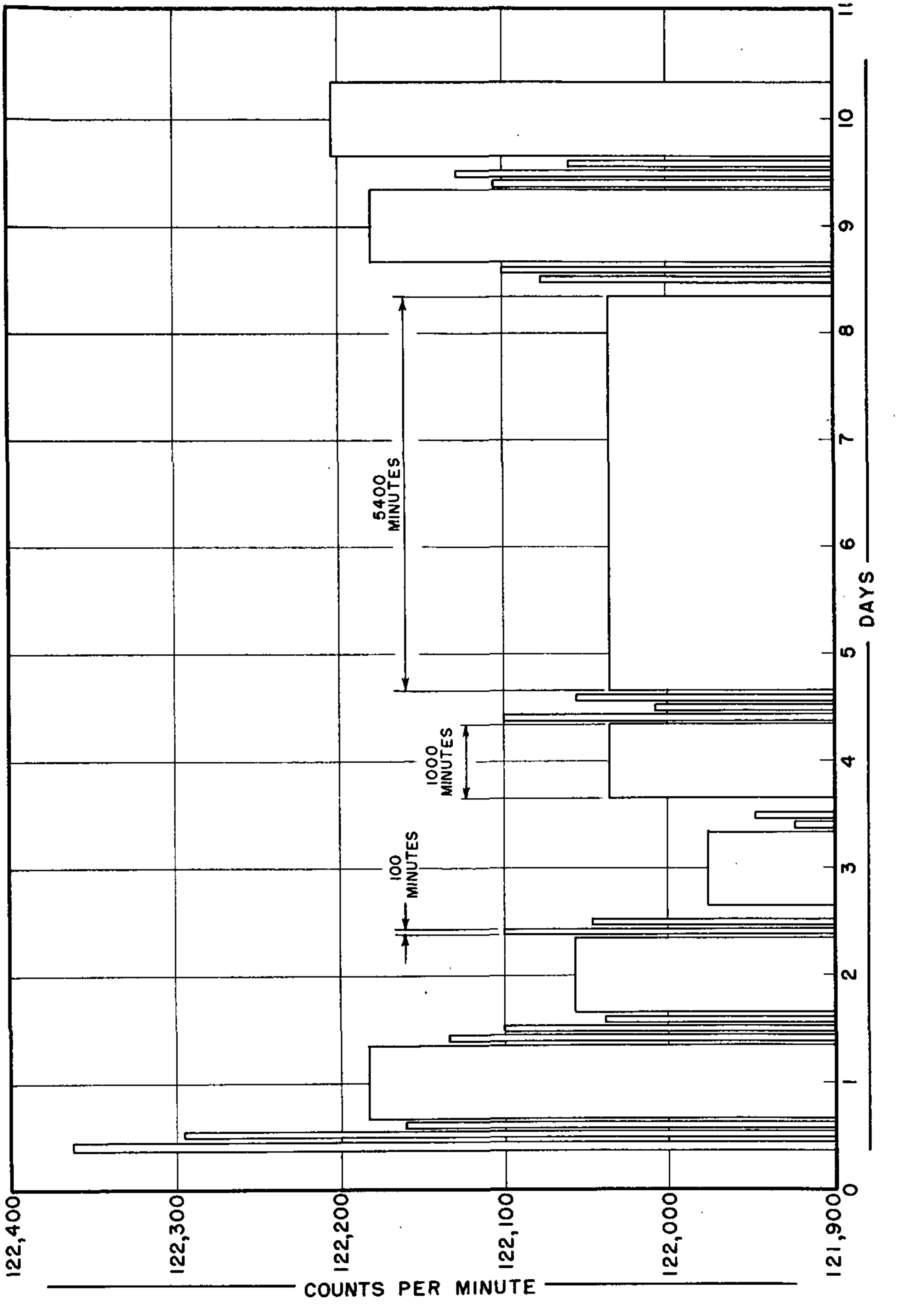
PHOSPHORS USED IN THE ALPHA AND GAMMA SCINTILLATION COUNTERS

FIGURE 4



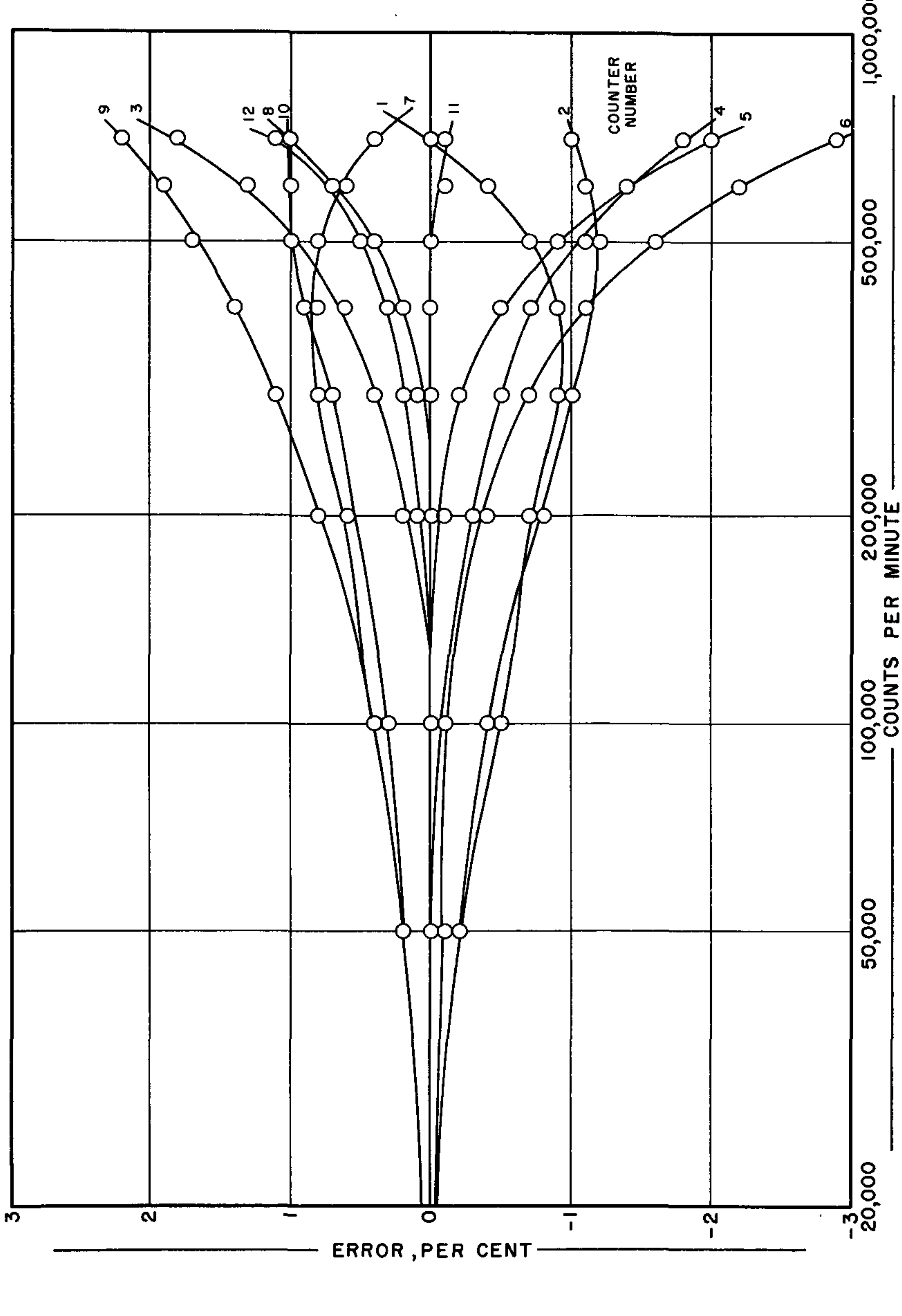
SCINTILLATION COUNTER PLATEAUS

FIGURE 5



PLOT OF COUNTING RATES VERSUS TIME SHOWING DRIFT

FIGURE 6



ERROR INTRODUCED BY USING "TABLE OF COINCIDENCE CORRECTIONS" TO CORRECT OBSERVED COUNT RATE

APPENDIX

The attached table shows coincidence corrections versus observed counting rate for both the alpha and gamma scintillation counters. The equation:

$$N = R + 6.335\ (10^{-8})R^2 + 5.553\ (10^{-14})\ R^3$$

was used to calculate these corrections. R is the observed counting rate, and N is the "true" counting rate. The table lists the correction to be added to the observed counting rate, in counts per minute, to obtain the "true" counting rate. Values for the observed counting rates between 10,000 and 500,000 counts per minute are listed in units of 1000 counts per minute. Interpolation in the table is not necessary since a maximum error of 0.01 per cent is introduced by reading the coincidence correction to the nearest thousand observed counts per minute. The vertical column of numbers at the left-hand edge gives the observed counting rate in units of 10,000 counts per minute. Intermediate values in units of 1000 counts per minute run across the top of the table. The following example illustrates the use of the table:

Observed counting rate (R)	157,203 c/m
Counting rate to nearest thousand	157,000 c/m
Coincidence correction (from table)	1,776 c/m
"True" counting rate (N)	158,979 c/m

	0000	1000	2000	3000	4000	5000	6000	7000	8000	9000	
1	6	8	9	11	13	14	16	19	21	23	1
2	26	28	31	34	37	40	44	47	51	55	2
3	59	63	67	71	75	80	85	90	95	100	3
4	105	110	116	122	127	133	139	146	152	159	4
5	165	172	179	186	193	201	208	216	224	232	5
6	240	248	257	265	274	283	292	301	310	320	6
7	329	339	349	359	369	380	390	401	412	423	7
8	434	445	457	468	480	492	504	516	528	541	8
9	554	566	579	593	606	619	633	647	661	675	9
10	689	703	718	733	748	763	778	793	809	825	10
11	840	856	873	889	906	922	939	956	973	991	11
12	1008	1026	1044	1062	1080	1098	1117	1136	1154	1173	12
13	1193	1212	1232	1251	1271	1291	1311	1332	1352	1373	13
14	1394	1415	1436	1458	1479	1501	1523	1545	1568	1590	14
15	1613	1636	1659	1682	1705	1729	1753	1776	1800	1825	15
16	1849	1874	1899	1924	1949	1974	2000	2025	2051	2077	16
17	2104	2130	2157	2184	2211	2238	2265	2293	2320	2348	17
18	2376	2405	2433	2462	2491	2520	2549	2578	2608	2638	18
19	2668	2698	2728	2759	2790	2821	2852	2883	2915	2946	19
20	2978	3010	3043	3075	3108	3141	3174	3207	3240	3274	20
21	3308	3342	3376	3411	3445	3480	3515	3551	3586	3622	21
22	3657	3693	3730	3766	3803	3840	3877	3914	3951	3989	22
23	4027	4065	4103	4142	4180	4219	4258	4298	4337	4377	23
24	4417	4457	4497	4538	4578	4619	4660	4702	4743	4785	24
25	4827	4869	4912	4954	4997	5040	5083	5127	5170	5214	25
	0000	1000	2000	3000	4000	5000	6000	7000	8000	9000	

TABLE OF COINCIDENCE CORRECTIONS FOR ALPHA AND GAMMA SCINTILLATION COUNTERS

	0000	1000	2000	3000	4000	5000	6000	7000	8000	9000	
26	5258	5303	5347	5392	5437	5482	5528	5573	5619	5665	26
27	5711	5758	5804	5851	5898	5946	5993	6041	6089	6137	27
28	6186	6234	6283	6332	6382	6431	6481	6531	6581	6631	28
29	6682	6733	6784	6835	6887	6939	6991	7043	7095	7148	29
30	7201	7254	7307	7361	7415	7469	7523	7577	7632	7687	30
31	7742	7798	7853	7909	7965	8022	8078	8135	8192	8249	31
32	8307	8364	8422	8481	8539	8598	8656	8716	8775	8835	32
33	8894	8954	9015	9075	9136	9197	9258	9320	9382	9444	33
34	9506	9568	9631	9694	9757	9820	9884	9948	10012	10077	34
35	10141	10206	10271	10336	10402	10468	10534	10600	10667	10734	35
36	10801	10868	10936	11004	11072	11140	11209	11277	11347	11416	36
37	11485	11555	11625	11696	11766	11837	11908	11979	12051	12123	37
38	12195	12267	12340	12413	12486	12559	12633	12706	12781	12855	38
39	12930	13004	13080	13155	13231	13306	13383	13459	13536	13613	39
40	13690	13767	13845	13923	14001	14080	14159	14238	14317	14396	40
41	14476	14556	14637	14717	14798	14879	14961	15042	15124	15207	41
42	15289	15372	15455	15538	15622	15705	15789	15874	15958	16043	42
43	16128	16214	16300	16386	16472	16558	16645	16732	16819	16907	43
44	16995	17083	17171	17260	17349	17438	17528	17618	17708	17798	44
45	17889	17979	18071	18162	18254	18346	18438	18531	18623	18717	45
46	18810	18903	18998	19092	19186	19281	19376	19472	19567	19663	46
47	19759	19856	19953	20050	20147	20245	20343	20441	20539	20638	47
48	20737	20836	20936	21036	21136	21237	21337	21438	21540	21641	48
49	21743	21846	21948	22051	22154	22257	22361	22465	22569	22674	49
50	22779										
	0000	1000	2000	3000	4000	5000	6000	7000	8000	9000	

TABLE OF COINCIDENCE CORRECTIONS FOR ALPHA AND GAMMA SCINTILLATION COUNTERS (Continued)