DP-61
Instrumentation

THE SRP STANDARD GEIGER-MUELLER COUNTER

by

C. A. Prohaska
Instrument Development Division

May 1954

E. I. du Pont de Nemours & Co.
Explosives Department — Atomic Energy Division
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Contract AT(07-2)-1 with the
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DP-61 THE SRP STANDARD
GEIGER-MUELLER COUNTER

The attached report is the first of a series which is being prepared on the various standard SRP counting room set-ups.

The G-M counter described here is defined as set #201 in the "Catalog of Counting Room Instruments and Equipment" which is also written and maintained by C. A. Prohaska (773-A/LD 108, Ext. 3445).

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ABSTRACT

The operating characteristics of the SRP standard GM counter were investigated. Plateaus are at least 150 volts long, with essentially zero slope. Reproducibility and background are satisfactory for this type of counter. The coincidence correction is less than one-half per cent per 10^3 counts per minute.

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THE SRP STANDARD GM COUNTER

INTRODUCTION

This investigation was part of a program to determine the characteristics and limitations of the various types of counting equipment to be used at the Savannah River Plant.

Performance of the Geiger-Mueller counter (consisting of a Tracerlab CC-10 scaler, a Tracerlab TGC-1 or TGC-2 GM tube, and a Technical Associates LS-6 lead shield) is described in the present report. GM counters are generally useful in detecting beta and/or gamma radiation.

SUMMARY AND CONCLUSIONS

Within the limitations discussed below, the GM counter was found satisfactory for general use at the Savannah River Plant for counting rates up to 10^4 counts per minute. It may be used at higher counting rates, but possible errors in reproducibility, after coincidence correction, become appreciable (greater than 2%).

Counting rates with different counters frequently vary by ± 10%. The effects of aging must be corrected by frequent checks with standard sources. The conclusions are based on the following test results.

PLATEAUS

Plateaus on satisfactory GM tubes are at least 150 volts long, with practically zero slope over this region. Plateaus begin about 100 volts above threshold, but threshold voltage varies from tube to tube as much as 200 volts. Threshold and plateau gradually shift to higher voltages as the tube ages.

BACKGROUND

Background varies depending upon the level of radioactivity in the vicinity of the GM counter. The natural background to be expected is about 20-25 counts per minute. This may rise to 40-50 counts per minute if hard gamma sources (Co^{60} for example) are brought near the shield.

REPRODUCIBILITY

With a single counter, the variation of replicate counts was somewhat greater than would be expected from statistics. The additional variability was found to beccharacteristic of the GM counter.

The maximum range of counting rates for any single source as measured on six counters was 23%. The range was generally in the neighborhood of 20% at counting rates between 6,000 and 57,000 counts per minute.

COINCIDENCE CORRECTION

The coincidence correction can be calculated from the following equation:

$$N = R + 2.211\ (10^{-6})R^2 + 2.505\ (10^{-11})R^3$$

Where N = corrected counting rate
R = observed counting rate

For $R = 5 \times 10^4$ counts per minute, the expected error in N is less than 10 per cent. A table of coincidence corrections for counting rates up to 50,000 counts per minute is included in the Appendix to this report.

EXPERIMENTAL WORK

The Geiger-Mueller counter consists of the following major components:

1 - scaler (Tracerlab Type CC-10)
1 - lead shield (Technical Associates Type LS-6)
1 - GM tube (Tracerlab Type TGC-1 or TGC-2)

Figure 1 is a photograph of the complete GM counter

PLATEAUS

The plateau of the GM tube used in the standard GM counter should have (manufacturer's specifications) a plateau at least 300 volts long with a slope of approximately one per cent per hundred volts. A plateau (plotted by the manufacturer) is supplied with each GM tube. These plateaus are determined with a Co^{60} source giving 10,000 - 15,000 counts per minute at a scaler sensitivity of 0.35 volts[1]. The two types of tubes, TGC-1 and TGC-2, have very similar plateaus and differ only in window thickness. The counters tested included both types.

The present investigation indicates that if the above conditions are duplicated, the manufacturer's plateaus can be checked quite closely. It is important, however, that the counting rate be held below 15,000 counts per minute. Reliable plateaus were not obtained with sources that gave high counting rates. Figure 2 indicates what happens at higher counting rates. The four plateaus shown were determined with the same counter and source, only the geometry being changed. The lowest plateau (slope $\cong$ 0%) was determined with the source on shelf 5 of the sample holder, while the highest plateau (slope $\cong$ 11%) was determined with the source on shelf 1 (the top shelf). Figure 2 shows how the plateau is distorted at higher counting rates.

The lower end of the plateau lies about 100-150 volts above the threshold voltage. The threshold voltage varies from tube to tube, but was between 1100 and 1300 volts for all of the new tubes that were tested. A typical series of plateaus is presented in the following table:

Collection Anode Voltage	Counts per Minute on Each of Five Different GM Tubes				
1500	15,227	13,661	14,789	13,421	14,388
1450	15,001	13,579	14,495	13,435	14,150
1400	15,089	13,475	14,462	13,304	13,997
1350	15,094	12,951	14,143	13,073	13,966
1300	14,919	11,173	13,348	12,777	13,641
1250	14,798	0	0	12,522	11,500
1200	13,648			10,380	0
1150	0			0	

As the GM tube ages, the threshold voltage, as well as the operating voltage, rises. A GM counter was started counting continuously, at a rate of about 13,800 counts per minute (approximately 2×10^7 counts per day). A plateau was run each day. The observed rise of threshold voltage is plotted in Figure 3.

BACKGROUND

The natural background for the standard GM counter lay between 20-25 counts per minute for all counters tested. The background is very sensitive to outside sources of radiation.

The background of a counter increased from 24 counts per minute to 43 counts per minute when a Co^{60} source was placed on the bench outside the shield. The strength of this source was 13,800 counts per minute on shelf 5. The background of the same counter increased from 24 counts per minute to 27

counts per minute when an ordinary wrist watch with a luminous dial was taped to the outside of the shield.

REPRODUCIBILITY

Variations With a Single Counter In collecting the data for calculating the coincidence correction, nine Co^{60} sources were each counted three times (10-minute counts) with six different counters. The variation of the three counts from the average of the three was considerably higher than would be expected from statistics. The two relations:

$$\sigma_1 = \sqrt{\frac{N-1}{N}} \cdot \frac{1.65}{\sqrt{M}} \qquad \sigma_2 = \sqrt{\frac{N-1}{N}} \cdot \frac{1.96}{\sqrt{M}}$$

were used to calculate the expected deviations from the average at the 90% and 95% confidence levels, where M is the average number of counts per observation, and N is the number of observations. Of the 162 counts made, only 129 (80%) were within the deviation σ_1 and 139 (86%) were within the deviation σ_2.

This complete series of counts is shown in Table 1. The values which lie outside the expected deviation at the 90% confidence level are starred. It will be noticed that more values outside the expected deviation were obtained with counter no. 5 than with any other counter. If we omit the results obtained on counter no. 5 completely, the figures at the 90% and 95% confidence levels become 83% and 90%.

A more complete statistical analysis of these data was made using a variance ratio (F) test. This was done in the following manner:

For each of the 54 sets of three counts, the three deviates were calculated:

$$t_i = \sqrt{\frac{3}{2}} \quad \frac{M_i - \bar{M}}{\sqrt{\bar{M}}} \qquad i = 1,2,3$$

where

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

From these deviates, the variance was calculated:

$$S^2 = F = \frac{\sum_{i=1}^{162} t_i^2}{162}$$

For the data in Table I, F = 3.3, which is to be compared with the value of 1.3 listed in a standard F table[2] for the 1% confidence limit.

The high value of F indicates a very low probability (much less than 1%) that the observed variations could be statistical in nature.

In another series of counts, a single source was counted seventy-six times on the same counter. Included were one 100-minute count, fifteen 10-minute counts, thirty 3-minute counts, and thirty 1-minute counts. The results of these counts are given in Table II. Again, the starred values are those which lie outside the expected deviation at the 90% confidence level.

The observed variation in counting rate was as follows:

	Maximum
10-minute counts (15)	+0.38% -0.65%
3-minute counts (30)	+0.96% -0.88%
1-minute counts (30)	+2.1% -1.6%

The expected statistical variations at this counting rate (13,500 counts per minute) for 90% confidence (σ_1) are:

10-minute count	±0.44%
3-minute count	±0.83%
1-minute count	±1.44%

Again, less than 90% of the counts were within the expected deviation. These data were also analyzed by means of the variance ratio (F) test, but the results of this analysis were inconclusive, perhaps because fewer data were available. The decrease in counting rate with increasing time of count, noted elsewhere[3], is apparent from the data in Table II.

It was concluded that counting rates measured with the standard GM counter are subject to greater variability than would be expected from statistical considerations.

Variation Among Several Counters Nine sources were counted on six counters having completely different components. The results are presented in Table III. Each count rate is the average of three 10-minute counts. Also listed is the count rate of each source averaged over the six counters. The maximum positive and negative deviations from the average are included. In general, agreement of better than 10% among counters cannot be expected.

COINCIDENCE CORRECTION

The method of paired sources[4] was used to determine the coincidence correction. A relationship between the observed counting rate "R" and the true counting rate "N" is:

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

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

The experimental data are given in Table IV. Each counting rate is the average of three 10-minute counts. The first two numbers are the individual counting rates of each one of a pair, and the third number is the combined counting rate. These data were then used to solve for τ and υ. The values appropriate for each counter are summarized below:

Counter	$\tau \times 10^6$	$\upsilon \times 10^{11}$
1	1.622	0.293
2	3.373	2.769
3	2.550	0.922
4	0.245	6.836
5	1.583	3.783
6	3.892	0.427
Average of the six counters	2.211	2.505

A comparison was then made between each of the six specific equations calculated for the six counters, and the general equation calculated from the average of the data from the six 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 six counters, when the observed counting rate was corrected by using the general equation. Figure 4 is a plot of this error versus counting

rate. The maximum error is appreciable, approaching 10% of the "true" counting rate at 50,000 counts per minute.

A table of coincidence corrections for counting rates up to 50,000 counts per minute is included in the Appendix. This table was calculated from the general equation determined for the six counters, and should be used with the knowledge that even at moderate counting rates (i.e., 20,000 counts per minute) the corrected value may be in error by several per cent.

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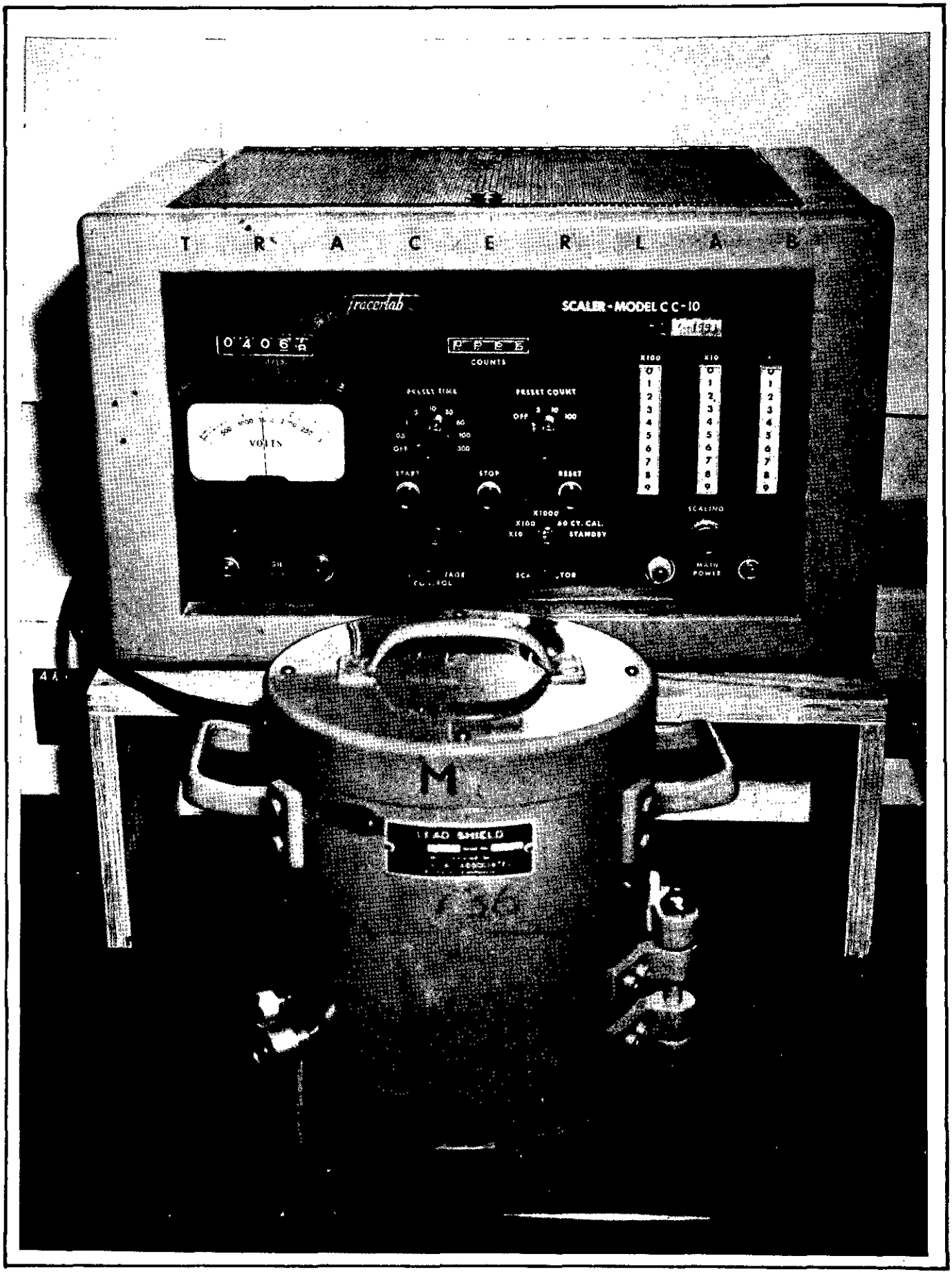
4. Kohman, T. P. A General Method for Determining Coincidence Corrections of Counting Instruments. United States Atomic Energy Commission MDDC-905, June 13, 1945.



PHOTOGRAPH OF THE STANDARD GM COUNTER

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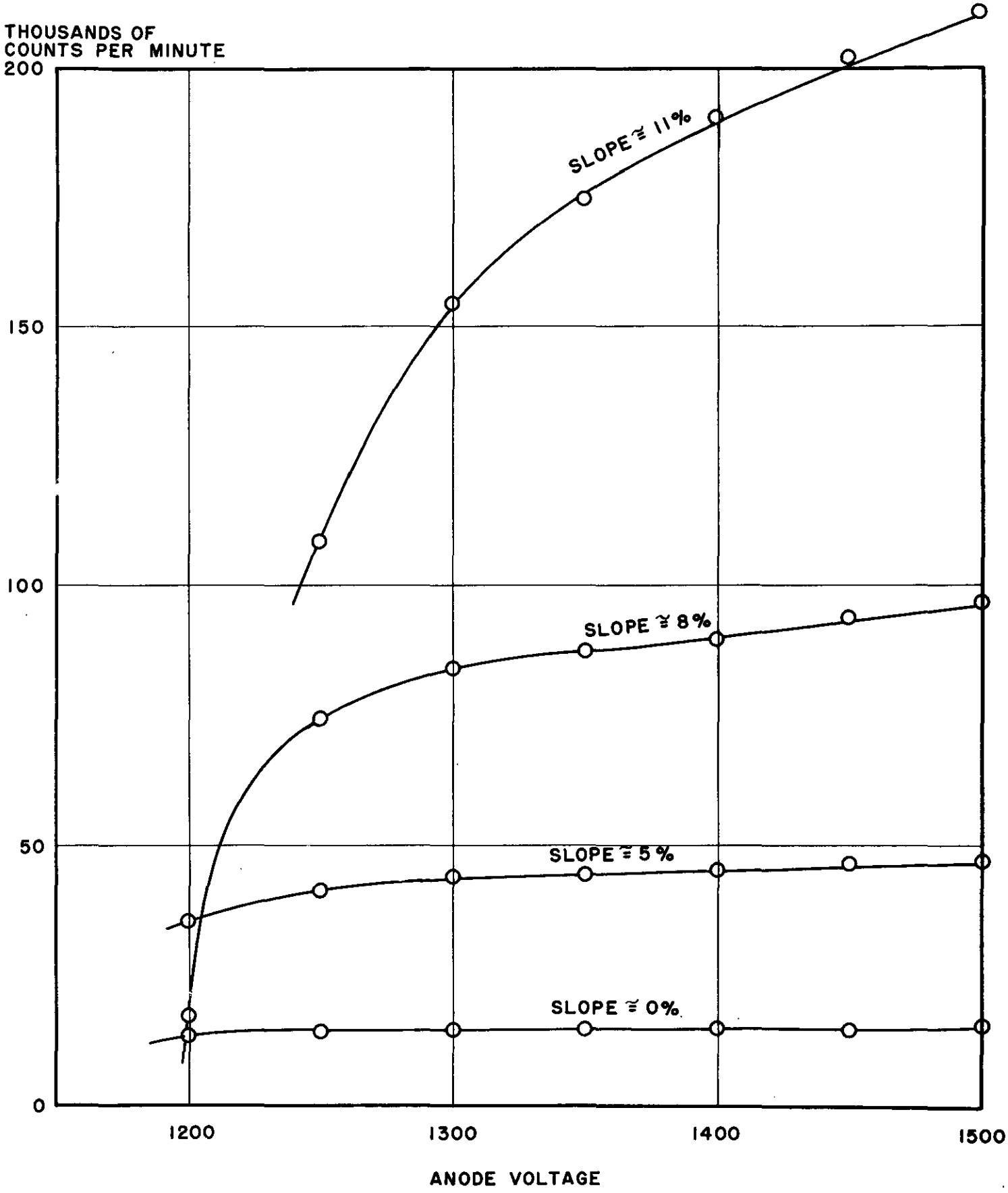
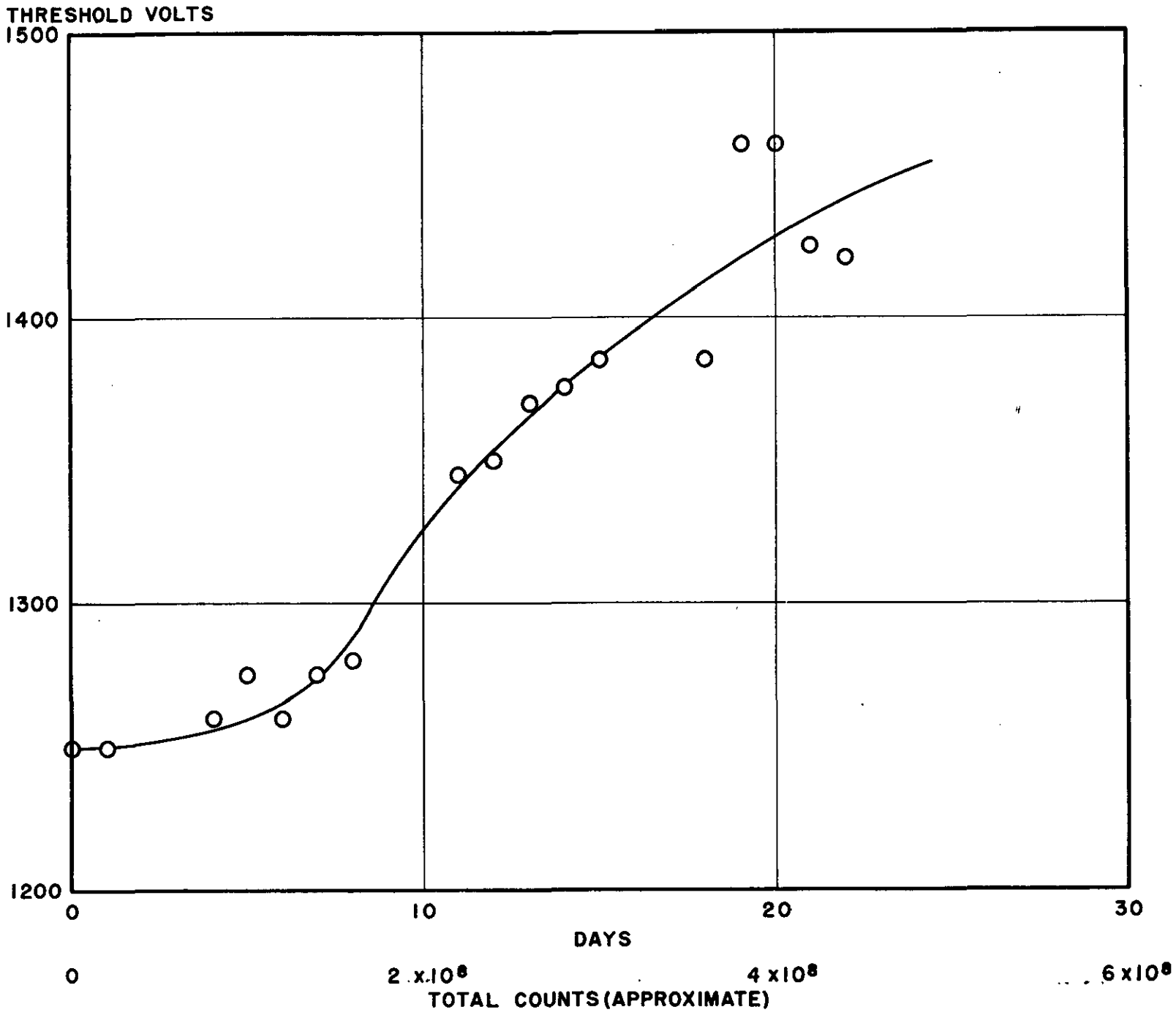
Figure 2

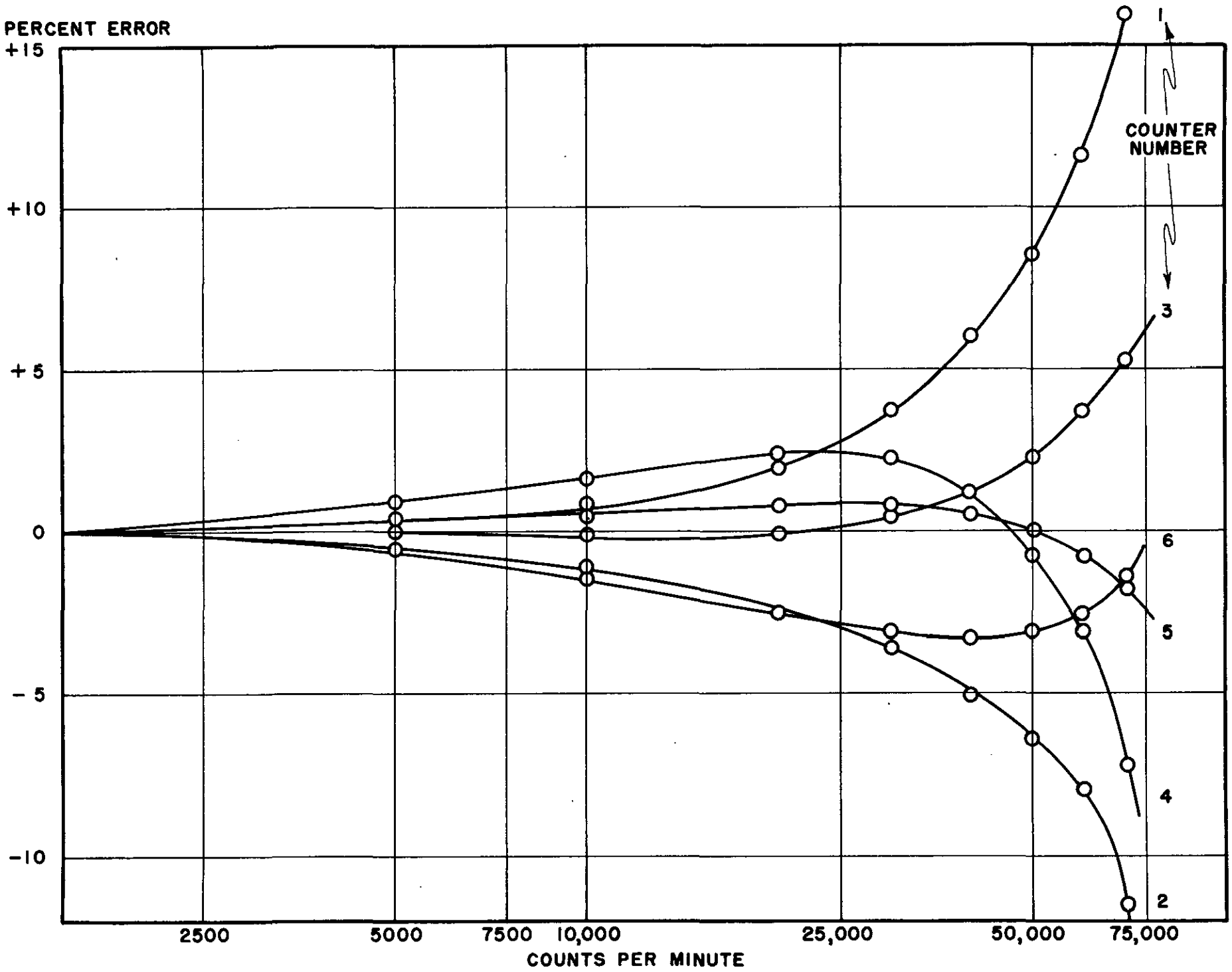


GM TUBE PLATEAUS AT VARIOUS COUNTING RATES



RISE OF THRESHOLD VOLTAGE WITH GM TUBE AGE

Figure 3



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

Figure 4

Table I

VARIATION IN COUNTING RATE WITH VARIOUS SOURCES
(TEN MINUTE COUNTS)

Counter Number	Three Observed Values of Counting Rate (counts per minute)			Average Value of Counting Rate
1	7077	7089	7085	7083
	5543	5525	5510	5526
	12427	12457	12401	12428
	14717	14633	14665	14671
	15194	15194	15229	15205
	29181	29219	29145	29181
	31999	31936	31895	31943
	29018*	28904	28817*	28913
	58009	58087*	57794*	57963
2	8673*	8450*	8517	8547
	6692	6729	6676	6699
	14648	14581	14652	14627
	16763	16781	16715	16753
	17578	17587	17512	17559
	32378	32482*	32324	32395
	34500	34475	34428	34468
	32367*	32323	32170*	32287
	58865	58879	58775	58840
3	8379	8296	8329	8335
	6366	6367	6346	6360
	14217	14227	14226	14223
	16989*	16860*	16909	16919
	17568	17593	17591	17584
	33313*	33193	33132	33213
	35999	35899	35923	35940
	32270	32267	32300	32279
	62416*	62637	62541	62531
4	7271	7302	7332	7302
	5873	5850	5839	5854
	13059	13059	13010	13043
	15444	15453	15428	15442
	15919*	16013	16034	15989
	29942	29922	29869	29911
	32584*	32410*	32479	32491
	30233*	30356	30398	30329
	55348	55246	55219	55271

TABLE I (Continued)

Counter Number	Three Observed Values of Counting Rate (counts per minute)			Average Value of Counting Rate
5	6824	6796	6810	6810
	5285	5297	5268	5283
	12038	11999	11952	11996
	14064	14045	14026	14045
	14332	14290	14226*	14282
	27166*	27114	26942*	27074
	29601*	29496	29413*	29504
	26864*	27511*	27618*	27331
	51494*	51468*	52169*	51710
6	7576*	7651	7731*	7653
	6189	6197	6205	6197
	13615	13597	13561	13591
	15778*	15850	15933*	15854
	16786	16783	16751	16774
	30764	30709	30650	30708
	32993	33001	33110	33035
	31537	31540	31470	31516
	58781	58772	58614*	58723

TABLE II

VARIATION IN THE COUNTING RATE WITH A SINGLE SOURCE

Counts per 100 minutes	Counts per 10 minutes	Counts per 3 minutes	Counts per 1 minute
1352163	134821	40751	13590
	135176	40584	13727
	135306	40792	13656
	134532*	40724	13733
	135553	40601	13950*
	134852	41027*	13929*
	135800	41065*	13498
	135526	40409	13476*
	135929	40572	13789
	135763	40316*	13781
	135681	40887	13825
	135560	40607	13698
	135290	40848	13980*
	135695	40828	13701
	135793	40397	13744
		40745	13608
		40522	13694
		40516	13730
		40769	13761
		40730	13621
		40515	13546
		40690	13518
		40802	13517
		40606	13638
		40447	13686
		40831	13668
		40688	13792
		40666	13559
		40518	13753
		40808	13618
Average 1352163	135418	40675	13693
Average Counts per minute			
13522	13542	13558	13693

Table III

VARIATION OF COUNTING RATE AMONG SEVERAL COUNTERS

Counter Number						Average	Maximum Deviation
1	2	3	4	5	6		
c/m	c/m	c/m	c/m	c/m	c/m	c/m	%
7083	8547	8335	7302	6810	7653	7622	+ 12 - 11
5526	6699	6360	5854	5283	6197	5987	+ 12 - 12
12428	14627	14223	13043	11996	13591	13318	+ 10 - 10
14671	16753	16919	15442	14045	15854	15614	+ 8 - 9
15205	17559	17584	15989	14282	16774	16232	+ 8 - 12
29181	32395	33213	29911	27074	30708	30414	+ 9 - 11
31943	34468	35940	32491	29504	33035	32897	+ 9 - 10
28913	32287	32279	30329	27331	31516	30443	+ 6 - 10
57963	58840	62531	55271	51710	58723	57506	+ 9 - 10

TABLE IV

COUNTING RATE OF PAIRED SOURCES

Counter	Pair 1	Pair 2	Pair 3
1	7083	14671	31943
	5526	15205	28913
	12428	29181	57963
2	8547	16753	34468
	6699	17559	32287
	14627	32395	58840
3	8335	16919	35940
	6360	17584	32279
	14223	33213	62531
4	7302	15442	32491
	5854	15989	30329
	13043	29911	55271
5	6810	14045	29504
	5283	14282	27331
	11996	27074	51710
6	7653	15854	33035
	6197	16774	31516
	13591	30708	58723

APPENDIX

The attached table shows coincidence corrections versus observed counting rate for the standard GM counter. This table lists the correction to be added to the observed counting rate (in counts per minute) to obtain the "true" counting rate. Values for observed counting rates between 0 and 50,000 counts per minute are listed in units of 100 counts per minute. Interpolation is not necessary since an error of less than 0.1% is introduced by reading the coincidence correction to the nearest hundred counts.

The vertical columns of numbers are the observed counting rates in units of 1000. Intermediate values in units of 100 run horizontally. The following example illustrates the use of the table:

Observed counting rate	9,273
Counting rate (to nearest hundred)	9,300
Correction (from table)	210
"True" counting rate	9,483

TABLE OF COINCIDENCE CORRECTIONS FOR COUNTING ROOM SET UP #201
(GM Counter)

	000	100	200	300	400	500	600	700	800	900	
0		0	0	0	0	1	1	1	1	2	0
1	2	3	3	4	4	5	6	6	7	8	1
2	9	10	11	12	13	14	15	16	18	19	2
3	20	22	23	25	26	28	30	31	33	35	3
4	37	39	41	43	45	47	49	51	53	56	4
5	58	60	63	65	68	71	73	76	79	82	5
6	84	87	90	93	97	100	103	106	109	113	6
7	116	120	123	127	130	134	138	142	146	149	7
8	153	157	162	166	170	174	178	183	187	192	8
9	196	201	205	210	215	220	225	230	235	240	9
10	245	250	255	260	266	271	277	282	288	293	10
11	299	305	311	317	323	329	335	341	347	353	11
12	360	366	373	379	386	392	399	406	413	419	12
13	426	433	440	448	455	462	469	477	484	492	13
14	499	507	515	523	530	538	546	554	563	571	14
15	579	587	596	604	613	621	630	639	647	656	15
16	665	674	683	692	702	711	720	730	739	749	16
17	758	768	778	788	797	807	817	828	838	848	17
18	858	869	879	890	900	911	922	933	943	954	18
19	965	977	988	999	1010	1022	1033	1045	1056	1068	19
20	1080	1092	1104	1116	1128	1140	1152	1164	1177	1189	20
21	1202	1214	1227	1240	1252	1265	1278	1291	1305	1318	21
22	1331	1344	1358	1371	1385	1399	1412	1426	1440	1454	22
23	1468	1482	1496	1511	1525	1540	1554	1569	1583	1598	23
24	1613	1628	1643	1658	1673	1689	1704	1719	1735	1750	24
25	1766	1782	1798	1814	1830	1846	1862	1878	1894	1911	25
	000	100	200	300	400	500	600	700	800	900	

Table of Coincidence Corrections for Counting Room Set Up #201
(GM Counter) - Continued.

	000	100	200	300	400	500	600	700	800	900	
26	1927	1944	1960	1977	1994	2011	2028	2045	2062	2079	26
27	2097	2114	2132	2149	2167	2185	2203	2220	2238	2257	27
28	2275	2293	2311	2330	2348	2367	2386	2404	2423	2442	28
29	2461	2480	2500	2519	2538	2558	2577	2597	2617	2637	29
30	2657	2677	2697	2717	2737	2758	2778	2799	2819	2840	30
31	2861	2882	2903	2924	2945	2967	2988	3009	3031	3053	31
32	3074	3096	3118	3140	3162	3185	3207	3229	3252	3274	32
33	3297	3320	3343	3366	3389	3412	3435	3458	3482	3505	33
34	3529	3553	3577	3601	3625	3649	3673	3697	3722	3746	34
35	3771	3795	3820	3845	3870	3895	3920	3945	3971	3996	35
36	4022	4048	4073	4099	4125	4151	4177	4204	4230	4256	36
37	4283	4310	4336	4363	4390	4417	4444	4472	4499	4526	37
38	4554	4582	4609	4637	4665	4693	4722	4750	4778	4807	38
39	4835	4864	4893	4922	4951	4980	5009	5038	5068	5097	39
40	5127	5156	5186	5216	5246	5276	5307	5337	5367	5398	40
41	5429	5459	5490	5521	5552	5584	5615	5646	5678	5709	41
42	5741	5773	5805	5837	5869	5902	5934	5966	5999	6032	42
43	6065	6097	6130	6164	6197	6230	6264	6297	6331	6365	43
44	6399	6433	6467	6501	6535	6570	6605	6639	6674	6709	44
45	6744	6779	6814	6850	6885	6921	6956	6992	7028	7064	45
46	7100	7137	7173	7210	7246	7283	7320	7357	7394	7431	46
47	7468	7506	7543	7581	7619	7656	7694	7733	7771	7809	47
48	7848	7886	7925	7964	8002	8042	8081	8120	8159	8199	48
49	8238	8278	8318	8358	8398	8438	8479	8519	8560	8600	49
50	8641										
	000	100	200	300	400	500	600	700	800	900	